

# MATHEMATICS

The department offers programs leading to the BS, MA, MS, and PhD degrees in Mathematics. Undergraduate minors are offered in Mathematics and Actuarial Science.

Students interested in teaching mathematics at the secondary level should contact a departmental advisor and discuss the Secondary Teaching Emphasis option available under the Mathematics major. Likewise, students interested in careers in the area of financial mathematics or as actuaries should meet with a member of the departmental Actuarial Sciences Committee.

Additional information pamphlets about both the undergraduate and graduate programs are available on the Department of Mathematics website.

## Departmental Requirements

The Mathematics major requirements at the upper division comprise about 45 credits of course work. This leaves about 45 credits of free electives that can be used to design a degree program in mathematics that is tailored to each major's particular interests.

## Undergraduate Programs

### Major

- Mathematics (<http://catalog.oregonstate.edu/college-departments/science/mathematics/mathematics-bs-hbs>)

#### Options

- *Applied and Computational Mathematics*
- *Mathematical Biology*
- *Secondary Teaching Emphasis*
- *Statistics*

### Minors

- Actuarial Science (<http://catalog.oregonstate.edu/college-departments/science/mathematics/actuarial-science-minor>)
- Mathematics (<http://catalog.oregonstate.edu/college-departments/science/mathematics/mathematics-minor>)

## Graduate Programs

### Major

- Mathematics (<http://catalog.oregonstate.edu/college-departments/science/mathematics/mathematics-ma-ms-phd-mais>)

### Minor

- Mathematics (<http://catalog.oregonstate.edu/college-departments/science/mathematics/mathematics-graduate-minor>)

**Enrique Thomann**, *Department Head*

368B Kidder Hall

Oregon State University

Corvallis, OR 97331-4605

541-737-1596

Email: [enrique.thomann@oregonstate.edu](mailto:enrique.thomann@oregonstate.edu)

Website: <http://www.math.oregonstate.edu/>

## Faculty

**Professors** Bogley, De Leenheer, Dick, Dray, Escher, Faridani, Finch, Flahive, Higdon, Kovchegov, Ossiander, Peszynska, Pohjanpelto, Restrepo, Schmidt, Showalter, Thomann

**Associate Professors** Bokil, Dascaliuc, Gibson, Guo, Petsche, Swisher

**Assistant Professors** Beisiegel, Cozzi, Dalziel, Koslicki, Lockwood

**Adjunct Professors** Batten (ME), Manogue (PH)

**Adjunct Associate Professor** Medlock (VBS), Zhang (ECE)

## Mathematics

### MTH 065. ELEMENTARY ALGEBRA. (3 Credits)

Arithmetic of signed numbers, order of operations, simplifying algebraic expressions, solutions of linear equations, and inequalities. Rules of exponents, addition, subtraction, and multiplication of polynomials, factoring, solution of quadratic equations by factoring, reducing rational expressions. Word problems involving linear equations, graphing of linear equations, inequalities. All courses used to satisfy MTH prerequisites must be completed with C- or better.

**Prerequisites:** Math Placement Test with a score of 05 or Math Placement - ALEKS with a score of 015

### MTH 095. INTERMEDIATE ALGEBRA. (3 Credits)

Addition, subtraction, multiplication, and division of rational expressions, long division of polynomials, solutions of fractional equations, applications involving linear equations. Fractional equations, inequalities, literal equations, and variations. Negative and fractional exponents, radicals, solutions of quadratic equations, and complex numbers. Cartesian coordinates, graphs of linear equations and inequalities, distance formula, slope, equations of lines, solutions of systems of linear equations in two unknowns and inequalities. All courses used to satisfy MTH prerequisites must be completed with C- or better.

**Prerequisites:** MTH 065 with C- or better or Math Placement Test with a score of 11 or Math Placement - ALEKS with a score of 030

### MTH 102. ALGEBRAIC FOUNDATIONS. (3 Credits)

This course is designed primarily for EOP students. They will use various computing technologies to explore realistic and interesting situations in which algebra is used. As they work through explorations, they will work with many of the fundamental ideas of algebra, ideas they will find important in their daily lives.

### MTH 103. ALGEBRAIC REASONING. (4 Credits)

Graphing data, functions, rate of change, linear equations, systems of linear equations, linear inequalities, linear functions, absolute value functions, quadratic functions, exponential functions. All courses used to satisfy MTH prerequisites must be completed with C- or better.

**Prerequisites:** MTH 065 with C- or better or Math Placement Test with a score of 11 or Math Placement - ALEKS with a score of 030

### MTH 105. \*INTRODUCTION TO CONTEMPORARY MATHEMATICS. (3 Credits)

Elementary linear programming, combinatorics, descriptive statistics, elementary probability, exponential growth and decay, examples of major mathematical ideas and models. Lec/rec. (Bacc Core Course)

**Attributes:** CSMA – Core, Skills, Math

**Recommended:** MTH 095 or MTH 103 or (MPT=Math Placement Test score of 17; MPAL=Math Placement Test-ALEKS score of 46%)

**MTH 111. \*COLLEGE ALGEBRA. (4 Credits)**

Polynomial equations and inequalities, polynomial functions and graphs, inverse functions, exponential and logarithmic functions, elementary mathematical modeling and applications. Lec/rec. All courses used to satisfy MTH prerequisites must be completed with a C- or better. (Bacc Core Course)

**Attributes:** CSMA – Core, Skills, Math

**Prerequisites:** MTH 095 with C- or better or MTH 103 with C- or better or Math Placement Test with a score of 17 or Math Placement - ALEKS with a score of 046

**MTH 112. \*ELEMENTARY FUNCTIONS. (4 Credits)**

Triangle trigonometry, circular functions and graphs, trigonometric equations and identities, inverse trigonometric functions, polar coordinates, vectors and applications. Lec/rec. All courses used to satisfy MTH prerequisites must be completed with C- or better. (Bacc Core Course)

**Attributes:** CSMA – Core, Skills, Math

**Prerequisites:** MTH 111 with C- or better or Math Placement Test with a score of 24 or Math Placement - ALEKS with a score of 060

**Equivalent to:** MTH 150X

**MTH 150X. PRECALCULUS. (4 Credits)**

Trigonometry. Exponential, logarithmic and trigonometric functions. Lec/rec.

**Prerequisites:** MTH 111 with C- or better or Math Placement Test with a score of 24 or Math Placement - ALEKS with a score of 060

**Equivalent to:** MTH 112

**MTH 199. SPECIAL TOPICS. (1-16 Credits)**

Maximum 3 credits per term, 9 credits total. Does not meet university group requirement in physical science.

*This course is repeatable for 9 credits.*

**MTH 211. \*FOUNDATIONS OF ELEMENTARY MATHEMATICS. (4 Credits)**

Introduction to problem solving, sets, whole numbers, number theory, fractions. Intended primarily for prospective elementary teachers. (Bacc Core Course)

**Attributes:** CSMA – Core, Skills, Math

**Prerequisites:** MTH 095 with C- or better or MTH 103 with C- or better or MTH 111 with C- or better or MTH 112 with C- or better or Math Placement Test with a score of 17 or Math Placement - ALEKS with a score of 046

**MTH 212. FOUNDATIONS OF ELEMENTARY MATHEMATICS. (4 Credits)**

Math 212 is the second of a three-term sequence of courses designed to help prepare prospective elementary and middle school teachers. Topics covered include fractions, decimals, percent, ratio and proportion, integers, rational numbers, real numbers, probability and statistics.

**Prerequisites:** MTH 211 with C- or better

**MTH 227. \*CALCULUS AND PROBABILITY FOR THE LIFE SCIENCES I. (4 Credits)**

Review of exponential and trigonometric functions, including examples of exponential and periodic behavior; discrete probability; examples of biologically motivated difference equations; differentiation of polynomials, exponential and trigonometric functions with applications to optimization. All courses used to satisfy MTH prerequisites must be completed with C- or better. (Bacc Core Course)

**Attributes:** CSMA – Core, Skills, Math

**Prerequisites:** MTH 112 with C- or better or MTH 150X with C- or better or Math Placement Test with a score of 33 or Math Placement - ALEKS with a score of 75

**MTH 228. CALCULUS AND PROBABILITY FOR THE LIFE SCIENCES II. (4 Credits)**

Continuation of MTH 227 with more general population growth models. Antidifferentiation; The Fundamental Theorem of Calculus applied to solving continuous growth models. Continuous random variables. Basic linear algebra of small systems sufficient to calculate eigenvalues and eigenvectors and appreciate their use in life science applications. Lec/rec.

