Mathematics

Website (https://cos.northeastern.edu/mathematics/)

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Mathematics is of ever-increasing importance to our society and everyday life. It has long been the language of science and technology and provides a rich source of methods for analyzing and solving problems encountered in the physical world. Today, mathematics is essential in virtually all fields of human endeavor, including business, the arts, and the social sciences.

The Bachelor of Arts degree requires at least 11 mathematics courses and two physics courses, in addition to the study of a foreign language; this program is appropriate for students who wish a broader liberal arts education. The Bachelor of Science degree requires at least 14 mathematics courses and two physics courses but no foreign language study; it is more specialized, and it is recommended for those strongly interested in mathematics and science. The department also offers a minor degree in mathematics.

The major programs provide flexibility with elective courses. Students may take advantage of a range of interdisciplinary programs and may join a major in mathematics with one in such fields as computer science, physics, and biology.

Exceptional students are accepted into the Honors Program and have the option to enroll in honors sections of several of their mathematics courses. All math majors may benefit from co-op opportunities in the scientific and business communities in Boston and elsewhere.

Many of the mathematics courses that we offer use computers for visualization, modeling, and numerical approximation.

Students planning to teach secondary-school mathematics must major in mathematics and take a specific minor in education, which includes coursework and student teaching.

Mathematical training may lead to opportunities in applied research (natural sciences, engineering, economics, management, computer science) as well as in mathematical research, teaching, or industry.

Programs

Bachelor of Arts (BA)
- Mathematics (http://catalog.northeastern.edu/undergraduate/science/mathematics/mathematics-ba/)

Bachelor of Science (BS)
- Mathematics (http://catalog.northeastern.edu/undergraduate/science/mathematics/mathematics-bs/)
- Biology and Mathematics (http://catalog.northeastern.edu/undergraduate/science/biology/biology-mathematics-bs/)
- Computer Science and Mathematics (http://catalog.northeastern.edu/undergraduate/computer-information-science/computer-information-science-combined-majors/computer-science-mathematics-bs/)
- Data Science and Mathematics (http://catalog.northeastern.edu/undergraduate/computer-information-science/computer-information-science-combined-majors/data-science-mathematics-bs/)
- Economics and Mathematics (http://catalog.northeastern.edu/undergraduate/social-sciences-humanities/economics/economics-mathematics-bs/)
- Graphic and Information Design and Mathematics (http://catalog.northeastern.edu/undergraduate/arts-media-design/art-design/graphic-and-information-design-mathematics-bs/)
- Mathematics and Business Administration (http://catalog.northeastern.edu/undergraduate/science/mathematics/mathematics-business-administration-bs/)
- Mathematics and Cultural Anthropology (http://catalog.northeastern.edu/undergraduate/science/mathematics/mathematics-cultural-anthropology-bs/)
- Mathematics and Physics (http://catalog.northeastern.edu/undergraduate/science/mathematics/mathematics-physics-bs/)
- Mathematics and Political Science (http://catalog.northeastern.edu/undergraduate/science/mathematics/mathematics-political-science-bs/)
- Mathematics and Psychology (http://catalog.northeastern.edu/undergraduate/science/mathematics/mathematics-psychology-bs/)
- Mathematics and Sociology (http://catalog.northeastern.edu/undergraduate/science/mathematics/mathematics-sociology-bs/)

Minor
- Mathematics (http://catalog.northeastern.edu/undergraduate/science/mathematics/mathematics-minor/)

Accelerated Programs
See Accelerated Bachelor/Graduate Degree Programs (http://catalog.northeastern.edu/undergraduate/science/accelerated-bachelor-graduate-degree-programs/#programstext)

Courses

Mathematics Courses
Search MATH Courses using FocusSearch (http://catalog.northeastern.edu/class-search/?subject=MATH)

MATH 1000. Mathematics at Northeastern. 1 Hour.
Designed for freshman math majors to introduce them to one another, their major, their college, and the University. Students are introduced to our advising system, register for next semester’s courses, and learn more about co-op. Also helps students develop the academic and interpersonal skills necessary to succeed as a university student.

