Mathematics (MA)

MA 101 Intermediate Algebra (4 credit hours)
Preparation for MA 103, MA 105, MA 107, MA 111, and MA 114. Reviews main topics from high school Algebra I and Algebra II emphasizing functions and problem solving. Other concepts and skills covered include algebraic operations, factoring, linear equations, graphs, exponents, radicals, complex numbers, quadratic equations, radical equations, inequalities, systems of equations, compound inequalities, absolute value in equations and inequalities. MA 101 may not be counted as credit toward meeting graduation. Credit for MA 101 is not allowed if student has prior credit in any other mathematical course.

Typically offered in Summer only

MA 103/MA 103A Topics in Contemporary Mathematics (3 credit hours)
Primarily for students in Humanities and Social Sciences. Illustrations of contemporary uses of mathematics, varying from semester to semester, frequently including sets and logic, counting procedures, probability, modular arithmetic, and game theory.

Prerequisite: MA 101 or equivalent completed in high school
GEP Mathematical Sciences
Typically offered in Fall, Spring, and Summer

MA 103A/MA 103 Topics in Contemporary Mathematics (3 credit hours)
Primarily for students in Humanities and Social Sciences. Illustrations of contemporary uses of mathematics, varying from semester to semester, frequently including sets and logic, counting procedures, probability, modular arithmetic, and game theory.

Prerequisite: MA 101 or equivalent completed in high school
GEP Mathematical Sciences
Typically offered in Fall and Spring

MA 105 Mathematics of Finance (3 credit hours)
Simple and compound interest, annuities and their application to amortization and sinking fund problems, installment buying, calculation of premiums of life annuities and life insurance.

Prerequisite: MA 101 or equivalent completed in high school
GEP Mathematical Sciences
Typically offered in Fall, Spring, and Summer

MA 107 Precalculus I (3 credit hours)
Algebra and basic trigonometry; polynomial, rational, exponential, logarithmic and trigonometric functions and their graphs. Credit for MA 107 does not count toward graduation for students in Engineering, College of Sciences, Bio and Ag Engineering (Science Program), Bio Sci (all options), Math Edu, Sci Edu, Textiles, and B.S. degrees in CHASS. Credit is not allowed for both MA 107 and MA 111

Prerequisite: C- or better in MA 101, or a 450 or better on the SAT Subject Test in Mathematics Level 2 or the NCSU Math Skills Test.
GEP Mathematical Sciences
Typically offered in Fall, Spring, and Summer

MA 108 Precalculus II (3 credit hours)
Algebra, analytic geometry and trigonometry; inequalities, conic sections, complex numbers, sequences and series, solving triangles, polar coordinates, and applications.Credit for MA 108 does not count toward graduation for students in Engineering, College of Sciences, Design, Bio and Ag Engineering (Science Program), Bio Sci (all options), Math Edu, Sci Edu, Textiles, and B.S. degrees in CHASS. Credit is not allowed for both MA 108 and MA 111. Also, MA 108 should not be counted toward the GER mathematical sciences.

Prerequisite: C- or better in MA 107
Typically offered in Spring only

MA 111 Precalculus Algebra and Trigonometry (3 credit hours)
The study of real numbers, functions and their graphs with an emphasis on absolute value, polynomial, piecewise, rational, exponential, logarithmic, and trigonometric functions. Credit is not allowed for both MA 111 and either MA 107 or MA 108. Note that this course does not count towards graduation for all programs: please check with your program.

GEP Mathematical Sciences
Typically offered in Fall, Spring, and Summer

MA 114 Introduction to Finite Mathematics with Applications (3 credit hours)
Elementary matrix algebra including arithmetic operations, inverses, and systems of equations; introduction to linear programming including simplex method; sets and counting techniques, elementary probability including conditional probability; Markov chains; applications in the behavioral, managerial and biological sciences. Computer use for completion of assignments.

Prerequisite: MA 101 or equivalent completed in high school.
GEP Mathematical Sciences
Typically offered in Fall, Spring, and Summer

MA 116 Introduction to Scientific Programming (Math) (3 credit hours)
Computer-based mathematical problem solving and simulation techniques using MATLAB. Emphasizes scientific programming constructs that utilize good practices in code development, including documentation and style. Covers user-defined functions, data abstractions, data visualization and appropriate use of pre-defined functions. Applications are from science and engineering.

Prerequisite: MA 141, and either COS 100 or E 115; Corequisite: MA 241
Typically offered in Fall and Spring

MA 121 Elements of Calculus (3 credit hours)
For students who require only a single semester of calculus. Emphasis on concepts and applications of calculus, along with basic skills. Algebra review, functions, graphs, limits, derivatives, integrals, logarithmic and exponential functions, functions of several variables, applications in business and management.

Prerequisite: C- or better in MA 107 or MA 111, or qualifying score on math placement exam. Credit is not allowed in more than one of MA 121, 131, 141.
GEP Mathematical Sciences
Typically offered in Fall, Spring, and Summer

MA 131 Calculus for Life and Management Sciences A (3 credit hours)
Derivatives - limits, power rule, graphing, and optimization; exponential and logarithmic functions - growth and decay models; integrals - computation, area, total change; applications in life, management, and social sciences.

Prerequisite: C- or better in MA 107 or MA 111, or qualifying score on math placement exam. Credit is not allowed in more than one of MA 121, MA 131, or MA 141.
GEP Mathematical Sciences
Typically offered in Fall, Spring, and Summer

MA 132 Computational Mathematics for Life and Management Sciences (1 credit hours)
Computational aspects of calculus for the life and management sciences; use of spreadsheets and a computer algebra system; applications to data models, differential equation models, and optimization.

Prerequisite: C- or better in MA 121 or MA 131
Typically offered in Fall and Spring

MA 141 Calculus I (4 credit hours)
First of three semesters in a calculus sequence for science and engineering majors. Functions, graphs, limits, derivatives, rules of differentiation, definite integrals, fundamental theorem of calculus, applications of derivatives and integrals.

Prerequisite: MA 111 or MA 108 with a grade C- or better or qualifying score on math placement exam. Credit is not allowed for both MA 141 and MA 121 or MA 131.
GEP Mathematical Sciences
Typically offered in Fall, Spring, and Summer

MA 151 Calculus for Elementary Education I (3 credit hours)
Calculus for Elementary Education I is the first semester of a two semester sequence of courses designed for the Elementary Education Program. Topics will include sequences, limit, and derivative. Also, topics related to teaching elementary mathematics will be discussed. Students cannot receive credit for more than one of MA 151, MA 121, MA 131, or MA 141. MA 151 is not an accepted prerequisite for MA 231 and MA 241. This course is restricted to Elementary Education majors only.

Prerequisite: C- or better in MA 107 or MA 111, or qualifying score on math placement exam. Credit is not allowed in more than one of MA 121, MA 131, or MA 141.
GEP Mathematical Sciences
Typically offered in Spring only

MA 152 Calculus for Elementary Education II (3 credit hours)
Calculus for Elementary Education II is the second semester of a two semester sequence of courses designed for the Elementary Education Program. Topics will include derivative, integrals, difference equations, and differential equations. Also, topics related to teaching elementary mathematics will be discussed. This course is restricted to Elementary Education majors only. Students cannot receive credit for both MA 152 and MA 121, MA 131, or MA 141. MA 152 is not an accepted prerequisite for MA 241.

Prerequisite: MA 151
GEP Mathematical Sciences
Typically offered in Fall only

MA 225 Foundations of Advanced Mathematics (3 credit hours)
Introduction to mathematical proof with focus on properties of the real number system. Elementary symbolic logic, mathematical induction, algebra of sets, relations, functions, countability. Algebraic and completeness properties of the reals.