**Prerequisites:** MTH 227 with C- or better or MTH 227X with C- or better

**MTH 231. ELEMENTS OF DISCRETE MATHEMATICS. (4 Credits)**

Elementary logic and set theory, functions, direct proof techniques, contradiction and contraposition, mathematical induction and recursion, elementary combinatorics, basic graph theory, minimal spanning trees. All courses used to satisfy MTH prerequisites must be completed with C- or better.

**Prerequisites:** MTH 112 with C- or better or Math Placement Test with a score of 33 or Math Placement - ALEKS with a score of 075

**Equivalent to:** MTH 231H

**MTH 231H. ELEMENTS OF DISCRETE MATHEMATICS. (4 Credits)**

Elementary logic and set theory, functions, direct proof techniques, contradiction and contraposition, mathematical induction and recursion, elementary combinatorics, basic graph theory, minimal spanning trees. All courses used to satisfy MTH prerequisites must be completed with C- or better.

**Attributes:** HNRS – Honors Course Designator

**Prerequisites:** MTH 112 with C- or better or Math Placement Test with a score of 33 or Math Placement - ALEKS with a score of 075

**Equivalent to:** MTH 231

**MTH 241. \*CALCULUS FOR MANAGEMENT AND SOCIAL SCIENCE. (4 Credits)**

Elementary differential calculus of polynomial, logarithmic, and exponential functions and their applications to business, management and social sciences. Lec/rec. (Bacc Core Course)

**Attributes:** CSMA – Core, Skills, Math

**Prerequisites:** MTH 111 with C- or better or Math Placement Test with a score of 24 or Math Placement - ALEKS with a score of 060

**MTH 245. \*MATHEMATICS FOR MANAGEMENT, LIFE, AND SOCIAL SCIENCES. (4 Credits)**

Techniques of counting, probability and elements of statistics including binomial and normal distributions. Introductory matrix algebra. Elements of linear programming. Lec/rec. All courses used to satisfy MTH prerequisites must be completed with C- or better. (Bacc Core Course)

**Attributes:** CSMA – Core, Skills, Math

**Prerequisites:** MTH 111 with C- or better or Math Placement Test with a score of 24 or Math Placement - ALEKS with a score of 060

**MTH 251. \*DIFFERENTIAL CALCULUS. (4 Credits)**

Differential calculus for engineers and scientists. Rates of change: the derivative, velocity, and acceleration. The algebraic rules of differential calculus and derivatives of polynomial, rational, and trigonometric functions. Maximum-minimum problems, curve sketching, and other applications. Antiderivatives and simple motion problems. Lec/rec. All courses used to satisfy MTH prerequisites must be completed with a C- or better. (Bacc Core Course)

**Attributes:** CSMA – Core, Skills, Math

**Prerequisites:** MTH 112 with C- or better or MTH 150X with C- or better or Math Placement Test with a score of 33 or Math Placement - ALEKS with a score of 075

**Equivalent to:** MTH 251H

**MTH 251H. \*DIFFERENTIAL CALCULUS. (4 Credits)**

Differential calculus for engineers and scientists. Rates of change: the derivative, velocity, and acceleration. The algebraic rules of differential calculus and derivatives of polynomial, rational, and trigonometric functions. Maximum-minimum problems, curve sketching, and other applications. Antiderivatives and simple motion problems. Lec/rec. All courses used to satisfy MTH prerequisites must be completed with C- or better. (Bacc Core Course)

**Attributes:** CSMA – Core, Skills, Math; HNRS – Honors Course Designator

**Prerequisites:** MTH 112 with C- or better or MTH 150X with C- or better or Math Placement Test with a score of 33 or Math Placement - ALEKS with a score of 075

**Equivalent to:** MTH 251

**MTH 252. INTEGRAL CALCULUS. (4 Credits)**

Definite integrals, elementary applications to area, force, and work. Integral tables and basic techniques of integration, calculus of logarithmic and exponential functions, polar coordinates, applications to areas, volumes, force, work, and growth and decay problems. Lec/rec. All courses used to satisfy MTH prerequisites must be completed with C- or better.

**Prerequisites:** MTH 251 with C- or better or MTH 251H with C- or better

**Equivalent to:** MTH 252H

**MTH 252H. INTEGRAL CALCULUS. (4 Credits)**

Definite integrals, elementary applications to area, force, and work. Integral tables and basic techniques of integration, calculus of logarithmic and exponential functions, polar coordinates, applications to areas, volumes, force, work, and growth and decay problems. All courses used to satisfy MTH prerequisites must be completed with C- or better.

**Attributes:** HNRS – Honors Course Designator

**Prerequisites:** MTH 251 with C- or better or MTH 251H with C- or better

**Equivalent to:** MTH 252

**MTH 253. INFINITE SERIES AND SEQUENCES. (4 Credits)**

Indeterminate forms. Improper integrals. Sequences and series, especially Taylor's formula and power series. Applications to numerical estimation with error analysis. Series with complex terms and the Euler identities. Lec/rec. All courses used to satisfy MTH prerequisites must be completed with C- or better.

**Prerequisites:** MTH 252 with C- or better or MTH 252H with C- or better

**MTH 254. VECTOR CALCULUS I. (4 Credits)**

Vectors, vector functions, and curves in two and three dimensions. Surfaces, partial derivatives, gradients, and directional derivatives. Multiple integrals in rectangular, polar, cylindrical, and spherical coordinates. Physical and geometric applications. Lec/rec. All courses used to satisfy MTH prerequisites must be completed with C- or better.

**Prerequisites:** MTH 252 with C- or better or MTH 252H with C- or better

**Equivalent to:** MTH 254H

**MTH 254H. VECTOR CALCULUS I. (4 Credits)**

Vectors, vector functions, and curves in two and three dimensions. Surfaces, partial derivatives, gradients, and directional derivatives. Multiple integrals in rectangular, polar, cylindrical, and spherical coordinates. Physical and geometric applications. Lec/rec. All courses used to satisfy MTH prerequisites must be completed with C- or better.

**Attributes:** HNRS – Honors Course Designator

**Prerequisites:** MTH 252 with C- or better or MTH 252H with C- or better

**Equivalent to:** MTH 254

**MTH 255. VECTOR CALCULUS II. (4 Credits)**

Brief review of vector functions, space curves, gradients, and directional derivatives. Introduction to vector analysis: vector fields, divergence, curl, line integrals, surface integrals, conservative fields, and the theorems of Gauss and Stokes with applications to force, work, mass, and charge. Lec/rec. All courses used to satisfy MTH prerequisites must be completed with C- or better.

**Prerequisites:** MTH 254 with C- or better or MTH 254H with C- or better

**Equivalent to:** MTH 255H

**MTH 255H. VECTOR CALCULUS II. (4 Credits)**

Brief review of vector functions, space curves, gradients, and directional derivatives. Introduction to vector analysis: vector fields, divergence, curl, line integrals, surface integrals, conservative fields, and the theorems of Gauss and Stokes with applications to force, work, mass, and charge. All courses used to satisfy MTH prerequisites must be completed with C- or better.

**Attributes:** HNRS – Honors Course Designator

**Prerequisites:** MTH 254 with C- or better or MTH 254H with C- or better

**Equivalent to:** MTH 255

**MTH 256. APPLIED DIFFERENTIAL EQUATIONS. (4 Credits)**

First order linear and nonlinear equations, and second order linear equations. Applications to electric circuits and mechanical oscillators. Introduction to the Laplace transform and higher order equations. Solution methods and applications appropriate for science and engineering. (Familiarity with complex numbers and Euler's identities is highly desirable.) Lec/rec. All courses used to satisfy MTH prerequisites must be completed with C- or better.

**Prerequisites:** MTH 254 with C- or better or MTH 254H with C- or better

**Equivalent to:** MTH 256H

**MTH 256H. APPLIED DIFFERENTIAL EQUATIONS. (4 Credits)**

First order linear and nonlinear equations, and second order linear equations. Applications to electric circuits and mechanical oscillators. Introduction to the Laplace transform and higher order equations. Solution methods and applications appropriate for science and engineering. (Familiarity with complex numbers and Euler's identities is highly desirable.) All courses used to satisfy MTH prerequisites must be completed with C- or better.

**Attributes:** HNRS – Honors Course Designator

**Prerequisites:** MTH 254 with C- or better or MTH 254H with C- or better

**Equivalent to:** MTH 256

**MTH 264. INTRODUCTION TO MATRIX ALGEBRA. (2 Credits)**

Introduction to matrix algebra: systematic solution to systems of linear equations; linear transformations; eigenvalue problems.

**Prerequisites:** MTH 252 with C- or better or MTH 252H with C- or better

**MTH 264H. INTRODUCTION TO MATRIX ALGEBRA. (2 Credits)**

Introduction to matrix algebra: systematic solution to systems of linear equations; linear transformations; eigenvalue problems.