MATH 1120. Precalculus. 4 Hours.
Focuses on linear, polynomial, exponential, logarithmic, and trigonometric functions. Emphasis is placed on understanding, manipulating, and graphing these basic functions, their inverses and compositions, and using them to model real-world situations (that is, exponential growth and decay, periodic phenomena). Equations involving these functions are solved using appropriate techniques. Special consideration is given to choosing reasonable functions to fit numerical data.
MATH 1130. College Math for Business and Economics. 4 Hours.
Introduces students to some of the important mathematical concepts and tools (such as modeling revenue, cost and profit with functions) used to solve problems in business and economics. Assumes familiarity with the basic properties of linear, polynomial, exponential, and logarithmic functions. Topics include the method of least squares, regression curves, solving equations involving functions, compound interest, amortization, and other consumer finance models. (Graphing calculator required, see instructor for make and model.)

MATH 1213. Interactive Mathematics. 4 Hours.
Develops problem-solving skills while simultaneously teaching mathematics concepts. Each unit centers on a particular applied problem, which serves to introduce the relevant mathematical topics. These may include but are not limited to polling theory, rate of change, the concepts behind derivatives, probability, binomial distributions, and statistics. The course is not taught in the traditional lecture format and is particularly suited to students who work well in collaborative groups and who enjoy writing about the concepts they are learning. Assessment is based on portfolios, written projects, solutions to “problems of the week,” and exams.

MATH 1215. Mathematical Thinking. 4 Hours.
Focuses on the development of mathematical thinking and its use in a variety of contexts to translate real-world problems into mathematical form and, through analysis, to obtain new information and reach conclusions about the original problems. Mathematical topics include symbolic logic, truth tables, valid arguments, counting principles, and topics in probability theory such as Bayes’ theorem, the binomial distribution, and expected value.

MATH 1216. Recitation for MATH 1215. 0 Hours.
Provides small-group discussion format to cover material in MATH 1215.

MATH 1220. Mathematics of Art. 4 Hours.
Presents mathematical connections and foundations for art. Topics vary and may include aspects of linear perspective and vanishing points, symmetry and patterns, tilings and polygons, Platonic solids and polyhedra, golden ratio, non-Euclidean geometry, hyperbolic geometry, fractals, and other topics. Includes connections and examples in different cultures.

MATH 1231. Calculus for Business and Economics. 4 Hours.
Provides an overview of differential calculus including derivatives of power, exponential, logarithmic, logistic functions, and functions built from these. Derivatives are used to model rates of change, to estimate change, to optimize functions, and in marginal analysis. The integral calculus is applied to accumulation functions and future value. Emphasis is on realistic business and economics problems, the development of mathematical models from raw business data, and the translation of mathematical results into verbal expression appropriate for the business setting. Also features a semester-long marketing project in which students gather raw data, model it, and use calculus to make business decisions; each student is responsible for a ten-minute presentation. (Graphing calculator required, see instructor for make and model.)

MATH 1241. Calculus 1. 4 Hours.
Serves as both the first half of a two-semester calculus sequence and as a self-contained one-semester course in differential and integral calculus. Introduces basic concepts and techniques of differentiation and integration and applies them to polynomial, exponential, log, and trigonometric functions. Emphasizes the derivative as rate of change and integral as accumulator. Applications include optimization, growth and decay, area, volume, and motion.

MATH 1242. Calculus 2. 4 Hours.
Continues MATH 1241. Introduces additional techniques of integration and numerical approximations of integrals and the use of integral tables; further applications of integrals. Also introduces differential equations and slope fields, and elementary solutions. Introduces functions of several variables, partial derivatives, and multiple integrals.

MATH 1245. Calculus with Applications. 4 Hours.
Covers differential and integral calculus of one variable and an introduction to differential equations. Includes applications that show how calculus is used to solve problems in science. Also includes a group project related to a real-world problem in students’ areas of study. The project involves a differential equation and compares the solution with experiment. Previous examples of projects include modeling of coral reefs, analysis of an epidemic using the data of the World Health Organization, analysis of a two-component kinetic model of drug concentration, and gate analysis of hip to knee experiment and comparison with the solution of the pendulum equation. Prior exposure to high-school-level calculus is recommended.