Prerequisite: MA 241
Typically offered in Fall, Spring, and Summer

MA 231 Calculus for Life and Management Sciences B (3 credit hours)
Functions of several variables - partial derivatives, optimization, least squares, Lagrange multiplier method; differential equations - population growth, finance and investment models, systems, numerical methods; MA 121 is not an accepted prerequisite for MA 231.

Prerequisite: MA 131 or MA 141; Credit is not allowed for both MA 231 and MA 241.
GEP Mathematical Sciences
Typically offered in Fall, Spring, and Summer

MA 241 Calculus II (4 credit hours)
Second of three semesters in a calculus sequence for science and engineering majors. Techniques and applications of integration, elementary differential equations, sequences, series, power series, and Taylor's Theorem. Use of computational tools.

Prerequisite: MA 141 with grade of C- or better or AP Calculus credit. Credit is not allowed for both MA 241 and MA 231.
GEP Mathematical Sciences
Typically offered in Fall, Spring, and Summer

MA 242 Calculus III (4 credit hours)
Third of three semesters in a calculus sequence for science and engineering majors. Vectors, vector algebra, and vector functions. Functions of several variables, partial derivatives, gradients, directional derivatives, maxima and mimima. Multiple integration. Line and surface integrals, Green's Theorem, Divergence Theorems, Stokes' Theorem, and applications. Use of computational tools.

Prerequisite: MA 241 with grade of C- or better or AP Calculus credit, or Higher Level IB credit.
Typically offered in Fall, Spring, and Summer

MA 302 Numerical Applications to Differential Equations (1 credit hours)
Numerical methods for approximating solutions for differential equations, with an emphasis on Runge-Kutta-Fehlberg methods with stepsize control. Applications to population, economic, orbital and mechanical models.

Prerequisite: MA 241
Typically offered in Fall and Spring

MA 303 Linear Analysis (3 credit hours)
Linear difference equations of first and second order, compound interest and amortization. Matrices and systems of linear equations, eigenvalues, diagonalization, systems of difference and differential equations, transform methods, population problems. Credit not allowed if credit has been obtained for MA 341 or MA 405

Prerequisite: MA 241
Typically offered in Fall and Spring

MA 305 Introductory Linear Algebra and Matrices (3 credit hours)
The course is an elementary introduction to matrix theory and linear algebra. Emphasis is given to topics that will be useful in other disciplines, including systems of equations, Euclidean vector spaces, determinants, eigenvalues and eigenvectors, linear transformations, similarity, and applications such as numerical solutions of equations and computer graphics. Compares with MA 405 Introductory Linear Algebra, more emphasis is placed on methods and calculations,. Credit is not allowed for both MA 305 and MA 405.

Prerequisite: MA 241 or MA 231 with MA 132
Typically offered in Fall, Spring, and Summer

MA 315/MEA 315 Mathematics Methods in Atmospheric Sciences (4 credit hours)
For sophomore meteorology and marine science students. A complement to MA 242 designed to prepare students for quantitative atmospheric applications. Topics include an introduction to vectors and vector calculus, atmospheric waves, phase and group velocity, perturbation analysis, fourier decomposition, matrix operations, chaos and predictability. For MY, MMY, and MRM majors only.

Prerequisite: MEA 217 or MA 116 or CSC 113; Corequisite: MA 242
Typically offered in Spring only

MA 325 Introduction to Applied Mathematics (3 credit hours)
Introduces students with multivariable calculus to five different areas of applied mathematics. These areas will be five three-week modules, which lead to higher level courses in the application areas. Topics will vary, and examples of modules areheat and mass transfer, biology and population, probability and finance, acoustic models, cryptography as well as others.

Prerequisite: (MA 231 or MA 242) and (MA 116 or CSC 112 or CSC 114 or CSC 116)
Typically offered in Spring only

MA 326 Mathematical Foundations of Data Science I (3 credit hours)
The course covers foundational mathematical concepts fundamental to data science and data-driven mathematical modeling. The course includes the following topics: introductory probability and vector calculus, theory for classification algorithms, linear and parametric classifiers, unsupervised and clustering methods, decision trees and ensemble methods. The focus is on applying mathematical concepts to data science methods. The course includes an introduction to Python, but some familiarity with programming is strongly recommended. Basic programming proficiency (Python preferred).

Prerequisite: MA 242 and (MA 303 or MA 305 or MA 405)
Typically offered in Fall and Spring

MA 331 Differential Equations for the Life Sciences (3 credit hours)
This course provides students with an understanding of how mathematics and life sciences can stimulate and enrich each other. The course topics include first order differential equations, separable equations, second order systems, vector and matrix systems, eigenvectors/ eigenvalues, graphical and qualitative methods. The methods are motivated with examples from the biological sciences (growth models, kinetics and compartmental models, epidemic models, predator-prey, etc). Computational modeling will be carried out using SimBiology, a MATLAB toolbox based graphical user interface, which which automates and simplifies the process of modeling biological systems. Credit cannot be given for both MA 341 and MA 331.

P: MA 231 or MA 241; X: Credit cannot be given for both MA 341 and MA 331
Typically offered in Fall only

MA 335/LOG 335 Symbolic Logic (3 credit hours)
Intermediate level introduction to modern symbolic logic focusing on standard first-order logic; topics include proofs, interpretations, applications and basic metalogical results.

Prerequisite: LOG 201 or MA 225 or CSC 226
GEP Mathematical Sciences
Typically offered in Fall only

MA 341 Applied Differential Equations I (3 credit hours)
Differential equations and systems of differential equations. Methods for solving ordinary differential equations including Laplace transforms, phase plane analysis, and numerical methods. Matrix techniques for systems of linear ordinary differential equations. Credit is not allowed for both MA 301 and MA 341

Prerequisite: MA 242 or (MA 132 and MA 231)
Typically offered in Fall, Spring, and Summer

MA 351 Introduction to Discrete Mathematical Models (3 credit hours)
Basic concepts of discrete mathematics, including graph theory, Markov chains, game theory, with emphasis on applications; problems and models from areas such as traffic flow, genetics, population growth, economics, and ecosystem analysis.

Prerequisite: MA 224, 225, 231 or 241
Typically offered in Fall only

MA 401 Applied Differential Equations II (3 credit hours)
Wave, heat and Laplace equations. Solutions by separation of variables and expansion in Fourier Series or other appropriate orthogonal sets. Sturm-Liouville problems. Introduction to methods for solving some classical partial differential equations.Use of power series as a tool in solving ordinary differential equations. Credit for both MA 401 and MA 501 will not be given

Prerequisite: MA 341; Credit not allowed for both MA 401 and MA 501
Typically offered in Fall, Spring, and Summer

MA 402 Mathematics of Scientific Computing (3 credit hours)
This course will provide an overview of methods to solve quantitative problems and analyze data. The tools to be introduced are mathematical in nature and have links to Algebra, Analysis, Geometry, Graph Theory, Probability and Topology. Students will acquire an appreciation of (I) the fundamental role played by mathematics in countless applications and (II) the exciting challenges in mathematical research that lie ahead in the analysis of large data and uncertainties. Students will work on a project for each unit. While this is not a programming class, the students will do some programming through their projects.