**Attributes:** HNRS – Honors Course Designator

**Prerequisites:** MTH 252 with C- or better or MTH 252H with C- or better

**MTH 265. INTRODUCTION TO SERIES. (2 Credits)**

Convergence and divergence of numerical series, including geometric series. Series of functions. Power series and their analytic properties. Taylor series expansions and Taylor polynomials.

**Prerequisites:** MTH 252 with C- or better or MTH 252H with C- or better

*This course is repeatable for 2 credits.*

**MTH 265H. INTRODUCTION TO SERIES. (2 Credits)**

Convergence and divergence of numerical series, including geometric series. Series of functions. Power series and their analytic properties. Taylor series expansions and Taylor polynomials.

**Attributes:** HNRS – Honors Course Designator

**Prerequisites:** MTH 252 with C- or better or MTH 252H with C- or better

**MTH 268. MATHEMATICAL IDEAS IN BIOLOGY. (4 Credits)**

Mathematical models of biological systems, with emphasis on population dynamics and ecology. Integral calculus with applications to biology. All courses used to satisfy MTH prerequisites must be completed with C- or better.

**Prerequisites:** MTH 251 with D- or better or MTH 251H with D- or better

**MTH 299. SPECIAL TOPICS. (0-16 Credits)**

Maximum 3 credits per term, 9 credits total.

*This course is repeatable for 9 credits.*

**MTH 306. MATRIX AND POWER SERIES METHODS. (4 Credits)**

Introduction to matrix algebra, determinants, systematic solution to linear systems, and eigenvalue problems. Convergence and divergence of series with emphasis on power series, Taylor series expansions, convergence tests for power series, and error estimates for truncated series used in practical approximations. Lec/rec. All courses used to satisfy MTH prerequisites must be completed with C- or better.

**Prerequisites:** MTH 252 with C- or better or MTH 252H with C- or better

**Equivalent to:** MTH 306H

**MTH 306H. MATRIX AND POWER SERIES METHODS. (4 Credits)**

Introduction to matrix algebra, determinants, systematic solution to linear systems, and eigenvalue problems. Convergence and divergence of series with emphasis on power series, Taylor series expansions, convergence tests for power series, and error estimates for truncated series used in practical approximations. Lec/rec. All courses used to satisfy MTH prerequisites must be completed with C- or better.

**Attributes:** HNRS – Honors Course Designator

**Prerequisites:** MTH 252 with C- or better or MTH 252H with C- or better

**Equivalent to:** MTH 306

**MTH 311. ADVANCED CALCULUS. (4 Credits)**

Rigorous development of calculus, axiomatic properties of  $\mathbb{R}$ , topology of the real line, convergence of sequences and series of real numbers, functions, limits of functions, basic properties of continuity and derivatives. Brief treatment of Riemann integration, improper integrals, sequences of functions, pointwise and uniform convergence, introductory aspects of multivariable calculus. All courses used to satisfy MTH prerequisites must be completed with C- or better.

**Prerequisites:** (MTH 255 with C- or better or MTH 255H with C- or better) and MTH 355 [C-]

**MTH 312. ADVANCED CALCULUS. (4 Credits)**

Rigorous development of calculus, axiomatic properties of  $\mathbb{R}$ , topology of the real line, convergence of sequences and series of real numbers, functions, limits of functions, basic properties of continuity and derivatives. Brief treatment of Riemann integration, improper integrals, sequences of functions, pointwise and uniform convergence, introductory aspects of multivariable calculus. All courses used to satisfy MTH prerequisites must be completed with C- or better.

**Prerequisites:** MTH 311 with C- or better and MTH 342 (may be taken concurrently) [C-]

**MTH 321. INTRODUCTORY APPLICATIONS OF MATHEMATICAL SOFTWARE. (3 Credits)**

An introduction to select mathematical software packages to support problem solving and applications. Topics include using computational resources to solve basic numerical and symbolic problems in mathematics, visualization and presentation of data, creation of simple programming scripts, and applications of basic programming techniques to promote mathematical understanding. The scientific typesetting language LaTeX will also be covered. All courses used to satisfy MTH prerequisites must be completed with a C- or better.

**Prerequisites:** (MTH 252 with C- or better or MTH 252H with C- or better) and (MTH 341 [C-] or MTH 306 [C-] or MTH 306H [C-])

**MTH 323. ^MATHEMATICAL MODELING. (3 Credits)**

A variety of mathematical modeling techniques will be introduced. Students will formulate models in response to practical problems drawn from the literature of ecology, environmental sciences, engineering or other fields. Informal writing assignments in class and formal written presentation of the models will be required. All courses used to satisfy MTH prerequisites must be completed with C- or better. (Writing Intensive Course)

**Attributes:** CWIC – Core, Skills, WIC

**Prerequisites:** (MTH 256 with C- or better or MTH 256H with C- or better) and MTH 341 [C-]

**MTH 333. ^FUNDAMENTAL CONCEPTS OF TOPOLOGY. (3 Credits)**

Open and closed sets, continuity, compactness, connectedness, winding number, fixed point theorems in the plane. All courses used to satisfy MTH prerequisites must be completed with C- or better. (Writing Intensive Course)

**Attributes:** CWIC – Core, Skills, WIC

**Prerequisites:** MTH 341 with C- or better or MTH 355 with C- or better

**MTH 338. ^NON-EUCLIDEAN GEOMETRY. (3 Credits)**

Introduction to non-Euclidean geometries. Selected topics such as hyperbolic and elliptic geometry, spherical geometry, projective geometry, geometries arising from alternative metrics. All courses used to satisfy MTH prerequisites must be completed with C- or better. (Writing Intensive Course)

**Attributes:** CWIC – Core, Skills, WIC

**Prerequisites:** MTH 252 with C- or better or MTH 252H with C- or better

**MTH 341. LINEAR ALGEBRA I. (3 Credits)**

Matrix algebra, determinants, systems of linear equations, subspaces, an introductory study of eigenvalues and eigenvectors. All courses used to satisfy MTH prerequisites must be completed with C- or better.

**Prerequisites:** MTH 254 with C- or better or MTH 254H with C- or better

**MTH 342. LINEAR ALGEBRA II. (4 Credits)**

Abstract (real or complex) vector spaces, linear transformations, inner product spaces, orthogonality, eigenspaces and diagonalization, spectral theorems, singular value decomposition. All courses used to satisfy MTH prerequisites must be completed with C- or better.

**Prerequisites:** MTH 341 with C- or better

**MTH 343. INTRODUCTION TO MODERN ALGEBRA. (3 Credits)**

Introduction to rings and fields with an emphasis on the integers and polynomial rings; selected applications. All courses used to satisfy MTH prerequisites must be completed with C- or better.

**Prerequisites:** MTH 341 with C- or better and MTH 355 [C-]

**MTH 351. INTRODUCTION TO NUMERICAL ANALYSIS. (3 Credits)**

Introduction to the computation of approximate solutions to mathematical problems that cannot be solved by hand: analysis of errors; rootfinding for nonlinear equations in one variable; interpolation of functions; numerical integration. All courses used to satisfy MTH prerequisites must be completed with C- or better.

**Prerequisites:** MTH 253 with C- or better or MTH 306 with C- or better or MTH 306H with C- or better

**Recommended:** Programming experience

**MTH 355. DISCRETE MATHEMATICS. (3 Credits)**

Proof analysis and development in the context of discrete mathematics for math majors transitioning to upper-division course work. Topics include elementary logic and set theory, quantifiers, basic counting principles, elementary combinatorics, equivalence relations, the binomial theorem, and mathematical induction. Additional topics may include recurrence relations, generating functions, and introductory graph theory. All courses used to satisfy MTH prerequisites must be completed with C- or better.

**Prerequisites:** MTH 253 with C- or better

**Recommended:** MTH 341

**MTH 361. INTRODUCTION TO PROBABILITY. (3 Credits)**

Probability problem solving using concepts developed in calculus. Topics include probability models, discrete and continuous random variables, expectation and variance, the law of large numbers, and the central limit theorem. All courses used to satisfy MTH prerequisites must be completed with C- or better.

**Prerequisites:** MTH 253 with C- or better or MTH 306 with C- or better or MTH 306H with C- or better

**MTH 390. FOUNDATIONS OF ELEMENTARY MATHEMATICS. (4 Credits)**

Math 390 is the third of a three-term sequence of classes designed to help prepare prospective elementary and middle school teachers. Topics covered include informal geometry, measurement, congruence, similarity, coordinate and transformational geometry.