MATH 1251. Calculus and Differential Equations for Biology 1. 4 Hours.
Begins with the fundamentals of differential calculus and proceeds to the specific type of differential equation problems encountered in biological research. Presents methods for the solutions of these equations and how the exact solutions are obtained from actual laboratory data. Topics include differential calculus: basics, the derivative, the rules of differentiation, curve plotting, exponentials and logarithms, and trigonometric functions; using technology to understand derivatives; biological kinetics: zero- and first-order processes, processes tending toward equilibrium, bi- and tri-exponential processes, and biological half-life; differential equations: particular and general solutions to homogeneous and nonhomogeneous linear equations with constant coefficients, systems of two linear differential equations; compartmental problems: nonzero initial concentration, two-compartment series dilution, diffusion between compartments, population dynamics; and introduction to integration.

MATH 1252. Calculus and Differential Equations for Biology 2. 4 Hours.
Continues MATH 1251. Begins with the integral calculus and proceeds quickly to more advanced topics in differential equations. Introduces linear algebra and uses matrix methods to analyze functions of several variables and to solve larger systems of differential equations. Advanced topics in reaction kinetics are covered. The integral and differential calculus of functions of several variables is followed by the study of numerical methods in integration and solutions of differential equations. Provides a short introduction to probability. Covers Taylor polynomials and infinite series. Special topics include reaction kinetics: Michaelis-Menten processes, tracer experiments, and inflow and outflow through membranes.

MATH 1260. Math Fundamentals for Games. 4 Hours.
Discusses linear algebra and vector geometry in two-, three-, and four-dimensional space. Examines length, dot product, and trigonometry. Introduces linear and affine transformations. Discusses complex numbers in two-space, cross product in three-space, and quaternions in four-space. Provides explicit formulas for rotations in three-space. Examines functions of one argument and treats exponentials and logarithms. Describes parametric curves in space. Discusses binomials, discrete probability, Bézier curves, and random numbers. Concludes with the concept of the derivative, the rules for computing derivatives, and the notion of a differential equation.
MATH 1340. Intensive Calculus for Engineers. 6 Hours.
Contains the material from the first semester of MATH 1341, preceded by material emphasizing the strengthening of precalculus skills. Topics include properties of exponential, logarithmic, and trigonometric functions; differential calculus; and introductory integral calculus.

MATH 1341. Calculus 1 for Science and Engineering. 4 Hours.
Covers definition, calculation, and major uses of the derivative, as well as an introduction to integration. Topics include limits; the derivative as a limit; rules for differentiation; and formulas for the derivatives of algebraic, trigonometric, and exponential/logarithmic functions. Also discusses applications of derivatives to motion, density, optimization, linear approximations, and related rates. Topics on integration include the definition of the integral as a limit of sums, antidifferentiation, the fundamental theorem of calculus, and integration by substitution.

MATH 1342. Calculus 2 for Science and Engineering. 4 Hours.
Covers further techniques and applications of integration, infinite series, and introduction to vectors. Topics include integration by parts; numerical integration; improper integrals; separable differential equations; and areas, volumes, and work as integrals. Also discusses convergence of sequences and series of numbers, power series representations and approximations, 3D coordinates, parameterizations, vectors and dot products, tangent and normal vectors, velocity, and acceleration in space. Requires prior completion of MATH 1341 or permission of head mathematics advisor.

MATH 1365. Introduction to Mathematical Reasoning. 4 Hours.
Covers the basics of mathematical reasoning and problem solving to prepare incoming math majors for more challenging mathematical courses at Northeastern. Focuses on learning to write logically sound mathematical arguments and to analyze such arguments appearing in mathematical books and courses. Includes fundamental mathematical concepts such as sets, relations, and functions.

MATH 1990. Elective. 1-4 Hours.
Offers elective credit for courses taken at other academic institutions. May be repeated without limit.

MATH 2201. History of Mathematics. 4 Hours.
Traces the development of mathematics from its earliest beginning to the present. Emphasis is on the contributions of various cultures including the Babylonians, Egyptians, Mayans, Greeks, Indians, and Arabs. Computations and constructions are worked out using the techniques and notations of these peoples. The role of mathematics in the development of science is traced throughout, including the contributions of Descartes, Kepler, Fermat, and Newton. More modern developments are discussed as time permits.