P: (MA 341 or MA 405) and programming proficiency (MATLAB, C++, Java, Fortran, or other language)
Typically offered in Fall and Spring

MA 403 Introduction to Modern Algebra (3 credit hours)
Sets and mappings, equivalence relations, rings, integral domains, ordered integral domains, ring of integers. Other topics selected from fields, polynomial rings, real and complex numbers, groups, permutation groups, ideals, and quotient rings. Credit is not allowed for both MA 403 and MA 407

Prerequisite: MA 225
Typically offered in Fall only

MA 404 Mathematical Foundations of Data Science II (3 credit hours)
The course covers foundational mathematical concepts fundamental to data science. It builds upon the basic concepts in MA 326 and develops theory for a range of central data science techniques. The course includes the following topics: Optimization algorithms, neural networks, graph-based models and generative learning. These algorithms will be explored computationally using Python and practical data sets.

Prerequisite: MA 326
Typically offered in Fall only

MA 405 Introduction to Linear Algebra (3 credit hours)
This course offers a rigorous treatment of linear algebra, including systems of linear equations, matrices, determinants, abstract vector spaces, bases, linear independence, spanning sets, linear transformations, eigenvalues and eigenvectors, similarity, inner product spaces, orthogonality and orthogonal bases, factorization of matrices. Compared with MA 305 Introductory Linear Algebra, more emphasis is placed on theory and proofs. MA 225 is recommended as a prerequisite. Credit is not allowed for both MA 305 and MA 405

Prerequisite: MA 241 (MA 225 recommended); Corequisite: MA 341 is recommended
Typically offered in Fall, Spring, and Summer

MA 407 Introduction to Modern Algebra for Mathematics Majors (3 credit hours)
Elementary number theory, equivalence relations, groups, homomorphisms, cosets, Cayley's Theorem, symmetric groups, rings, polynomial rings, quotient fields, principal ideal domains, Euclidean domains. Credit is not allowed for both MA 403 and MA 407

Prerequisite: MA 225 and MA 405
Typically offered in Fall and Spring

MA 408 Foundations of Euclidean Geometry (3 credit hours)
An examination of Euclidean geometry from a modern perspective. The axiomatic approach with alternative possibilities explored using models.

Prerequisite: MA 225
Typically offered in Fall and Spring

MA 410 Theory of Numbers (3 credit hours)
Arithmetic properties of integers. Congruences, arithmetic functions, diophantine equations. Other topics chosen from quadratic residues, the quadratic reciprocity Law of Gauss, primitive roots, and algebraic number fields.

Prerequisite: One year of calculus
Typically offered in Spring only

MA 412/ST 412 Long-Term Actuarial Models (3 credit hours)
Long-term probability models for risk management systems. Theory and applications of compound interest, probability distributions of failure time random variables, present value models of future contingent cash flows, applications to insurance, health care, credit risk, environmental risk, consumer behavior and warranties.

Prerequisite: MA 241 or MA 231, Corequisite: MA 421, BUS(ST) 350, ST 301, ST 305, ST 311, ST 361, ST 370, ST 371, ST 380 or equivalent
Typically offered in Fall and Summer

MA 413/ST 413 Short-Term Actuarial Models (3 credit hours)
Short-term probability models for risk management systems. Frequency distributions, loss distributions, the individual risk model, the collective risk model, stochastic process models of solvency requirements, applications to insurance and businessdecisions.

Prerequisite: MA 241 or MA 231, and one of MA 421, ST 301, ST 305, ST 370, ST 371, ST 380, ST 421.
Typically offered in Summer only

MA 414/MA 514/CSC 414/CSC 514 Foundations of Cryptography (3 credit hours)
Cryptography is the study of mathematical techniques for securing digital information, systems and distributed computation against adversarial attacks. In this class you will learn the concepts and the algorithms behind the most used cryptographic protocols: you will learn how to formally define security properties and how to formally prove/disprove that a cryptographic protocol achieves a certain security property. You will also discover that cryptography has a much broader range of applications. It solves absolutely paradoxical problems such as proving knowledge of a secret without ever revealing the secret (zero-knowledge proof), or computing the output of a function without ever knowing the input of the function (secure computation). Finally, we will look closely at one of the recent popular application of cryptography: the blockchain technology. Additionally, graduate students will study some of the topics in greater depth.

Prerequisite: (CSC 226 AND CSC 333) OR MA 225
Typically offered in Spring only

MA 416/CSC 416 Introduction to Combinatorics (3 credit hours)
Basic principles of counting: addition and multiplication principles, generating functions, recursive methods, inclusion-exclusion, pigeonhole principle; basic concepts of graph theory: graphs, digraphs, connectedness, trees; additional topics from:Polya theory of counting, Ramsey theory; combinatorial optimization - matching and covering, minimum spanning trees, minimum distance, maximum flow; sieves; mobius inversion; partitions; Gaussian numbers and q-analogues; bijections and involutions; partially ordered sets.

Prerequisite: Grade of C or better in either MA 225 or CSC 226
Typically offered in Spring only
This course is offered alternate years

MA 421 Introduction to Probability (3 credit hours)
Axioms of probability, conditional probability and independence, basic combinatorics, discrete and continuous random variables, joint densities and mass functions, expectation, central, limit theorem, simple stochastic processes.

Prerequisite: MA 242
Typically offered in Fall, Spring, and Summer

MA 425 Mathematical Analysis I (3 credit hours)
Real number system, functions and limits, topology on the real line, continuity, differential and integral calculus for functions of one variable. Infinite series, uniform convergence. Credit is not allowed for both MA 425 and MA 511.

Prerequisite: MA 225 (MA 407 desirable)
Typically offered in Fall and Spring

MA 426 Mathematical Analysis II (3 credit hours)
Calculus of several variables, topology in n-dimensions, limits, continuity, differentiability, implicit functions, integration. Credit is not allowed for both MA 426 and MA 512.

Prerequisite: MA 425 and 405
Typically offered in Fall and Spring

MA 427/CSC 427 Introduction to Numerical Analysis I (3 credit hours)
Theory and practice of computational procedures including approximation of functions by interpolating polynomials, numerical differentiation and integration, and solution of ordinary differential equations including both initial value and boundary value problems. Computer applications and techniques.

Prerequisite: (MA 341 or MA 301) and (CSC 111 or CSC 112 or CSC 113 or CSC 114 or CSC 116 or MA 116 or PY 251 or ST 114 or ECE 209)
Typically offered in Fall only

MA 428/CSC 428 Introduction to Numerical Analysis II (3 credit hours)
Computational procedures including direct and iterative solution of linear and nonlinear equations, matrices and eigenvalue calculations, function approximation by least squares, smoothing functions, and minimax approximations.

Prerequisite: (MA 305 or MA 405) and (CSC 111 or CSC 112 or CSC 113 or CSC 114 or CSC 116 or MA 116 or PY 251 or ST 114 or ECE 209)
Typically offered in Spring only

MA 430 Mathematical Models in the Physical Sciences (3 credit hours)
Application of mathematical techniques to topics in the physical sciences. Problems from such areas as conservative and dissipative dynamics, calculus of variations, control theory, and crystallography.

Prerequisite: MA 341 and MA 405
Typically offered in Fall only

MA 432 Mathematical Models in Life Sciences (3 credit hours)
Topics from differential and difference equations, and matrix algebra applied to formulation and analysis of mathematical models in biological science (e.g., population growth or disease models).

Prerequisite: (MA 331 or MA 341) and (MA 305 or MA 405).
Programming proficiency and some experience with basic statistics is recommended.
Typically offered in Spring only

MA 437 Applications of Algebra (3 credit hours)
Error correcting codes, cryptography, crystallography, enumeration techniques, exact solutions of linear equations, and block designs.

Prerequisite: MA 403 or 407, MA 405
Typically offered in Fall and Spring

MA 444 Problem Solving Strategies for Competitions (1 credit hours)
Analyze the most common problem-solving techniques and illustrate their use by interesting examples from past Putnam and Virginia Tech math competitions. Problem solving methods are divided into groups and taught by professors of the math department. After the lecture, students practice writing the solutions for the assignment and have informal discussions in the next class.