**Prerequisites:** MTH 211 with C- or better and MTH 212 [C-]

**MTH 399. SPECIAL TOPICS. (1-16 Credits)**

**Equivalent to:** MTH 399H

*This course is repeatable for 16 credits.*

**MTH 399H. SPECIAL TOPICS. (1-16 Credits)**

**Attributes:** HNRS – Honors Course Designator

**Equivalent to:** MTH 399

*This course is repeatable for 16 credits.*

**MTH 401. RESEARCH. (1-16 Credits)**

*This course is repeatable for 16 credits.*

**MTH 403. THESIS. (1-16 Credits)**

*This course is repeatable for 16 credits.*

**MTH 405. READING AND CONFERENCE. (1-16 Credits)**

*This course is repeatable for 16 credits.*

**MTH 406. PROJECTS. (1-3 Credits)**

Graded P/N.

*This course is repeatable for 16 credits.*

**MTH 407. SEMINAR. (3 Credits)**

*This course is repeatable for 99 credits.*

**MTH 410. OCCUPATIONAL INTERNSHIP. (3-12 Credits)**

Planned and supervised training experience at selected government, industrial, or business placement sites. Must be followed by a one-hour post-internship seminar. Consult departmental head advisor. Graded P/N.

*This course is repeatable for 16 credits.*

**MTH 411. REAL ANALYSIS. (3 Credits)**

Properties of metric spaces and normed spaces, including  $l_p$  spaces. Completeness and applications, including fixed point theorems. Compactness. Equicontinuity and the Arzela-Ascoli theorem. Uniform continuity and uniform convergence, including applications.

**Prerequisites:** MTH 312 with B+ or better and MTH 341 [B+]

*This course is repeatable for 18 credits.*

**MTH 412. REAL ANALYSIS. (3 Credits)**

Measure and integration theory, basic convergence theorems, Lebesgue spaces, Fubini's theorem, Radon-Nikodym theorem, and applications. Banach spaces including Baire category theorems, and Hilbert spaces.

**Prerequisites:** MTH 411 with C- or better or MTH 511 with C- or better

*This course is repeatable for 18 credits.*

**MTH 413. REAL ANALYSIS. (3 Credits)**

Measure and integration theory, basic convergence theorems, Lebesgue spaces, Fubini's theorem, Radon-Nikodym theorem, and applications. Banach spaces including Baire category theorems, and Hilbert spaces.

**Prerequisites:** MTH 412 with C- or better or MTH 512 with C- or better

*This course is repeatable for 18 credits.*

**MTH 419. MULTIVARIABLE ADVANCED CALCULUS. (3 Credits)**

A rigorous development of multivariable advanced calculus, including continuity and compactness in multivariable Euclidean spaces, differentiation and approximation of multivariable functions, the inverse function theorem and the implicit function theorem, integration in several variables.

**Prerequisites:** MTH 312 with B or better

**MTH 420. MODELS AND METHODS OF APPLIED MATHEMATICS. (3 Credits)**

Discrete and continuous mathematical models and methods for analysis, including linear analysis, equilibrium and minimum principles, calculus of variations, principal component analysis and orthogonal expansions, asymptotic and Fourier analysis, least squares, constrained and unconstrained optimization, inverse problems, and Monte Carlo techniques. Particular models and methods covered may vary annually. All courses used to satisfy MTH prerequisites must be completed with C- or better.

**Prerequisites:** (MTH 256 with C- or better or MTH 256H with C- or better) and MTH 341 [C-]

**MTH 427. INTRODUCTION TO MATHEMATICAL BIOLOGY. (3 Credits)**

Modeling and mathematical analysis of biological processes using first principles at scales ranging from the molecular to the population level. Deterministic models are studied in both discrete and continuous time and analyzed using linearization principles, linear and nonlinear stability techniques, phase plane methods, and methods from partial differential equations. Results obtained from mathematical analysis will be qualitatively interpreted and applied to the biological process under investigation. All courses used to satisfy MTH prerequisites must be completed with a C- or better.

**Prerequisites:** (MTH 256 with C- or better or MTH 256H with C- or better) and MTH 341 [C-]

**MTH 428. STOCHASTIC ELEMENTS IN MATHEMATICAL BIOLOGY. (3 Credits)**

An introduction to stochastic modeling of biological processes. The stochastic models covered may include Markov processes in both continuous and discrete time, urn models, branching processes, and coalescent processes. The biological applications may include genetic drift, population dynamics, genealogy, demography, and epidemiology. Mathematical results will be qualitatively interpreted and applied to the biological process under investigation.

**Prerequisites:** MTH 341 with C or better and (MTH 361 [C] or MTH 463 [C] or MTH 563 [C])

**MTH 430. METRIC SPACES AND TOPOLOGY. (3 Credits)**

Fundamental notions of metric space topology. Examples of Euclidean, non-Euclidean and other fundamental metric spaces including the Hilbert Cube and two-dimensional surfaces. Characterization and classification results for metric spaces. Selected applications of topology, possibly including the structure of molecules and/or networks. All courses used to satisfy MTH prerequisites must be completed with C- or better.

**Prerequisites:** MTH 342 with C- or better or MTH 355 with C- or better

**Recommended:** MTH 311

**MTH 434. INTRODUCTION TO DIFFERENTIAL GEOMETRY. (3 Credits)**

Curves and surfaces in Euclidean space; geodesics; curvature; introduction to tensor algebra and differential forms; selected applications. All courses used to satisfy MTH prerequisites must be completed with C- or better.

**Prerequisites:** (MTH 255 with C- or better or MTH 255H with C- or better) and MTH 342 [C-]

**Recommended:** MTH 311

**MTH 435. DIFFERENTIAL GEOMETRY. (3 Credits)**

Differentiable 2-manifolds; curvature; geodesics; tensor algebra and the algebra of exterior differential forms with emphasis on Euclidean space; differentiation of tensors and forms; integration of forms; selected applications. All courses used to satisfy MTH prerequisites must be completed with C- or better.

**Prerequisites:** MTH 434 with C- or better or MTH 534 with C- or better

**MTH 437. GENERAL RELATIVITY. (3 Credits)**

Geometry of special relativity. Tensor analysis, metrics, geodesics, curvature. Einstein field equations, cosmological models, black holes. Selected topics such as global structure, conserved quantities, spinors. All courses used to satisfy MTH prerequisites must be completed with C- or better.

**Prerequisites:** (MTH 434 with C- or better or MTH 534 with C- or better)

**Recommended:** MTH 311

**MTH 440. COMPUTATIONAL NUMBER THEORY. (3 Credits)**

Development of the number theory used in some basic tests of primality and methods of factoring integers. Applications to cryptology. All courses used to satisfy MTH prerequisites must be completed with C- or better.

**Prerequisites:** MTH 231 with C- or better or MTH 343 with C- or better or MTH 355 with C- or better

**MTH 441. APPLIED AND COMPUTATIONAL ALGEBRA. (3 Credits)**

Applications of fundamental algebraic systems to topics such as factorization of polynomials, finding roots of polynomials, error correcting codes. All courses used to satisfy MTH prerequisites must be completed with C- or better.

**Prerequisites:** MTH 343 with C- or better and (MTH 342 [C-] or MTH 440 [C-] or MTH 540 [C-])

**MTH 442. APPLIED AND COMPUTATIONAL ALGEBRA. (3 Credits)**

Applications of fundamental algebraic systems to topics such as factorization of polynomials, finding roots of polynomials, error correcting codes. All courses used to satisfy MTH prerequisites must be completed with C- or better.

**Prerequisites:** MTH 441 with C- or better or MTH 541 with C- or better

**MTH 443. ABSTRACT LINEAR ALGEBRA. (3 Credits)**

Abstract vector spaces. Linear transformations, eigenvalues and eigenvectors, the Jordan canonical form, inner product spaces. All courses used to satisfy MTH prerequisites must be completed with C- or better.

**Prerequisites:** MTH 342 with C- or better or MTH 343 with C- or better

**MTH 451. NUMERICAL LINEAR ALGEBRA. (3 Credits)**

Computation of solutions of linear systems using direct and iterative methods; least-squares solution of overdetermined systems; computation of eigenvalues and eigenvectors. All courses used to satisfy MTH prerequisites must be completed with C- or better.

**Prerequisites:** MTH 341 with C- or better

**Recommended:** Programming experience, MTH 342 and MTH 351

**MTH 452. NUMERICAL SOLUTION OF ORDINARY DIFFERENTIAL EQUATIONS. (3 Credits)**

Numerical solution of initial-value problems using Runge-Kutta methods and linear multistep methods; introduction to boundary-value problems. Analysis of stability, accuracy, and implementation of methods. All courses used to satisfy MTH prerequisites must be completed with C- or better.