MATH 2230. Mathematical Encounters. 4 Hours.
Covers interesting and significant developments in pure and applied mathematics, from ancient times to the present. Fundamental mathematical ideas have a power and utility that are undeniable and a beauty and clarity that can be inspirational. Selected topics may include: prime and irrational numbers, different infinities and different geometries, map coloring, and famous unsolved and recently solved problems. Provides students with an opportunity for hands-on experience actually doing some of the mathematics discussed and to research topics in the library and on the Web.

MATH 2280. Statistics and Software. 4 Hours.
Provides an introduction to basic statistical techniques and the reasoning behind each statistical procedure. Covers appropriate statistical data analysis methods for applications in health and social sciences. Also examines a statistical package such as SPSS or SAS to implement the data analysis on computer. Topics include descriptive statistics, elementary probability theory, parameter estimation, confidence intervals, hypothesis testing, nonparametric inference, and analysis of variance and regression with a minimum of mathematical derivations.

MATH 2321. Calculus 3 for Science and Engineering. 4 Hours.
Extends the techniques of calculus to functions of several variables; introduces vector fields and vector calculus in two and three dimensions. Topics include lines and planes, 3D graphing, partial derivatives, the gradient, tangent planes and local linearization, optimization, multiple integrals, line and surface integrals, the divergence theorem, and theorems of Green and Stokes with applications to science and engineering and several computer lab projects. Requires prior completion of MATH 1342 or MATH 1252.

MATH 2322. Recitation for MATH 2321. 0 Hours.
Provides small-group discussion format to cover material in MATH 2321.

MATH 2323. Calculus 3 for Business, Economics, and Mathematics. 4 Hours.
Covers multivariable calculus with applications from economics and business. Designed for combined majors in business and mathematics and in economics and mathematics, but open to all who have taken first-year calculus. Topics include Gaussian elimination, matrix algebra, determinants, linear independence, calculus of several variables, chain rule, implicit differentiation, optimization, Lagrange multipliers, and integration of functions of several variables with applications to probability.

MATH 2331. Linear Algebra. 4 Hours.
Uses the Gauss-Jordan elimination algorithm to analyze and find bases for subspaces such as the image and kernel of a linear transformation. Covers the geometry of linear transformations: orthogonality, the Gram-Schmidt process, rotation matrices, and least squares fit. Examines diagonalization and similarity, and the spectral theorem and the singular value decomposition. Is primarily for math and science majors; applications are drawn from many technical fields. Computation is aided by the use of software such as Maple or MATLAB, and graphing calculators.

MATH 2341. Differential Equations and Linear Algebra for Engineering. 4 Hours.
Studies ordinary differential equations, their applications, and techniques for solving them including numerical methods (through computer labs using MS Excel and MATLAB), Laplace transforms, and linear algebra. Topics include linear and nonlinear first-and second-order equations and applications include electrical and mechanical systems, forced oscillation, and resonance. Topics from linear algebra, such as matrices, row-reduction, vector spaces, and eigenvalues/eigenvectors, are developed and applied to systems of differential equations. Requires prior completion of MATH 1342.

MATH 2342. Recitation for MATH 2341. 0 Hours.
Provides small-group discussion format to cover material in MATH 2341.

MATH 2990. Elective. 1-4 Hours.
Offers elective credit for courses taken at other academic institutions. May be repeated without limit.
MATH 3000. Co-op and Experiential Learning Reflection Seminar 1. 1 Hour.
Intended for math majors who have completed their first co-op assignment or other integrated experiential learning component of the NU Core. The goal is to examine the mathematical problems encountered in these experiences and relate them to courses already taken and to the student's future program. Faculty members and other guests contribute to the discussion. Grades are determined by the student's participation in the course and the completion of a final paper.

MATH 3081. Probability and Statistics. 4 Hours.
Focuses on probability theory. Topics include sample space; conditional probability and independence; discrete and continuous probability distributions for one and for several random variables; expectation; variance; special distributions including binomial, Poisson, and normal distributions; law of large numbers; and central limit theorem. Also introduces basic statistical theory including estimation of parameters, confidence intervals, and hypothesis testing.