Typically offered in Fall only

MA 450 Methods of Applied Mathematics I (3 credit hours)
Mathematical methods covered include dimensional analysis, asymptotics, continuum modeling and traffic flow analysis. These topics are discussed in the context of applications and real data. This course is independent of MA 451 Methods of Applied Mathematics II.

Prerequisite: MA 341
Typically offered in Fall only

MA 451 Methods of Applied Mathematics II (3 credit hours)
The mathematical methods of this course give insight into physical continuum processes such as fluid flow and the deformation of solid elastic materials. Techniques include the modeling and formulation of equations of motion, the use of Lagrangian and Eulerian variables; further topics are: examples of incompressible fluid flow, calculus of variations and applications to optimal control problems. This course is independent of MA 450 Methods of Applied Mathematics I.

Prerequisite: MA 341
Typically offered in Spring only

MA 491 Reading in Honors Mathematics (1-6 credit hours)
A reading (independent study) course available as an elective for students participating in the mathematics honors program.

Prerequisite: Membership in honors program
Typically offered in Fall and Spring

MA 493 Special Topics in Mathematics (1-6 credit hours)
Directed individual study or experimental course offerings.

Typically offered in Fall and Spring

MA 494 Major Paper in Math (1 credit hours)
Introduces students to one or more forms of writing used in scientific and research environments. Students are required to take a companion math course at the 400-level or above, and adapt writing assignment(s) to the topics in the companion course.Instruction covers all phases of the writing process (planning, drafting, revising, and critiquing other people's work). Emphasis is placed on organizing for needs of a variety of readers; concise, clear expression.

Corequisite: MA class at the 400-level or above
Typically offered in Fall and Spring

MA 499 Independent Research in Mathematics (1-6 credit hours)
Study and research in mathematics. Topics for theoretical, modeling or computational investigation. Consent of Department Head. Honors Program should enroll in MA 491H. At most 6 hours total of MA 499 and 491H credit can be applied towards an undergraduate degree. Individualized/Independent Study and Research courses require a Course Agreement for Students Enrolled in Non-Standard Courses be completed by the student and faculty member prior to registration by the department.

Typically offered in Fall, Spring, and Summer

MA 501 Advanced Mathematics for Engineers and Scientists I (3 credit hours)
Survey of mathematical methods for engineers and scientists. Ordinary differential equations and Green's functions; partial differential equations and separation of variables; special functions, Fourier series. Applications to engineering and science. May not be taken for graduate credit by Master's or Ph.D. students in Mathematics or Applied Mathematics. Credit for this course and MA 401 is not allowed.

Prerequisite: MA 341; credit not allowed for both MA 501 and MA 401
Typically offered in Fall, Spring, and Summer

MA 502 Advanced Mathematics for Engineers and Scientists II (3 credit hours)
Determinants and matrices; line and surface integrals, integral theorems; complex integrals and residues; distribution functions of probability. Not for credit by mathematics majors. Any student receiving credit for MA 502 may receive credit for, atmost, one of the following: MA 405, MA 512, MA 513

Prerequisite: MA 341.
Typically offered in Spring only

MA 504/OR 504 Introduction to Mathematical Programming (3 credit hours)
Basic concepts of linear, nonlinear and dynamic programming theory. Not for majors in OR at Ph.D. level.

Prerequisite: MA 242, MA 405
Typically offered in Fall only

MA 505/OR 505/ISE 505 Linear Programming (3 credit hours)
Introduction including: applications to economics and engineering; the simplex and interior-point methods; parametric programming and post-optimality analysis; duality matrix games, linear systems solvability theory and linear systems duality theory; polyhedral sets and cones, including their convexity and separation properties and dual representations; equilibrium prices, Lagrange multipliers, subgradients and sensitivity analysis.

Prerequisite: An introductory linear algebra course similar to MA 405
Typically offered in Fall only

MA 507 Survey of Real Analysis (3 credit hours)
A broad overview of topics in analysis. Historical development, logical refinement and applications of concepts such as limits, continuity, differentiation and integration. May not be taken for graduate credit by Master's or Ph.D. students in Mathematics or Applied Mathematics.

Prerequisite: Graduate standing
Typically offered in Fall, Spring, and Summer
This course is offered alternate years

MA 508 Survey of Geometry (3 credit hours)
A broad overview of topics in geometry. Various approaches to study of geometry, including vector geometry, transformational geometry and axiomatics. May not be taken for graduate credit by Master's or Ph.D. students in Mathematics or Applied Mathematics.

Prerequisite: Graduate standing
Typically offered in Fall, Spring, and Summer
This course is offered alternate years

MA 509 Survey of Abstract Algebra (3 credit hours)
A broad overview of topics in abstract algebra. Theory of equations, polynomial rings, rational functions and elementary number theory. May not be taken for graduate credit by Master's or Ph.D. students in Mathematics or Applied Mathematics.

Prerequisite: Graduate standing
Typically offered in Fall, Spring, and Summer
This course is offered alternate years

MA 510 Selected Topics In Mathematics For Secondary Teachers (1-6 credit hours)
Coverage of various topics in mathematics of concern to secondary teachers. Topics selected from areas such as mathematics of finance, probability, statistics, linear programming and theory of games, intuitive topology, recreational math, computers and applications of mathematics. Course may be taken for graduate credit for certification renewal by secondary school teachers. Credit towards a graduate degree may be allowed only for students in mathematics education.

Prerequisite: Graduate standing
Typically offered in Spring and Summer
This course is offered alternate years

MA 511 Advanced Calculus I (3 credit hours)
Fundamental theorems on continuous functions; convergence theory of sequences, series and integrals; the Riemann integral. Credit for both MA 425 and MA 511 is not allowed

Prerequisite: MA 341
Typically offered in Fall and Spring

MA 513 Introduction To Complex Variables (3 credit hours)
Operations with complex numbers, derivatives, analytic functions, integrals, definitions and properties of elementary functions, multivalued functions, power series, residue theory and applications, conformal mapping.

Prerequisite: MA 242
Typically offered in Fall and Spring

MA 514/CSC 414/CSC 514/MA 414 Foundations of Cryptography (3 credit hours)
Cryptography is the study of mathematical techniques for securing digital information, systems and distributed computation against adversarial attacks. In this class you will learn the concepts and the algorithms behind the most used cryptographic protocols: you will learn how to formally define security properties and how to formally prove/disprove that a cryptographic protocol achieves a certain security property. You will also discover that cryptography has a much broader range of applications. It solves absolutely paradoxical problems such as proving knowledge of a secret without ever revealing the secret (zero-knowledge proof), or computing the output of a function without ever knowing the input of the function (secure computation). Finally, we will look closely at one of the recent popular application of cryptography: the blockchain technology. Additionally, graduate students will study some of the topics in greater depth.

Prerequisite: (CSC 226 AND CSC 333) OR MA 225
Typically offered in Fall only

MA 515 Analysis I (3 credit hours)
Metric spaces: contraction mapping principle, Tietze extension theorem, Ascoli-Arzela lemma, Baire category theorem, Stone-Weierstrass theorem, LP spaces. Banach spaces: linear operators, Hahn-Banach theorem, open mapping and closed graph theorems. Hilbert spaces: projection theorem, Riesz representation theorem, Lax-Milgram theorem, complete orthonormal sets.