**Prerequisites:** (MTH 256 with C- or better or MTH 256H with C- or better) and (MTH 306 [C-] or MTH 306H [C-] or MTH 341 [C-])

**Recommended:** MTH 351 or MTH 451 or MTH 551

**MTH 453. NUMERICAL SOLUTION OF PARTIAL DIFFERENTIAL EQUATIONS. (3 Credits)**

Numerical solution of boundary value problems and initial-boundary value problems using finite difference and finite element methods. Analysis of stability, accuracy, and implementation of methods. All courses used to satisfy MTH prerequisites must be completed with C- or better.

**Prerequisites:** MTH 452 with C- or better or MTH 552 with C- or better

**MTH 463. PROBABILITY I. (3 Credits)**

An introduction to probability theory; topics covered include: the axioms of probability, probability spaces and models, independence, random variables; densities, distributions, expectation, and variance; probability inequalities, the law of large numbers, and the binomial central limit theorem. All courses used to satisfy MTH prerequisites must be completed with C- or better.

**Prerequisites:** MTH 312 with C- or better

**MTH 464. PROBABILITY II. (3 Credits)**

Transformations of random variables; sums of independent random variables, generating functions, characteristic functions, the central limit theorem and other weak limit theorems. All courses used to satisfy MTH prerequisites must be completed with C- or better.

**Prerequisites:** (MTH 463 with C- or better or MTH 563 with C- or better) and MTH 341 [C-]

**MTH 465. PROBABILITY III. (3 Credits)**

Random variables, central limit theorem; distributions of standard statistics; Markov chains, continuous and discontinuous stochastic processes. All courses used to satisfy MTH prerequisites must be completed with C- or better.

**Prerequisites:** MTH 464 with C- or better or MTH 564 with C- or better

**MTH 467. ACTUARIAL MATHEMATICS. (3 Credits)**

Foundations of actuarial science from the point of view of mathematical models that arise in the design and management of insurance systems. Most models will be life insurance based. All courses used to satisfy MTH prerequisites must be completed with C- or better.

**Prerequisites:** MTH 463 with C- or better or MTH 563 with C- or better or ST 421 with C- or better

**MTH 480. SYSTEMS OF ORDINARY DIFFERENTIAL EQUATIONS. (3 Credits)**

Systems of two first-order differential equations, phase portraits, linearization and the stability of equilibria, conservative systems, reversible systems, limit cycles and the Poincare-Bendixson Theorem. Additional topics selected from Hamiltonian systems, Hopf bifurcation or Lorenz equations and chaos. MTH 480 and MTH 481 cannot both be taken for credit. All courses used to satisfy MTH prerequisites must be completed with C- or better.

**Prerequisites:** (MTH 256 with C- or better or MTH 256H with C- or better) and MTH 341 [C-]

**MTH 481. APPLIED ORDINARY DIFFERENTIAL EQUATIONS. (3 Credits)**

Linear and nonlinear systems of ordinary differential equations, elementary stability theory, higher order equations, boundary value problems, series solution of ordinary differential equations. All courses used to satisfy MTH prerequisites must be completed with a C- or better.

**Prerequisites:** (MTH 256 with C- or better or MTH 256H with C- or better) and ((MTH 253 with C- or better or MTH 253H with C- or better) and MTH 341 [C-]) or (MTH 306 [C-] or MTH 306H [C-])

**MTH 482. APPLIED PARTIAL DIFFERENTIAL EQUATIONS. (3 Credits)**

Partial differential equations, Bessel's and Legendre's equations, Fourier analysis, separation of variables, transform methods. All courses used to satisfy MTH prerequisites must be completed with a C- or better.

**Prerequisites:** MTH 480 with C- or better or MTH 481 with C- or better or MTH 581 with C- or better

**MTH 483. COMPLEX VARIABLES. (3 Credits)**

Introduction to the complex differential and integral calculus: Cauchy's theorem and formula, the residue calculus, power series and Laurent series, harmonic functions, conformal mapping, and applications. All courses used to satisfy MTH prerequisites must be completed with a C- or better.

**Prerequisites:** (MTH 256 with C- or better or MTH 256H with C- or better) and (MTH 253 [C-] or MTH 306 [C-] or MTH 306H [C-])

**MTH 490. INTENSIVE SUMMER RESEARCH IN MATHEMATICS. (12 Credits)**

Combination of seminar, lectures, and individual research projects designed to introduce students to research mathematics.

*This course is repeatable for 99 credits.*

**MTH 491. ALGEBRA AND GEOMETRIC TRANSFORMATIONS. (3 Credits)**

Ordered fields, number systems (natural, integer, rational, real, and complex), fundamental theorems of arithmetic and algebra, algebraic and transcendental numbers, constructible points and numbers and the classical geometric constructions, Polya's problem solving heuristics and strategies. Intended primarily for prospective mathematics teachers. All courses used to satisfy MTH prerequisites must be completed with C- or better.

**Prerequisites:** MTH 341 with C- or better

**MTH 492. ALGEBRA AND GEOMETRIC TRANSFORMATIONS. (3 Credits)**

Major results of Euclidean geometry, axiom systems for Euclidean geometry, dependency tree of Euclidean theorems, groups of geometric transformations with applications to symmetries of plane and solid objects, Euler's formula, tilings and tessellations, isometries and similitudes of the plane (translations, rotations, reflections, glide reflections, dilations). Intended primarily for prospective mathematics teachers. All courses used to satisfy MTH prerequisites must be completed with C- or better.

**Prerequisites:** MTH 491 with C- or better or MTH 591 with C- or better

**MTH 493. ALGEBRA AND GEOMETRIC TRANSFORMATIONS. (3 Credits)**

Geometric transformations as real, complex, and matrix functions, invariants and genealogy of geometric transformations, extensions to transformations of the sphere and of three-dimensional space, selected applications chosen from fractals, analysis of frieze and crystallographic patterns, problem solving, groups of symmetries, computer graphics, and the use of dynamic geometry software. Intended primarily for prospective mathematics teachers. All courses used to satisfy MTH prerequisites must be completed with C- or better.

**Prerequisites:** MTH 492 with C- or better or MTH 592 with C- or better

**MTH 499. SPECIAL TOPICS. (0-16 Credits)**

*This course is repeatable for 16 credits.*

**MTH 501. RESEARCH. (1-16 Credits)**

*This course is repeatable for 16 credits.*

**MTH 503. THESIS. (1-16 Credits)**

*This course is repeatable for 999 credits.*

**MTH 505. READING AND CONFERENCE. (1-16 Credits)**

*This course is repeatable for 16 credits.*

**MTH 506. PROJECTS. (1-16 Credits)**

Graded P/N.

*This course is repeatable for 16 credits.*

**MTH 507. SEMINAR. (1-16 Credits)**

*This course is repeatable for 16 credits.*

**MTH 508. WORKSHOP. (1-16 Credits)**

*This course is repeatable for 16 credits.*

**MTH 510. OCCUPATIONAL INTERNSHIP. (3-12 Credits)**

Planned and supervised training experience at selected government, industrial, or business placement sites. Must be followed by a one-hour post-internship seminar. Consult departmental head advisor. Graded P/N.

*This course is repeatable for 16 credits.*

**MTH 511. REAL ANALYSIS. (3 Credits)**

Properties of metric spaces and normed spaces, including  $l_p$  spaces. Completeness and applications, including fixed point theorems. Compactness. Equicontinuity and the Arzela-Ascoli theorem. Uniform continuity and uniform convergence, including applications.

*This course is repeatable for 18 credits.*

**Recommended:** MTH 312 and MTH 341

**MTH 512. REAL ANALYSIS. (3 Credits)**

Measure and integration theory, basic convergence theorems, Lebesgue spaces, Fubini's theorem, Radon-Nikodym theorem, and applications. Banach spaces including Baire category theorems, and Hilbert spaces.

**Prerequisites:** MTH 511 with C- or better

*This course is repeatable for 18 credits.*

**MTH 513. REAL ANALYSIS. (3 Credits)**

Measure and integration theory, basic convergence theorems, Lebesgue spaces, Fubini's theorem, Radon-Nikodym theorem, and applications. Banach spaces including Baire category theorems, and Hilbert spaces.

**Prerequisites:** MTH 512 with C- or better

*This course is repeatable for 18 credits.*

**MTH 520. MODELS AND METHODS OF APPLIED MATHEMATICS. (3 Credits)**

Discrete and continuous mathematical models and methods for analysis, including linear analysis, equilibrium and minimum principles, calculus of variations, principal component analysis and orthogonal expansions, asymptotic and Fourier analysis, least squares, constrained and unconstrained optimization, inverse problems, and Monte Carlo techniques. Particular models and methods covered may vary annually. All courses used to satisfy MTH prerequisites must be completed with C or better.