MATH 3082. Recitation for MATH 3081. 0 Hours.
Provides small-group discussion format to cover material in MATH 3081.

MATH 3090. Exploration of Modern Mathematics. 4 Hours.
Offers students a research-minded, elementary, and intuitive introduction to the interplay between algebra, geometry, analysis, and topology using an interactive and experimental approach. Intended for math majors, math combined majors, and students pursuing a math minor, all others should obtain permission of instructor.

MATH 3150. Real Analysis. 4 Hours.
Provides the theoretical underpinnings of calculus and the advanced study of functions. Emphasis is on precise definitions and rigorous proof. Topics include the real numbers and completeness, continuity and differentiability, the Riemann integral, the fundamental theorem of calculus, inverse function and implicit function theorems, and limits and convergence. Required of all mathematics majors.

MATH 3175. Group Theory. 4 Hours.
Presents basic concepts and techniques of the group theory; symmetry groups, axiomatic definition of groups, important classes of groups (abelian groups, cyclic groups, additive and multiplicative groups of residues, and permutation groups), Cayley table, subgroups, group homomorphism, cosets, the Lagrange theorem, normal subgroups, quotient groups, and direct products. Studies structural properties of groups. Possible applications include geometry, number theory, crystallography, physics, and combinatorics.

MATH 3275. Advanced Group Theory. 4 Hours.
Serves as an accelerated introduction to the theory of groups, intended for students who wish to take a more advanced version of MATH 3175. Prior knowledge of group theory is not assumed. Introduces homomorphisms, subgroups, normal subgroups, quotient groups, and group actions, illustrated with a variety of examples. Subsequent topics include the class equation, simple groups, the Sylow theorems, and their applications to the classification of finite simple groups. Discusses classical matrix groups, with an emphasis on SU(2) and SO(3) as fundamental examples, and introduces the notion of a Lie algebra. Develops representation theory of finite groups and its correspondence to the representation theory of compact Lie groups sketched, again using SU(2) as an example. Students not meeting course prerequisites may seek permission of instructor.

MATH 3311. Differential Geometry. 4 Hours.
Studies differential geometry, focusing on curves and surfaces in 3D space. The material presented here can serve as preparation for a more advanced course in Riemannian geometry or differential topology.

MATH 3341. Dynamical Systems. 4 Hours.
Studies dynamical systems and their applications as they arise from differential equations. Solutions are obtained and analyzed as parameterized curves in the plane and used as a means of understanding the evolution of physical processes. Applications include conservative systems, predator-prey interactions, and cooperation and competition of species.

MATH 3527. Number Theory 1. 4 Hours.
Introduces number theory. Topics include linear diophantine equations, congruences, design of magic squares, Fermat's little theorem, Euler's formula, Euler's phi function, computing powers and roots in modular arithmetic, the RSA encryption system, primitive roots and indices, and the law of quadratic reciprocity. As time permits, may cover diophantine approximation and Pell's equation, elliptic curves, points on elliptic curves, and Fermat's last theorem.

MATH 3530. Numerical Analysis. 4 Hours.
Considers various problems including roots of nonlinear equations; simultaneous linear equations: direct and iterative methods of solution; eigenvalue problems; interpolation; and curve fitting. Emphasizes understanding issues rather than proving theorems or coming up with numerical recipes.

MATH 3533. Combinatorial Mathematics. 4 Hours.
Introduces techniques of mathematical proofs including mathematical induction. Explores various techniques for counting such as permutation and combinations, inclusion-exclusion principle, recurrence relations, generating functions, Pólya enumeration, and the mathematical formulations necessary for these techniques including elementary group theory and equivalence relations.

MATH 3545. Introduction to Graph Theory. 4 Hours.
Offers a mathematical introduction to networks and graphs, which find applications in social and natural sciences. Introduces paths, cycles, trees, bipartite graphs, matchings, colorings, connectivity, and network flows. Discusses special cases of planar, Eulerian, and Hamiltonian graphs; Tait's theorem; and possible advanced topics. Students who do not meet course prerequisites may seek permission of instructor.