Prerequisite: MA 426
Typically offered in Fall only

MA 518 Geometry of Curves and Surfaces (3 credit hours)
Geometry of curves and surfaces in space; Arclength, torsion, and curvature of curves; Tangent spaces, shape operators, and curvatures of surfaces; metrics, covariant derivatives, geodesics, and holonomy. Applications in the physical sciences and/or projects using computer algebra.

Prerequisite: MA 242 and MA 405
Typically offered in Spring only

MA 520 Linear Algebra (3 credit hours)
Vector spaces. Bases and dimension. Changes of basis. Linear transformations and their matrices. Linear functionals. Simultaneous triangularization and diagonalization. Rational and Jordan canonical forms. Bilinear forms.

Prerequisite: MA 405
Typically offered in Fall and Spring

MA 521 Abstract Algebra I (3 credit hours)
Groups, quotient groups, group actions, Sylow's Theorems. Rings, ideals and quotient rings, factorization, principal ideal domains. Fields, field extensions, Galois theory.

Prerequisite: MA 405 and MA 407
Typically offered in Fall only

MA 522 Computer Algebra (3 credit hours)
Basic techniques and algorithms of computer algebra. Integer arithmetic, primality tests and factorization of integers, polynomial arithmetic, polynomial factorization, Groebner bases, integration in finite terms.

Prerequisite: MA 405 and MA 407
Typically offered in Fall only

MA 523 Linear Transformations and Matrix Theory (3 credit hours)
Vector spaces, linear transformations and matrices, orthogonality, orthogonal transformations with emphasis on rotations and reflections, matrix norms, projectors, least squares, generalized inverses, definite matrices, singular values.

Prerequisite: MA 405
Typically offered in Fall and Spring

MA 524 Combinatorics I (3 credit hours)
Enumerative combinatorics, including placements of balls in bins, the twelvefold way, inclusion/exclusion, sign-reversing involutions and lattice path enumeration. Partically ordered sets, lattices, distributive lattices, Moebius functions, and rational generating functions.

Prerequisite: MA 405 and MA 407
Typically offered in Fall only

MA 528/ECG 528/FIM 528 Options and Derivatives Pricing (3 credit hours)
The course covers (i) structure and operation of derivative markets, (ii) valuation of derivatives, (iii) hedging of derivatives, and (iv) applications of derivatives in areas of risk management and financial engineering. Models and pricing techniques include Black-Scholes model, binomial trees, Monte-Carlo simulation. Specific topics include simple no-arbitrage pricing relations for futures/forward contracts; put-call parity relationship; delta, gamma, and vega hedging; implied volatility and statistical properties; dynamic hedging strategies; interest-rate risk, pricing of fixed-income product; credit risk, pricing of defaultable securities.

Prerequisites: MA 341 and MA 405 and MA 421
Typically offered in Fall only

MA 531/E 531/OR 531 Dynamic Systems and Multivariable Control I (3 credit hours)
Introduction to modeling, analysis and control of linear discrete-time and continuous-time dynamical systems. State space representations and transfer methods. Controllability and observability. Realization. Applications to biological, chemical, economic, electrical, mechanical and sociological systems.

Prerequisite: MA 341, MA 405
Typically offered in Fall only

MA 532 Ordinary Differential Equations I (3 credit hours)
Existence and uniqueness theorems, systems of linear equations, fundamental matrices, matrix exponential, nonlinear systems, plane autonomous systems, stability theory.

Prerequisite: MA 341, 405, 425 or 511, Corequisite: MA 426 or 512
Typically offered in Fall only

MA 534 Introduction To Partial Differential Equations (3 credit hours)
Linear first order equations, method of characteristics. Classification of second order equations. Solution techniques for the heat equation, wave equation and Laplace's equation. Maximum principles. Green's functions and fundamental solutions.

Prerequisite: MA 425 or MA 511, MA 341, Corequisite: MA 426 or 512
Typically offered in Fall only

MA 537 Nonlinear Dynamics and Chaos (3 credit hours)
Usage of computer experiments for demonstration of nonlinear dynamics and chaos and motivation of mathematical definitions and concepts. Examples from finance and ecology as well as traditional science and engineering. Difference equations and iteration of functions as nonlinear dynamical systems. Fixed points, periodic points and general orbits. Bifurcations and transition to chaos. Symbolic dynamics, chaos, Sarkovskii's Theorem, Schwarzian derivative, Newton's method and fractals.

Prerequisite: MA 341 and MA 405
Typically offered in Spring only

MA 540 Uncertainty Quantification for Physical and Biological Models (3 credit hours)
Introduction to uncertainty quantification for physical and biological models. Parameter selection techniques, Bayesian model calibration, propagation of uncertainties, surrogate model construction, local and global sensitivity analysis.

Prerequisite: MA 341 and basic knowledge of probability, linear algebra, and scientific computation
Typically offered in Fall and Spring
This course is offered alternate even years

MA 542 Convex Optimization Methods in Data Science (3 credit hours)
Convex optimization methods and their applications in various areas of data science including, but not limited to, signal and image processing, inverse problems, statistical data analysis, machine learning and classification. Basic theory, algorithm design and concrete applications.

Prerequisite: MA 141, 241, 242, or equivalent and MA 405 or equivalent; Some notions of elementary convex analysis are an asset but are neither required nor assumed known.
Typically offered in Fall only

MA 544 Computer Experiments In Mathematical Probability (3 credit hours)
Exposure of student to practice of performing mathematical experiments on computer, with emphasis on probability. Programming in an interactive language such as APL, MATLAB or Mathematica. Mathematical treatment of random number generation and application of these tools to mathematical topics in Monte Carlo method, limit theorems and stochastic processes for purpose of gaining mathematical insight.

Prerequisite: MA 421
Typically offered in Spring only

MA 546/ST 546 Probability and Stochastic Processes I (3 credit hours)
Mathematical foundations of probability theory. Probabilistic measure theory, random variables and their distributions, construction of expectation. Notions of convergence: almost sure, in probability, in L^p, weak convergence, vague convergence. Conditioning, independence, Borel-Cantelli lemmas, weak and strong laws of large numbers, characteristic functions, central limit theorem, and related concentration inequalities.

Prerequisite: MA 421 and MA 425 or MA 511
Typically offered in Fall only

MA 547/FIM 547 Stochastic Calculus for Finance (3 credit hours)
This course explores stochastics calculus with its applications in pricing and hedging problems for financial derivatives such as options. Topics to be covered in the course include 1) discrete and continuous martingales, 2) Brownian motions and Ito's stochastic calculus, and 3) Black-Scholas framework for financial derivatives pricing and hedging.

Prerequisite: FIM 528 and MA(ST) 546
Typically offered in Spring only

MA 548/FIM 548 Monte Carlo Methods for Financial Math (3 credit hours)
Monte Carlo (MC) methods for accurate option pricing, hedging and risk management. Modeling using stochastic asset models (e.g. geometric Brownian motion) and parameter estimation. Stochastic models, including use of random number generators, random paths and discretization methods (e.g. Euler-Maruyama method), and variance reduction. Implementation using Matlab. Incorporation of the latest developments regarding MC methods and their uses in Finance.

Prerequisites: (MA 421 or ST 421), MA 341, and MA 405
Typically offered in Spring only

MA 549/FIM 549 Financial Risk Analysis (3 credit hours)
This course focuses on mathematical methods to analyze and manage risks associated with financial derivatives. Topics covered include aggregate loss distributions, extreme value theory, default probabilities, Value-at-Risk and expected shortfall, coherent risk measures, correlation and copula, applications of principle component analysis and Monte Carlo simulations in financial risk management, how to use stochastic differential equations to price financial risk derivatives, and how to back-test and stress-test models.