**Recommended:** (MTH 256 or MTH 256H) and MTH 341

**MTH 524. DYNAMICAL SYSTEMS THEORY AND APPLICATIONS. (3 Credits)**

Theory, models, and problems for discrete and/or continuous dynamical systems. Depending on term, the emphasis may be toward deterministic or stochastic systems. Topics generally include stability theory, periodic behavior, and chaotic systems. Models selected from biology, economics, fluid dynamics, and electrical and mechanical systems. May be repeated once for credit with a different topic. All courses used to satisfy MTH prerequisites must be completed with C or better.

*This course is repeatable for 6 credits.*

**Recommended:** MTH 341 and MTH 342 and MTH 311 and MTH 312 and MTH 361

**MTH 525. DYNAMICAL SYSTEMS THEORY AND APPLICATIONS. (3 Credits)**

Theory, models, and problems for discrete and/or continuous dynamical systems. Depending on term, the emphasis may be toward deterministic or stochastic systems. Topics generally include stability theory, periodic behavior, and chaotic systems. Models selected from biology, economics, fluid dynamics, and electrical and mechanical systems. May be repeated once for credit with a different topic. All courses used to satisfy MTH prerequisites must be completed with C or better.

*This course is repeatable for 6 credits.*

**Recommended:** MTH 341 and MTH 342 and MTH 311 and MTH 312 and MTH 361

**MTH 527. INTRODUCTION TO MATHEMATICAL BIOLOGY. (3 Credits)**

Modeling and mathematical analysis of biological processes using first principles at scales ranging from the molecular to the population level. Deterministic models are studied in both discrete and continuous time and analyzed using linearization principles, linear and nonlinear stability techniques, phase plane methods, and methods from partial differential equations. Results obtained from mathematical analysis will be qualitatively interpreted and applied to the biological process under investigation. All courses used to satisfy MTH prerequisites must be completed with a C or better.

**Recommended:** (MTH 256 or MTH 256H) and MTH 341

**MTH 528. STOCHASTIC ELEMENTS IN MATHEMATICAL BIOLOGY. (3 Credits)**

An introduction to stochastic modeling of biological processes. The stochastic models covered may include Markov processes in both continuous and discrete time, urn models, branching processes, and coalescent processes. The biological applications may include genetic drift, population dynamics, genealogy, demography, and epidemiology. Mathematical results will be qualitatively interpreted and applied to the biological process under investigation. All courses used to satisfy MTH prerequisites must be completed with a C or better.

**Recommended:** MTH 341 and (MTH 361 or MTH 463 or MTH 563)

**MTH 531. GENERAL TOPOLOGY AND FUNDAMENTAL GROUPS. (3 Credits)**

Topological spaces and maps. Separation axioms, compactness, convergence, extension theorems, metrizable and compactification. Product spaces and simplicial complexes. Definition and basic properties of the fundamental group functor, with applications to the theory of covering spaces. Selected topics from dimension theory, manifold theory, and other areas of topology. All courses used to satisfy MTH prerequisites must be completed with C or better.

**MTH 532. GENERAL TOPOLOGY AND FUNDAMENTAL GROUPS. (3 Credits)**

Topological spaces and maps. Separation axioms, compactness, convergence, extension theorems, metrizable and compactification. Product spaces and simplicial complexes. Definition and basic properties of the fundamental group functor, with applications to the theory of covering spaces. Selected topics from dimension theory, manifold theory, and other areas of topology. All courses used to satisfy MTH prerequisites must be completed with C or better.

**MTH 534. INTRODUCTION TO DIFFERENTIAL GEOMETRY. (3 Credits)**

Curves and surfaces in Euclidean space; geodesics; curvature; introduction to tensor algebra and differential forms; selected applications. All courses used to satisfy MTH prerequisites must be completed with C or better.

**Recommended:** (MTH 255 or MTH 255H) and MTH 342 and MTH 311

**MTH 535. DIFFERENTIAL GEOMETRY. (3 Credits)**

Differentiable 2-manifolds; curvature; geodesics; tensor algebra and the algebra of exterior differential forms with emphasis on Euclidean space; differentiation of tensors and forms; integration of forms; selected applications. All courses used to satisfy MTH prerequisites must be completed with C or better.

**Recommended:** MTH 434 or MTH 534

**MTH 537. GENERAL RELATIVITY. (3 Credits)**

Geometry of special relativity. Tensor analysis, metrics, geodesics, curvature. Einstein field equations, cosmological models, black holes. Selected topics such as global structure, conserved quantities, spinors. All courses used to satisfy MTH prerequisites must be completed with C or better.

**Prerequisites:** MTH 434 with C or better or MTH 534 with C or better

**Recommended:** MTH 311

**MTH 540. COMPUTATIONAL NUMBER THEORY. (3 Credits)**

Development of the number theory used in some basic tests of primality and methods of factoring integers. Applications to cryptography. All courses used to satisfy MTH prerequisites must be completed with C or better.

**Recommended:** MTH 231 or MTH 343 or MTH 355



**MTH 541. APPLIED AND COMPUTATIONAL ALGEBRA. (3 Credits)**

Applications of fundamental algebraic systems to topics such as factorization of polynomials, finding roots of polynomials, error correcting codes. All courses used to satisfy MTH prerequisites must be completed with C or better.

**Recommended:** MTH 343 and (MTH 342 or MTH 440 or MTH 540)

**MTH 542. APPLIED AND COMPUTATIONAL ALGEBRA. (3 Credits)**

Applications of fundamental algebraic systems to topics such as factorization of polynomials, finding roots of polynomials, error correcting codes. All courses used to satisfy MTH prerequisites must be completed with C or better.

**Recommended:** MTH 441 or MTH 541

**MTH 543. ABSTRACT LINEAR ALGEBRA. (3 Credits)**

Abstract vector spaces. Linear transformations, eigenvalues and eigenvectors, the Jordan canonical form, inner product spaces. All courses used to satisfy MTH prerequisites must be completed with C or better.

**Recommended:** MTH 342 and MTH 343

**MTH 551. NUMERICAL LINEAR ALGEBRA. (3 Credits)**

Computation of solutions of linear systems using direct and iterative methods; least-squares solution of overdetermined systems; computation of eigenvalues and eigenvectors. All courses used to satisfy MTH prerequisites must be completed with C or better.

**Recommended:** MTH 341, MTH 342, MTH 351 and programming experience

**MTH 552. NUMERICAL SOLUTION OF ORDINARY DIFFERENTIAL EQUATIONS. (3 Credits)**

Numerical solution of initial-value problems using Runge-Kutta methods and linear multistep methods; introduction to boundary-value problems. Analysis of stability, accuracy, and implementation of methods. All courses used to satisfy MTH prerequisites must be completed with C or better.

**Recommended:** Programming experience and (MTH 256 or MTH 256H) and (MTH 306 or MTH 306H or MTH 341) and (MTH 351 or MTH 451 or MTH 551)

**MTH 553. NUMERICAL SOLUTION OF PARTIAL DIFFERENTIAL EQUATIONS. (3 Credits)**

Numerical solution of boundary value problems and initial-boundary value problems using finite difference and finite element methods. Analysis of stability, accuracy, and implementation of methods. All courses used to satisfy MTH prerequisites must be completed with C or better.

**Recommended:** MTH 452 or MTH 552

**MTH 563. PROBABILITY I. (3 Credits)**

An introduction to probability theory; topics covered include: the axioms of probability, probability spaces and models, independence, random variables; densities, distributions, expectation, and variance; probability inequalities, the law of large numbers, and the binomial central limit theorem. All courses used to satisfy MTH prerequisites must be completed with C or better.

**Recommended:** MTH 312

**MTH 564. PROBABILITY II. (3 Credits)**

Transformations of random variables; sums of independent random variables, generating functions, characteristic functions, the central limit theorem and other weak limit theorems. All courses used to satisfy MTH prerequisites must be completed with C or better.

**Recommended:** MTH 341 and (MTH 463 or MTH 563)

**MTH 565. PROBABILITY III. (3 Credits)**

Random variables, central limit theorem; distributions of standard statistics; Markov chains, continuous and discontinuous stochastic processes. All courses used to satisfy MTH prerequisites must be completed with C or better.

**Recommended:** MTH 464 or MTH 564

**MTH 567. ACTUARIAL MATHEMATICS. (3 Credits)**

Foundations of actuarial science from the point of view of mathematical models that arise in the design and management of insurance systems. Most models will be life insurance based. All courses used to satisfy MTH prerequisites must be completed with C or better.

**Recommended:** (MTH 463 or MTH 563) or ST 421.

**MTH 574. NUMBER SYSTEMS AND OPERATIONS IN K-8 MATHEMATICS. (3 Credits)**

Key ideas and topics in number systems, operations, place value, and algorithms critical for the mathematics content knowledge of elementary teachers in grades K-8. Based on the recommendations of The Mathematical Education of Teachers by the Conference Board of the Mathematical Sciences. All courses used to satisfy MTH prerequisites must be completed with C or better.