MATH 3560. Geometry. 4 Hours.
Studies classical geometry and symmetry groups of geometric figures, with an emphasis on Euclidean geometry. Teaches how to formulate mathematical propositions precisely and how to construct and understand mathematical proofs. Provides a line between classical and modern geometry with the aim of preparing students for further study in group theory and differential geometry.

MATH 3990. Elective. 1-4 Hours.
Offers elective credit for courses taken at other academic institutions. May be repeated without limit.

MATH 4020. Research Capstone. 4 Hours.
Offers students the experience of engaging in mathematical research that builds upon the math courses that they have taken and, possibly, their co-op assignments. Requires students to complete a research project of their own choosing. Focus is on the project and on the students presenting their work. Also requires students to write a reflection paper. Intended for juniors or seniors with experience or interest in mathematics research. Students who do not meet course prerequisites may seek permission of instructor.

MATH 4025. Applied Mathematics Capstone. 4 Hours.
Emphasizes the use of a variety of methods—such as optimization, differential equations, probability, and statistics—to study problems that arise in epidemiology, finance, and other real-world settings. Course work includes assigned exercises, a long-term modeling project on a topic of the student's choosing, and a reflection paper.
MATH 4525. Applied Analysis. 4 Hours.
Demonstrates the applications of mathematics to interesting physical and biological problems. Methods are chosen from ordinary and partial differential equations, calculus of variations, Laplace transform, perturbation theory, special functions, dimensional analysis, asymptotic analysis, and other techniques of applied mathematics.

MATH 4527. Number Theory 2. 4 Hours.
Continues MATH 3527. Topics include Diophantine approximation, the Gaussian integers, irrational numbers and transcendental numbers, nonlinear polynomial congruences, systems of linear congruences, mobius inversion, elliptic curves, modular curves, modular forms, and L-functions.

MATH 4541. Advanced Calculus. 4 Hours.
Offers a deeper and more generalized look at the ideas and objects of study of calculus. Topics include the generalized calculus of n-space, the inverse and implicit function theorems, differential forms and general Stokes-type theorems, geometry of curves and surfaces, and special functions.

MATH 4545. Fourier Series and PDEs. 4 Hours.
Provides a first course in Fourier series, Sturm-Liouville boundary value problems, and their application to solving the fundamental partial differential equations of mathematical physics: the heat equation, the wave equation, and Laplace's equation. Green's functions are also introduced as a means of obtaining closed-form solutions.

MATH 4555. Complex Variables. 4 Hours.
Provides an introduction to the analysis of functions of a complex variable. Starting with the algebra and geometry of complex numbers, basic derivative and contour integral properties are developed for elementary algebraic and transcendental functions as well as for other analytic functions and functions with isolated singularities. Power and Laurent series representations are given. Classical integral theorems, residue theory, and conformal mapping properties are studied. Applications of harmonic functions are presented as time permits.

MATH 4565. Topology. 4 Hours.
Introduces the student to fundamental notions of topology. Introduces basic set theory, then covers the foundations of general topology (axioms for a topological space, continuous functions, homeomorphisms, metric spaces, the subspace, product and quotient topologies, connectedness, compactness, and the Hausdorff condition). Also introduces algebraic and geometric topology (homotopy, covering spaces, fundamental groups, graphs, surfaces, and manifolds) and applications. Other topics are covered if time permits.

MATH 4567. Differential Topology. 4 Hours.
Introduces students to the geometry of smooth manifolds. Topics include transversality, oriented intersection theory, Lefschetz fixed-point theory, Poincare-Hopf theorem, Hopf degree theorem, differential forms, and integration. Explores concepts and techniques of smooth geometry for understanding significant topological characteristics of manifolds. Students not meeting course prerequisites may seek permission of instructor.

MATH 4569. Knot Theory. 4 Hours.
Introduces the mathematical study of knots and links in space. Knot theory provides a concrete application for fundamental ideas in topology. Topics include knot diagrams and Reidemeister moves; connected sum and prime decomposition; satellites and companionship; Seifert surfaces and knot genus; Seifert matrices; knot signature and determinant; the Alexander polynomial; the Kauffman bracket and Jones polynomial; and braid presentations. Also discusses examples of knotting phenomena in physical systems.