Prerequisites: MA 405 and (MA 421 or ST 421) and (MA/ST 412 or MA/ST 413)
Typically offered in Spring only

MA 551 Introduction to Topology (3 credit hours)
Set theory, topological spaces, metric spaces, continuous functions, separation, cardinality properties, product and quotient topologies, compactness, connectedness.

Prerequisite: MA 426
Typically offered in Fall only

MA 555 Introduction to Manifold Theory (3 credit hours)
An introduction to smooth manifolds. Topics include: topological and smooth manifolds, smooth maps and differentials, vector fields and flows, Lie derivatives, vector bundles, tensors, differential forms, exterior calculus, and integration on manifolds.

Prerequisite: MA 405 and MA 426
Typically offered in Fall only

MA 561 Set Theory and Foundations Of Mathematics (3 credit hours)
Logic and axiomatic approach, the Zermelo-Fraenkel axioms and other systems, algebra of sets and order relations, equivalents of the Axiom of Choice, one-to-one correspondences, cardinal and ordinal numbers, the Continuum Hypothesis.

Prerequisite: MA 407
Typically offered in Spring only

MA 565/OR 565/CSC 565 Graph Theory (3 credit hours)
Basic concepts of graph theory. Trees and forests. Vector spaces associated with a graph. Representation of graphs by binary matrices and list structures. Traversability. Connectivity. Matchings and assignment problems. Planar graphs. Colorability. Directed graphs. Applications of graph theory with emphasis on organizing problems in a form suitable for computer solution.

Prerequisite: CSC 226 or MA 351.
Typically offered in Spring only
This course is offered alternate even years

MA 573/BMA 573 Mathematical Modeling of Physical and Biological Processes I (3 credit hours)
Introduction to model development for physical and biological applications. Mathematical and statistical aspects of parameter estimation. Compartmental analysis and conservation laws, heat transfer, and population and disease models. Analytic and numerical solution techniques and experimental validation of models. Knowledge of high-level programming languages required.

Prerequisite: MA 341 and knowledge of high-level programming language.
Typically offered in Fall only

MA 574/BMA 574 Mathematical Modeling of Physical and Biological Processes II (3 credit hours)
Model development, using Newtonian and Hamiltonian principles, for acoustic and fluid applications, and structural systems including membranes, rods, beams, and shells. Fundamental aspects of electromagnetic theory. Analytic and numerical solution techniques and experimental validation of models.

Prerequisite: MA/BMA 573
Typically offered in Spring only

MA 580/CSC 580 Numerical Analysis I (3 credit hours)
Algorithm behavior and applicability. Effect of roundoff errors, systems of linear equations and direct methods, least squares via Givens and Householder transformations, stationary and Krylov iterative methods, the conjugate gradient and GMRES methods, convergence of method.

Prerequisite: MA 405; MA 425 or MA 511; high-level computer language
Typically offered in Fall and Spring

MA 583/CSC 583 Introduction to Parallel Computing (3 credit hours)
Introduction to basic parallel architectures, algorithms and programming paradigms; message passing collectives and communicators; parallel matrix products, domain decomposition with direct and iterative methods for linear systems; analysis of efficiency, complexity and errors; applications such as 2D heat and mass transfer.

Prerequisite: CSC 302 or MA 402 or MA/CSC 428 or MA/CSC 580
Typically offered in Spring only

MA 584 Numerical Solution of Partial Differential Equations--Finite Difference Methods (3 credit hours)
Survey of finite difference methods for partial differential equations including elliptic, parabolic and hyperbolic PDE's. Consideration of both linear and nonlinear problems. Theoretical foundations described; however, emphasis on algorithm design and implementation.

Prerequisite: MA 501; knowledge of a high level programming language
Typically offered in Fall only

MA 587 Numerical Solution of Partial Differential Equations--Finite Element Method (3 credit hours)
Introduction to finite element method. Applications to both linear and nonlinear elliptic and parabolic partial differential equations. Theoretical foundations described; however, emphasis on algorithm design and implementation.

Prerequisite: MA 501; knowledge of a high level programming language
Typically offered in Spring only

MA 591 Special Topics (1-6 credit hours)
Typically offered in Fall and Spring

MA 601 Seminar (1 credit hours)
Review and discussion of scientific articles, progress reports on research and special problems of interest to mathematicians.

P: Graduate Standing
Typically offered in Fall and Spring

MA 630 Independent Study in Mathematics (1-6 credit hours)
Independent study of an advanced mathematics topic under the direction of mathematics faculty member on tutorial basis. Requires a faculty sponsor and departmental approval.

R: Graduate Standing
Typically offered in Fall, Spring, and Summer

MA 635 Readings in Mathematics (1-6 credit hours)
Readings in advanced topics in mathematics

R: Graduate Standing
Typically offered in Fall, Spring, and Summer

MA 676 Master's Project (3 credit hours)
Investigation of some topic in mathematics to a deeper and broader extent than typically done in a classroom situation. For the applied mathematics student the topic usually consists of a realistic application of mathematics to student's minor area.A written and oral report on the project required.

Typically offered in Fall, Spring, and Summer

MA 685 Master's Supervised Teaching (1-3 credit hours)
Teaching experience under the mentorship of faculty who assist the student in planning for the teaching assignment, observe and provide feedback to the student during the teaching assignment, and evaluate the student upon completion of the assignment.

Prerequisite: Master's student
Typically offered in Fall and Spring

MA 689 Non-Thesis Master Continuous Registration - Full Time Registration (3 credit hours)
For students in non-thesis master's programs who have completed all credit hour requirements for their degree but need to maintain full-time continuous registration to complete incomplete grades, projects, final master's exam, etc. Students may register for this course a maximum of one semester.

Prerequisite: Master's student
Typically offered in Fall, Spring, and Summer

MA 690 Master's Examination (1-9 credit hours)
For students in non thesis master's programs who have completed all other requirements of the degree except preparing for and taking the final master's exam.

Prerequisite: Master's student
Typically offered in Fall and Spring

MA 693 Master's Supervised Research (1-9 credit hours)
Instruction in research and research under the mentorship of a member of the Graduate Faculty.

Prerequisite: Master's student
Typically offered in Fall, Spring, and Summer

MA 695 Master's Thesis Research (1-9 credit hours)
Thesis Research

Prerequisite: Master's student
Typically offered in Fall and Spring

MA 696 Summer Thesis Research (1 credit hours)
For graduate students whose programs of work specify no formal course work during a summer session and who will be devoting full time to thesis research.

Prerequisite: Master's student
Typically offered in Summer only

MA 699 Master's Thesis Preparation (1-9 credit hours)
For students who have completed all credit hour requirements and full-time enrollment for the master's degree and are writing and defending their thesis. Credits Arranged

Prerequisite: Master's student
Typically offered in Fall, Spring, and Summer

MA 706/OR 706/ST 706 Nonlinear Programming (3 credit hours)
An advanced mathematical treatment of analytical and algorithmic aspects of finite dimensional nonlinear programming. Including an examination of structure and effectiveness of computational methods for unconstrained and constrained minimization. Special attention directed toward current research and recent developments in the field.

Prerequisite: OR(IE,MA) 505 and MA 425
Typically offered in Spring only

MA 708/OR 708/ISE 708 Integer Programming (3 credit hours)
General integer programming problems and principal methods of solving them. Emphasis on intuitive presentation of ideas underlying various algorithms rather than detailed description of computer codes. Students have some "hands on" computing experience that should enable them to adapt ideas presented in course to integer programming problems they may encounter.