**Recommended:** MTH 390 or instructor approval required.

**MTH 575. COMPARING GEOMETRIES IN K-8 MATHEMATICS. (3 Credits)**

Key ideas and topics in Euclidean and non-Euclidean geometries critical for the mathematics content knowledge of elementary teachers in grades K-8. Based on the recommendations of The Mathematical Education of Teachers by the Conference Board of the Mathematical Sciences. All courses used to satisfy MTH prerequisites must be completed with C or better.

**Recommended:** MTH 390 or instructor approval required.

**MTH 576. ALGEBRA AND FUNCTION IN K-8 MATHEMATICS. (3 Credits)**

Key ideas and topics in algebra and function concepts critical for the mathematics content knowledge of elementary teachers in grades K-8. Based on the recommendations of The Mathematical Education of Teachers by the Conference Board of the Mathematical Sciences. All courses used to satisfy MTH prerequisites must be completed with C or better.

**Recommended:** MTH 390 or instructor approval required.

**MTH 578. PROBABILITY AND DATA ANALYSIS IN K-8 MATHEMATICS. (3 Credits)**

Key ideas and topics in probability, data analysis, and statistics critical for the mathematics content knowledge of elementary teachers in grades K-8. Based on the recommendations of The Mathematical Education of Teachers by the Conference Board of the Mathematical Sciences. All courses used to satisfy MTH prerequisites must be completed with C or better.

**Recommended:** MTH 390

**MTH 581. APPLIED ORDINARY DIFFERENTIAL EQUATIONS. (3 Credits)**

Linear and nonlinear systems of ordinary differential equations, elementary stability theory, higher order equations, boundary value problems, series solution of ordinary differential equations. All courses used to satisfy MTH prerequisites must be completed with C or better.

**Recommended:** (MTH 256 or MTH 256H) and (((MTH 253 or MTH 253H) and MTH 341) or (MTH 306 or MTH 306H))

**MTH 582. APPLIED PARTIAL DIFFERENTIAL EQUATIONS. (3 Credits)**

Partial differential equations, Bessel's and Legendre's equations, Fourier analysis, separation of variables, transform methods. All courses used to satisfy MTH prerequisites must be completed with C or better.

**Recommended:** MTH 480 or MTH 481 or MTH 581

**MTH 583. COMPLEX VARIABLES. (3 Credits)**

Introduction to the complex differential and integral calculus: Cauchy's theorem and formula, the residue calculus, power series and Laurent series, harmonic functions, conformal mapping, and applications. All courses used to satisfy MTH prerequisites must be completed with C or better.

**Recommended:** (MTH 256 or MTH 256H) and (MTH 253 or MTH 306 or MTH 306H)

**MTH 590. TOPICS IN SECONDARY MATHEMATICS. (3 Credits)**

Key ideas and topics in discrete mathematics critical for the mathematics content knowledge of middle and high school teachers in grades 6-12.

Based on the recommendations of The Mathematical Education of Teachers by the Conference Board of the Mathematical Sciences. All courses used to satisfy MTH prerequisites must be completed with C or better.

**Recommended:** MTH 390

**MTH 591. ALGEBRA AND GEOMETRIC TRANSFORMATIONS. (3 Credits)**

Ordered fields, number systems (natural, integer, rational, real, and complex), fundamental theorems of arithmetic and algebra, algebraic and transcendental numbers, constructible points and numbers and the classical geometric constructions, Polya's problem solving heuristics and strategies. Intended primarily for prospective mathematics teachers. All courses used to satisfy MTH prerequisites must be completed with C or better.

**Recommended:** MTH 341

**MTH 592. ALGEBRA AND GEOMETRIC TRANSFORMATIONS. (3 Credits)**

Major results of Euclidean geometry, axiom systems for Euclidean geometry, dependency tree of Euclidean theorems, groups of geometric transformations with applications to symmetries of plane and solid objects, Euler's formula, tilings and tessellations, isometries and similitudes of the plane (translations, rotations, reflections, glide reflections, dilations). Intended primarily for prospective mathematics teachers. All courses used to satisfy MTH prerequisites must be completed with C or better.

**Recommended:** MTH 491 or MTH 591

**MTH 593. ALGEBRA AND GEOMETRIC TRANSFORMATIONS. (3 Credits)**

Geometric transformations as real, complex, and matrix functions, invariants and genealogy of geometric transformations, extensions to transformations of the sphere and of three-dimensional space, selected applications chosen from fractals, analysis of frieze and crystallographic patterns, problem solving, groups of symmetries, computer graphics, and the use of dynamic geometry software. Intended primarily for prospective mathematics teachers. All courses used to satisfy MTH prerequisites must be completed with C or better.

**Recommended:** MTH 492 or MTH 592

**MTH 594. NUMBER SYSTEMS AND OPERATIONS IN SECONDARY MATHEMATICS. (3 Credits)**

Key ideas and topics in number systems, operations, place value, and algorithms critical for the mathematics content knowledge of middle and high school teachers in grades 6-12. Based on the recommendations of The Mathematical Education of Teachers by the Conference Board of the Mathematical Sciences. All courses used to satisfy MTH prerequisites must be completed with C or better.

**Recommended:** MTH 390

**MTH 595. COMPARING GEOMETRIES IN SECONDARY MATHEMATICS. (3 Credits)**

Key ideas and topics in Euclidean and non-Euclidean geometries critical for the mathematics content knowledge of middle and high school teachers in grades 6-12. Based on the recommendations of The Mathematical Education of Teachers by the Conference Board of the Mathematical Sciences. All courses used to satisfy MTH prerequisites must be completed with C or better.

**Recommended:** MTH 390 or instructor approval required.

**MTH 596. ALGEBRA AND FUNCTION IN SECONDARY MATHEMATICS. (3 Credits)**

Key ideas and topics in algebra and function concepts critical for the mathematics content knowledge of middle and high school teachers in grades 6-12. Based on the recommendations of The Mathematical Education of Teachers by the Conference Board of the Mathematical Sciences. All courses used to satisfy MTH prerequisites must be completed with C or better.

**Recommended:** MTH 390 or instructor approval required.

**MTH 598. PROBABILITY AND DATA ANALYSIS IN SECONDARY MATHEMATICS. (3 Credits)**

Key ideas and topics in probability, data analysis, and statistics critical for the mathematics content knowledge of middle and high school teachers in grades 6-12. Based on the recommendations of The Mathematical Education of Teachers by the Conference Board of the Mathematical Sciences. All courses used to satisfy MTH prerequisites must be completed with C or better.

**Recommended:** MTH 390

**MTH 599. SPECIAL TOPICS. (0-16 Credits)**

Topics may vary.

*This course is repeatable for 18 credits.*

**MTH 601. RESEARCH. (1-16 Credits)**

*This course is repeatable for 16 credits.*

**MTH 603. THESIS. (1-16 Credits)**

*This course is repeatable for 999 credits.*

**MTH 605. READING AND CONFERENCE. (1-16 Credits)**

*This course is repeatable for 16 credits.*

**MTH 606. SPECIAL PROJECTS. (1-16 Credits)**

Graded P/N.

*This course is repeatable for 16 credits.*

**MTH 607. SEMINAR. (1-16 Credits)**

*This course is repeatable for 99 credits.*

**MTH 611. COMPLEX ANALYSIS. (3 Credits)**

Basic theory of analytic functions of a complex variable, including Cauchy's theorem, residue theorem, analytic continuation, conformal mappings, entire, and meromorphic functions. All courses used to satisfy MTH prerequisites must be completed with C or better.

**Recommended:** MTH 411 or MTH 511

**MTH 612. COMPLEX ANALYSIS. (3 Credits)**

Basic theory of analytic functions of a complex variable, including Cauchy's theorem, residue theorem, analytic continuation, conformal mappings, entire, and meromorphic functions. All courses used to satisfy MTH prerequisites must be completed with C or better.

**Recommended:** MTH 611

**MTH 614. FUNCTIONAL ANALYSIS. (3 Credits)**

Topological vector spaces, generalized functions, operator theory. Normally offered alternate years. All courses used to satisfy MTH prerequisites must be completed with C or better.

**Recommended:** MTH 513

**MTH 619. TOPICS IN ANALYSIS. (1-12 Credits)**

*This course is repeatable for 12 credits.*

**MTH 621. PARTIAL DIFFERENTIAL EQUATIONS. (3 Credits)**

Partial differential equations of physics, including those of potential theory, wave propagation, and heat flow, treated by classical means, generalized functions and variational principles. Square summable function methods and integral equations. This course is the first in a year-long sequence of MTH 621, MTH 622, MTH 623. All courses used to satisfy MTH prerequisites must be completed with C or better.