MATH 4571. Advanced Linear Algebra. 4 Hours.
Provides a more detailed study of linear transformations and matrices: LU factorization, QR factorization, Spectral theorem and singular value decomposition, Jordan form, positive definite matrices, quadratic forms, partitioned matrices, and norms and numerical issues. Topics and emphasis change from year to year.

MATH 4575. Introduction to Cryptography. 4 Hours.
Introduces the mathematical foundations of cryptography, beginning with the study of divisibility of integers, the Euclidian Algorithm, and an analysis of the Extended Euclidian Algorithm. Includes a short study of groups, semigroups, residue class rings, fields, Fermat's Little Theorem, Chinese Remainder Theorem, polynomials over fields, and the multiplicative group of residues modulo a prime number. Introduces fundamental notions used to describe encryption schemes together with examples, which include affine linear ciphers and cryptanalysis and continues with probability and perfect secrecy. Presents the Data Encryption Standard (DES) and culminates in the study of the Advanced Encryption Standard (AES), the standard encryption scheme in the United States since 2001.

MATH 4576. Rings and Fields. 4 Hours.
Introduces commutative rings, ideals, integral domains, fields, and the theory of extension fields. Topics include Gaussian integers, Galois groups, and the fundamental theorem of Galois theory. Applications include the impossibility of angle-trisection and the general insolubility of fifth- and higher-degree polynomials. Other topics are covered as time permits.

MATH 4577. Commutative Algebra. 4 Hours.
Introduces the basics of commutative algebra. Emphasizes rigorously building the mathematical background needed for studying this subject in more depth. Seeks to prepare students for more advanced classes in algebraic geometry, robotics, invariant theory of finite groups, and cryptography. Covers geometry, algebra, and algorithms; Grobner bases; elimination theory; the algebra-geometry dictionary; robotics and automatic geometric theorem proving.

MATH 4581. Statistics and Stochastic Processes. 4 Hours.
Continues topics introduced in MATH 3081. The first part of the course covers classical procedures of statistics including the t-test, linear regression, and the chi-square test. The second part provides an introduction to stochastic processes with emphasis on Markov chains, random walks, and Brownian motion, with applications to modeling and finance.

MATH 4586. Algebraic Geometry. 4 Hours.
Concentrates on the basics of algebraic geometry, which is the study of geometric objects, such as curves and surfaces, defined by solutions of polynomial equations. Algebraic geometry has links to many other areas of mathematics—number theory, differential geometry, topology, mathematical physics—and has important applications in such fields as engineering, computer science, statistics, and computational biology. Emphasizes examples and indicates along the way interesting problems that can be studied using algebraic geometry.

MATH 4606. Mathematical and Computational Methods for Physics. 4 Hours.
Covers advanced mathematical methods topics that are commonly used in the physical sciences, such as complex calculus, Fourier transforms, special functions, and the principles of variational calculus. Applies these methods to computational simulation and modeling exercises. Introduces basic computational techniques and numerical analysis, such as Newton's method, Monte Carlo integration, gradient descent, and least squares regression. Uses a simple programming language, such as MATLAB, for the exercises.
MATH 4681. Probability and Risks. 4 Hours. 
Reviews main probability and statistics concepts from the point of view of decision risks in actuarial and biomedical contexts, including applications of normal approximation for evaluating statistical risks. Also examines new topics, such as distribution of extreme values and nonparametric statistics with examples. May be especially useful for students preparing for the first actuarial exam on probability and statistics.

MATH 4682. Theory of Interest and Basics of Life Insurance. 4 Hours. 
Reviews basic financial instruments in the presence of interest rates, including the measurement of interest and problems in interest (equations of value, basic and more general annuities, yield rates, amortization schedules, bonds and other securities). Examines numerous practical applications. Also introduces problems of life insurance with examples. May be especially useful for students preparing for the second actuarial exam on theory of interest.

MATH 4683. Financial Derivatives. 4 Hours. 
Presents the mathematical basis of actuarial models and their application to insurance and other financial risks. Includes but is not limited to financial derivatives such as options and futures. Techniques and applications may be useful for students preparing for actuarial Exam 3F (Society of Actuaries Exam MFE).