Prerequisite: MA 405, OR (MA,IE) 505, Corequisite: Some familiarity with computers (e.g., CSC 112)
Typically offered in Spring only
This course is offered alternate years

MA 715 Analysis II (3 credit hours)
Integration: Legesgue measure and integration, Lebesgue-dominated convergence and monotone convergence theorems, Fubini's theorem, extension of the fundamental theorem of calculus. Banach spaces: Lp spaces, weak convergence, adjoint operators, compact linear operators, Fredholm-Fiesz Schauder theory and spectral theorem.

Prerequisite: MA 515
Typically offered in Spring only

MA 716 Advanced Functional Analysis (3 credit hours)
Advanced topics in functional analysis such as linear topological spaces; Banach algebra, spectral theory and abstract measure theory and integration.

Prerequisite: MA 715
Typically offered in Fall only
This course is offered alternate years

MA 719/OR 719 Vector Space Methods in System Optimization (3 credit hours)
Introduction to algebraic and function-analytic concepts used in system modeling and optimization: vector space, linear mappings, spectral decomposition, adjoints, orthogonal projection, quality, fixed points and differentials. Emphasis on geometricinsight. Topics include least square optimization of linear systems, minimum norm problems in Banach space, linearization in Hilbert space, iterative solution of system equations and optimization problems. Broad range of applications in operations research and system engineering including control theory, mathematical programming, econometrics, statistical estimation, circuit theory and numerical analysis.

Prerequisite: MA 405, 511
Typically offered in Fall only

MA 720 Lie Algebras (3 credit hours)
Definition of Lie algebras and examples. Nilpotent, solvable and semisimple Lie algebras. Engel's theorem, Lie's Theorem, Killing form and Cartan's criterion. Weyl's theorem on complete reducibility. Representations of s1(2,C). Root space decomposition of semisimple Lie algebras. Root system and Weyl group.

Prerequisite: MA 520
Typically offered in Spring only

MA 721 Abstract Algebra II (3 credit hours)
This course covers: Module theory including the structure theory of modules over a PID and primary decomposition; Tensor, exterior, and symmetric algebras; introductory homological algebra including: complexes, derived functors, Ext and Tor; and the representation theory of groups. Further topics will be covered as time permits.

Prerequisite: MA 521
Typically offered in Spring only

MA 722 Computer Algebra II (3 credit hours)
Effective algorithms for symbolic matrices, commutative algebra, real and complex algebraic geometry, and differential and difference equations. The emphasis is on the algorithmic aspects.

Prerequisite: MA 522
Typically offered in Spring only

MA 723 Theory of Matrices and Applications (3 credit hours)
Canonical forms, functions of matrices, variational methods, perturbation theory, numerical methods, nonnegative matrices, applications to differential equations, Markov chains.

Prerequisite: MA 520 or 523
Typically offered in Spring only

MA 724 Combinatorics II (3 credit hours)
Polytopes(V-polytopes and H-polytopes). Fourier-Motzkin elimination, Farkas Lemma, face numbers of polytopes, graphs of polytopes, linear programming for geometers, Balinski's Theorem, Steinitz' Theorem, Schlegel diagrams, polyhedral complexes, shellability, and face rings.

Prerequisite: MA 524
Typically offered in Spring only

MA 725 Lie Algebra Representation Theory (3 credit hours)
Semisimple Lie algebras, root systems, Weyl groups, Cartan matrices and Dynkin diagrams, universal enveloping algebras, Serre's Theorem, Kac-Moody algebras, highest weight representations of finite dimensional semisimple algebras and affine Lie algebras, Kac-Weyl character formula.

Prerequisite: MA 720
Typically offered in Fall only
This course is offered alternate odd years

MA 726 Algebraic Geometry (3 credit hours)
Abstract theory of solutions of systems of polynomial equations. Topics covered: ideals and affine varieties, the Nullstellensatz, irreducible varieties and primary decomposition, morphisms and rational maps, computational aspects including Groebner bases and elimination theory, projective varieties and homogeneous ideals, Grassmannians, graded modules, the Hilbert function, Bezout's theorem.

Prerequisite: MA 521
Typically offered in Spring only

MA 731/OR 731/E 731 Dynamic Systems and Multivariable Control II (3 credit hours)
Stability of equilibrium points for nonlinear systems. Liapunov functions. Unconstrained and constrained optimal control problems. Pontryagin's maximum principle and dynamic programming. Computation with gradient methods and Newton methods. Multidisciplinary applications.

Prerequisite: OR(E,MA) 531
Typically offered in Spring only
This course is offered alternate years

MA 732 Ordinary Differential Equations II (3 credit hours)
Existence-uniqueness theory, periodic solutions, invariant manifolds, bifurcations, Fredholm's alternative.

Prerequisite: MA 532, Corequisite: MA 515
Typically offered in Spring only

MA 734 Partial Differential Equations (3 credit hours)
Linear second order parabolic, elliptic and hyperbolic equations. Initial value problems and boundary value problems. Iterative and variational methods. Existence, uniqueness and regularity. Nonlinear equations and systems.

Prerequisite: MA 515 and MA 534
Typically offered in Spring only

MA 747/ST 747 Probability and Stochastic Processes II (3 credit hours)
Advanced development of stochastic processes. Conditional expectation, filtrations of sigma-algebras, stopping times. Martingales, associated convergence theorems and inequalities, martingale decomposition, optional stopping. Markov chains including random walks, recurrence versus transience, asymptotic behavior. General Markov processes and the related semigroup operators. Construction and properties of Brownian motion, Donsker's invariance principle. Other potential topics include stationary processes, Birkhoff's ergodic theorem, branching processes, Poisson processes.

Prerequisite: MA(ST) 546
Typically offered in Spring only

MA 748/ST 748 Stochastic Differential Equations (3 credit hours)
Theory of stochastic differential equations driven by Brownian motions. Current techniques in filtering and financial mathematics. Construction and properties of Brownian motion, wiener measure, Ito's integrals, martingale representation theorem, stochastic differential equations and diffusion processes, Girsanov's theorem, relation to partial differential equations, the Feynman-Kac formula.

Prerequisite: MA(ST) 747
Typically offered in Fall only

MA 753 Algebraic Topology (3 credit hours)
Homotopy, fundamental group, covering spaces, classification of surfaces, homology and cohomology.

Prerequisite: MA 551 or MA 555
Typically offered in Spring only

MA 754 Advanced Algebraic Topology (3 credit hours)
Properties of cohomology, homotopy groups, fiber bundles, characteristic classes, and homological algebra. Additional topics may include spectra, spectral sequences, K-theory, group cohomology, and connections with smooth manifold topology.

Prerequisite: MA 753
Typically offered in Fall only
This course is offered alternate odd years

MA 755 Introduction to Riemannian Geometry (3 credit hours)
An introduction to smooth manifolds with metric. Topics include: Riemannian metric and generalizations, connections, covariant derivatives, parallel translation, Riemannian (or Levi-Civita) connection, geodesics and distance, curvature tensor, Bianchi identities, Ricci and scalar curvatures, isometric embeddings, Riemannian submanifolds, hypersurfaces, Gauss Bonnet Theorem; applications and connections to other fields.

Prerequisite: MA 555
Typically offered in Spring only
This course is offered alternate years

MA 766/OR 766/ISE 766 Network Flows (3 credit hours)
Study of problems of flows in networks. These problems include the determination of shortest chain, maximal flow and minimal cost flow in networks. Relationship between network flows and linear programming developed as well as problems with nonlinear cost functions, multi-commodity flows and problem of network synthesis.