*This course is repeatable for 6 credits.*

**Recommended:** 6 credits of senior-level analysis

**MTH 622. PARTIAL DIFFERENTIAL EQUATIONS. (3 Credits)**

Partial differential equations of physics, including those of potential theory, wave propagation, and heat flow, treated by classical means, generalized functions and variational principles. Square summable function methods and integral equations. This course is the first in a year-long sequence of MTH 621, MTH 622, MTH 623. All courses used to satisfy MTH prerequisites must be completed with C or better.

**Prerequisites:** MTH 621 with C or better

*This course is repeatable for 6 credits.*

**MTH 623. PARTIAL DIFFERENTIAL EQUATIONS. (3 Credits)**

Partial differential equations of physics, including those of potential theory, wave propagation, and heat flow, treated by classical means, generalized functions and variational principles. Square summable function methods and integral equations. This course is the third one in year-long sequence. All courses used to satisfy MTH prerequisites must be completed with C or better.

**Prerequisites:** MTH 621 with C or better and MTH 622 [C]

*This course is repeatable for 6 credits.*

**MTH 627. ADVANCED PARTIAL DIFFERENTIAL EQUATIONS. (3 Credits)**

Advanced theory including existence proofs and distributional approach. Normally offered fall term in odd years. All courses used to satisfy MTH prerequisites must be completed with C or better.

*This course is repeatable for 6 credits.*

**Recommended:** MTH 413 or MTH 513

**MTH 628. ADVANCED PARTIAL DIFFERENTIAL EQUATIONS. (3 Credits)**

Advanced theory including existence proofs and distributional approach. Normally offered winter term in even years. All courses used to satisfy MTH prerequisites must be completed with C or better.

*This course is repeatable for 6 credits.*

**Recommended:** MTH 627

**MTH 634. ALGEBRAIC TOPOLOGY. (3 Credits)**

Simplicial and singular homology, products, and cohomology; applications to fixed-point and separation theorems. Topics selected from homotopy, manifold and obstruction theory. Normally offered alternate years. All courses used to satisfy MTH prerequisites must be completed with C or better.

**Recommended:** MTH 532

**MTH 635. ALGEBRAIC TOPOLOGY. (3 Credits)**

Simplicial and singular homology, products, and cohomology; applications to fixed-point and separation theorems. Topics selected from homotopy, manifold and obstruction theory. Normally offered alternate years. All courses used to satisfy MTH prerequisites must be completed with C or better.

**Recommended:** MTH 532 and MTH 634

**MTH 636. ALGEBRAIC TOPOLOGY. (3 Credits)**

Simplicial and singular homology, products, and cohomology; applications to fixed-point and separation theorems. Topics selected from homotopy, manifold and obstruction theory. Normally offered alternate years. All courses used to satisfy MTH prerequisites must be completed with C or better.

**Recommended:** MTH 532 and MTH 635

**MTH 644. ABSTRACT ALGEBRA I. (3 Credits)**

Group theory, rings and fields, Galois theory. All courses used to satisfy MTH prerequisites must be completed with C or better.

**Recommended:** MTH 443 or MTH 543

**MTH 645. ABSTRACT ALGEBRA II. (3 Credits)**

Group theory, rings and fields, Galois theory. All courses used to satisfy MTH prerequisites must be completed with C or better.

**Recommended:** MTH 644

**MTH 649. TOPICS IN ALGEBRA AND NUMBER THEORY. (3 Credits)**

*This course is repeatable for 27 credits.*

**MTH 654. NUMERICAL ANALYSIS. (3 Credits)**

Advanced topics in numerical analysis, such as finite volume methods and finite element methods for partial differential equations, numerical methods for inverse problems, and image processing. All courses used to satisfy MTH prerequisites must be completed with C or better.

*This course is repeatable for 12 credits.*

**Recommended:** Familiarity with numerical methods

**MTH 655. NUMERICAL ANALYSIS. (3 Credits)**

Advanced topics in numerical analysis, such as finite volume methods and finite element methods for partial differential equations, numerical methods for inverse problems, and image processing. All courses used to satisfy MTH prerequisites must be completed with C or better.

*This course is repeatable for 12 credits.*

**Recommended:** Familiarity with numerical methods

**MTH 656. NUMERICAL ANALYSIS. (3 Credits)**

Advanced topics in numerical analysis, such as finite volume methods and finite element methods for partial differential equations, numerical methods for inverse problems, and image processing. All courses used to satisfy MTH prerequisites must be completed with C or better.

*This course is repeatable for 12 credits.*

**Recommended:** Familiarity with numerical methods

**MTH 657. TOPICS IN APPLIED MATHEMATICS. (1-12 Credits)**

Previous topics have included turbulence, financial mathematics and probability methods in partial differential equations.

*This course is repeatable for 12 credits.*

**MTH 658. TOPICS IN MATHEMATICAL MODELING. (1-12 Credits)**

Mathematical treatment of topics of current interest in the physical and biological sciences and technology. May be repeated for credit when topic varies.

*This course is repeatable for 12 credits.*

**MTH 659. TOPICS IN NUMERICAL ANALYSIS. (1-12 Credits)**

*This course is repeatable for 12 credits.*

**MTH 664. PROBABILITY THEORY. (3 Credits)**

General theory of probability measures and random variables, including weak convergence, characteristic functions, central limit theory, conditional expectations, martingales. All courses used to satisfy MTH prerequisites must be completed with C or better.

**Recommended:** MTH 411 or MTH 511

**MTH 665. PROBABILITY THEORY. (3 Credits)**

General theory of probability measures and random variables, including weak convergence, characteristic functions, the central limit theorem, and the Brownian motion process. All courses used to satisfy MTH prerequisites must be completed with C or better.

**Recommended:** MTH 664

**MTH 669. TOPICS IN STOCHASTIC PROCESSES. (1-12 Credits)**

Previous topics have included Markov processes, martingales, branching processes, and stochastic differential equations.

*This course is repeatable for 12 credits.*

**MTH 674. DIFFERENTIAL GEOMETRY OF MANIFOLDS. (3 Credits)**

Differentiable manifolds, tangent bundles, vector fields and flows, submanifolds, Riemannian metrics, differential forms, integration on manifolds. Selected topics such as foliations, Lie groups, and de Rham cohomology. All courses used to satisfy MTH prerequisites must be completed with C or better.

**Recommended:** MTH 341 and (MTH 411 or MTH 511)

**MTH 675. DIFFERENTIAL GEOMETRY OF MANIFOLDS. (3 Credits)**

Differentiable manifolds, connections in linear bundles, Riemannian manifolds and submanifolds. Selected topics such as variational theory of geodesics, harmonic forms, and characteristic classes. Normally offered alternate years. All courses used to satisfy MTH prerequisites must be completed with C or better.

**Recommended:** MTH 674

**MTH 676. TOPICS IN TOPOLOGY. (3 Credits)**

*This course is repeatable for 27 credits.*

**MTH 679. TOPICS IN GEOMETRY. (1-12 Credits)**

*This course is repeatable for 12 credits.*

**MTH 680. MODERN APPROACHES TO CALCULUS. (3 Credits)**

Alternative approaches to calculus instruction based on the availability of computers and calculators. Applications of symbolic-graphical calculators, spreadsheets, symbolic algebra systems, and graphics packages to the teaching of calculus. All courses used to satisfy MTH prerequisites must be completed with C or better.

**Recommended:** MTH 253

**MTH 682. TEACHING AND LEARNING PROBABILITY AND STATISTICS. (3 Credits)**

Experimental, activity-based approaches to introductory probability and statistics are explored. Topics include computer simulations, exploratory data analysis, misuses of statistics, and misconceptions of probability. All courses used to satisfy MTH prerequisites must be completed with C or better.

**MTH 684. COMPUTERS AND MATHEMATICS. (3 Credits)**

A variety of mathematical problems are investigated with a laboratory approach using microcomputers and a wide variety of software. Problems may be taken from number theory, calculus, geometry, probability, and elementary numerical analysis. All courses used to satisfy MTH prerequisites must be completed with C or better.

**Recommended:** Ability to program in either BASIC or PASCAL

**MTH 685. ADVANCED PROBLEM SOLVING. (3 Credits)**

Mathematical problem solving using the heuristic approach of George Polya. Problems may be taken from a variety of areas, including number theory, calculus, geometry, probability, abstract and linear algebra. All courses used to satisfy MTH prerequisites must be completed with C or better.

**MTH 689. TOPICS IN MATHEMATICS EDUCATION. (1-12 Credits)**

Topics may vary.

*This course is repeatable for 12 credits.*

**MTH 699. SPECIAL TOPICS. (1-16 Credits)**

*This course is repeatable for 16 credits.*