Prerequisite: OR(IE,MA) 505
Typically offered in Spring only
This course is offered alternate years

MA 771/ST 771/BMA 771 Biomathematics I (3 credit hours)
Role of theory construction and model building in development of experimental science. Historical development of mathematical theories and models for growth of one-species populations (logistic and off-shoots), including considerations of age distributions (matrix models, Leslie and Lopez; continuous theory, renewal equation). Some of the more elementary theories on the growth of organisms (von Bertalanffy and others; allometric theories; cultures grown in a chemostat). Mathematical theories oftwo and more species systems (predator-prey, competition, symbosis; leading up to present-day research) and discussion of some similar models for chemical kinetics. Much emphasis on scrutiny of biological concepts as well as of mathematical structureof models in order to uncover both weak and strong points of models discussed. Mathematical treatment of differential equations in models stressing qualitative and graphical aspects, as well as certain aspects of discretization. Difference equation models.

Prerequisite: Advanced calculus, reasonable background in biology
Typically offered in Fall only

MA 772/ST 772/BMA 772 Biomathematics II (3 credit hours)
Continuation of topics of BMA 771. Some more advanced mathematical techniques concerning nonlinear differential equations of types encountered in BMA 771: several concepts of stability, asymptotic directions, Liapunov functions; different time-scales. Comparison of deterministic and stochastic models for several biological problems including birth and death processes. Discussion of various other applications of mathematics to biology, some recent research.

Prerequisite: BMA 771, elementary probability theory
Typically offered in Spring only

MA 773/OR 773/ST 773/BMA 773 Stochastic Modeling (3 credit hours)
Survey of modeling approaches and analysis methods for data from continuous state random processes. Emphasis on differential and difference equations with noisy input. Doob-Meyer decomposition of process into its signal and noise components. Examples from biological and physical sciences, and engineering. Student project.

Prerequisite: BMA 772 or ST (MA) 746
Typically offered in Spring only
This course is offered alternate years

MA 774/BMA 774/OR 774 Partial Differential Equation Modeling in Biology (3 credit hours)
Modeling with and analysis of partial differential equations as applied to real problems in biology. Review of diffusion and conservation laws. Waves and pattern formation. Chemotaxis and other forms of cell and organism movement. Introduction to solid and fluid mechanics/dynamics. Introductory numerical methods. Scaling. Perturbations, Asymptotics, Cartesian, polar and spherical geometries. Case studies.

Prerequisite: BMA 771 or MA/OR 731; BMA 772 or MA 401 or MA 501
Typically offered in Spring only

MA 780/CSC 780 Numerical Analysis II (3 credit hours)
Approximation and interpolation, Fast Fourier Transform, numerical differentiation and integration, numerical solution of initial value problems for ordinary differential equations.

Prerequisite: MA 580
Typically offered in Spring only

MA 782 Computational Methods for Variational Inverse Problems (3 credit hours)
Computational methods for inverse problems that are governed by partial differential equations. Topics will include variational formulations, ill-posedness, regularization, discretization methods, and optimization algorithms, statistical formulations, and numerical implementations.

P: MA 401 and MA 580 or equivalent.
Typically offered in Spring only

MA 784 Numerical Methods for Nonlinear Equations and Optimization (3 credit hours)
The course provides a graduate-level introduction to the numerical methods of solving linear and nonlinear optimization problems and nonlinear equations, along with the fundamental mathematical theory necessary to develop these algorithms. Topics selected from: Newton's method and Quasi-Newton methods for nonlinear equations and optimization problems, globally convergent extensions, methods for sparse problems, applications to differential equations, integral equations and general minimization problems, methods appropriate for boundary value problems, conic programming, first-order methods for large-scale optimization problems.

P: MA 580 or MA 523
Typically offered in Spring only

MA 788 Numerical Nonlinear Partial Differential Equations (3 credit hours)
A review of modern numerical techniques for time-dependent nonlinear partial differential equations. Topics include Finite Difference, Finite Volume, Particle and Hybrid Eulerian- Lagrangian Methods; Splitting Methods and Implicit-Explicit Discretization; Spectral and Pseudo-Spectral Methods including Stochastic Galerkin and Stochastic Collocation Methods, and others. Applications including problems in fluid and gas dynamics, geophysics, meteorology, astrophysics, biology, and other fields.

Prerequisite: MA 401 or MA 427 or MA 428; knowledge of a high level programming language
Typically offered in Spring only
This course is offered alternate years

MA 790 Special Topics (1-6 credit hours)
Special advanced topics in mathematics.

R: Graduate Standing
Typically offered in Fall, Spring, and Summer

MA 791 Special Topics In Real Analysis (1-6 credit hours)
Typically offered in Fall and Spring

MA 792 Special Topics In Algebra (1-6 credit hours)
Typically offered in Fall and Spring

MA 793 Special Topics In Differential Equations (1-6 credit hours)

MA 796 Special Topics In Combinatorial Analysis (1-6 credit hours)

MA 797 Special Topics In Applied Mathematics (1-6 credit hours)

MA 798 Special Topics In Numerical Analysis (1-6 credit hours)

MA 810 Special Topics (1-6 credit hours)
Typically offered in Fall and Spring

MA 812/ISE 812 Special Topics in Mathematical Programming (1-6 credit hours)
Study of special advanced topics in area of mathematical programming. Discussion of new techniques and current research in this area. The faculty responsible for this course select areas to be covered during semester according to their preference and interest. This course not necessarily taught by an individual faculty member but can, on occasion, be joint effort of several faculty members from this university as well as visiting faculty from other institutions. To date, a course of Theory of Networks and another on Integer Programming offered under the umbrella of this course. Anticipation that these two topics will be repeated in future together with other topics.

Prerequisite: IE(MA,OR) 505
Typically offered in Spring only
This course is offered alternate years

MA 816/ISE 816 Advanced Special Topics Sys Opt (1-6 credit hours)
Advanced topics in some phase of system optimization. Identification of various specific topics and prerequisite for each section from term to term.

Typically offered in Fall and Spring

MA 830 Independent Study in Mathematics (1-6 credit hours)
Independent study of an advanced mathematics topic under the direction of mathematics faculty member on tutorial basis. Requires a faculty sponsor and departmental approval.

R: Graduate Standing
Typically offered in Fall, Spring, and Summer

MA 835 Readings in Mathematics (1-6 credit hours)
Readings in advanced topics in mathematics

R: Graduate Standing
Typically offered in Fall, Spring, and Summer

MA 885 Doctoral Supervised Teaching (1-3 credit hours)
Teaching experience under the mentorship of faculty who assist the student in planning for the teaching assignment, observe and provide feedback to the student during the teaching assignment, and evaluate the student upon completion of the assignment.

Prerequisite: Doctoral student
Typically offered in Fall and Spring

MA 890 Doctoral Preliminary Examination (1-9 credit hours)
For students who are preparing for and taking written and/or oral preliminary exams.

Prerequisite: Doctoral student
Typically offered in Fall and Spring

MA 893 Doctoral Supervised Research (1-9 credit hours)
Instruction in research and research under the mentorship of a member of the Graduate Faculty.

Prerequisite: Doctoral student
Typically offered in Fall, Spring, and Summer

MA 895 Doctoral Dissertation Research (1-9 credit hours)
Dissertation Research

Prerequisite: Doctoral student
Typically offered in Fall and Spring

MA 896 Summer Dissertation Research (1 credit hours)
For graduate students whose programs of work specify no formal course work during a summer session and who will be devoting full time to thesis research.

Prerequisite: Doctoral student
Typically offered in Summer only

MA 899 Doctoral Dissertation Preparation (1-9 credit hours)
For students who have completed all credit hour requirements, full-time enrollment, preliminary examination, and residency requirements for the doctoral degree, and are writing and defending their dissertations.

Prerequisite: Doctoral student
Typically offered in Fall, Spring, and Summer