MATH 4970. Junior/Senior Honors Project 1. 4 Hours. 
Focuses on in-depth project in which a student conducts research or produces a product related to the student's major field. Combined with Junior/Senior Project 2 or college-defined equivalent for 8-credit honors project. May be repeated without limit.

MATH 4971. Junior/Senior Honors Project 2. 4 Hours. 
Focuses on second semester of in-depth project in which a student conducts research or produces a product related to the student's major field. May be repeated without limit.

MATH 4990. Elective. 1-4 Hours. 
Offers elective credit for courses taken at other academic institutions. May be repeated without limit.

MATH 4991. Research. 4 Hours. 
Offers an opportunity to conduct research under faculty supervision.

MATH 4992. Directed Study. 1-4 Hours. 
Offers independent work under the direction of members of the department on a chosen topic. Course content depends on instructor. May be repeated without limit.

MATH 4993. Independent Study. 1-4 Hours. 
Offers independent work under the direction of members of the department on a chosen topic. Course content depends on instructor. May be repeated without limit.

MATH 4994. Internship. 4 Hours. 
Offers students an opportunity for internship work. May be repeated without limit.

MATH 4996. Experiential Education Directed Study. 4 Hours. 
Draws upon the student's approved experiential activity and integrates it with study in the academic major. Restricted to mathematics majors who are using it to fulfill their experiential education requirement; for these students it may count as a mathematics elective, subject to approval by instructor and adviser. May be repeated without limit.

MATH 5050. Advanced Engineering Calculus with Applications. 4 Hours. 
Introduces methods of vector analysis. Expect students to master over thirty predefined types of problems. Topics include analytic geometry in three dimensions, geometric vectors and vector algebra, curves in three-space, linear approximations, the gradient, the chain rule, the Lagrange multiplier, iterated integrals, integrals in curvilinear coordinates, change of variables, vector fields, line integrals, conservative fields, surfaces and surface integrals, the flux and the circulation of a vector field, Green's theorem, the divergence theorem, and Stokes' theorem. Illustrates the material by real-world science and engineering applications using the above techniques. Requires familiarity with single-variable calculus.

MATH 5101. Analysis 1: Functions of One Variable. 4 Hours. 
Offers a rigorous, proof-based introduction to mathematical analysis and its applications. Topics include metric spaces, convergence, compactness, and connectedness; continuous and uniformly continuous functions; derivatives, the mean value theorem, and Taylor series; Riemann integration and the fundamental theorem of calculus; interchanging limit operations; sequences of functions and uniform convergence; Arzela-Ascoli and Stone-Weierstrass theorems; inverse and implicit function theorems; successive approximations and existence/uniqueness for ordinary differential equations; linear operators on finite-dimensional vector spaces and applications to systems of ordinary differential equations. Provides a series of computer projects that further develop the connections between theory and applications. Requires permission of instructor and head advisor for undergraduate students.

MATH 5102. Analysis 2: Functions of Several Variables. 4 Hours. 
Continues MATH 5101. Studies basics of analysis in several variables. Topics include derivative and partial derivatives; the contraction principle; the inverse function and implicit function theorems; derivatives of higher order; Taylor formula in several variables; differentiation of integrals depending on parameters; integration of functions of several variables; change of variables in integrals; differential forms and their integration over simplexes and chains; external multiplication of forms; differential of forms; Stokes' formula; set functions; Lebesgue measure; measure spaces; measurable functions; integration; comparison with the Riemann integral; $L^2$ as a Hilbert space; and Parseval theorem and Riesz-Fischer theorem. Requires permission of instructor and head advisor for undergraduate students.

MATH 5110. Applied Linear Algebra and Matrix Analysis. 4 Hours. 
Offers a robust introduction to the basic results of linear algebra on real and complex vector spaces with applications to differential equations and Markov chains. Introduces theoretical results along the way, along with matrix analysis, eigenvalue analysis, and spectral decomposition. Includes a significant computational component, focused on applications of linear algebra to mathematical modeling.

MATH 5111. Algebra 1. 4 Hours. 
Covers vector spaces and linear maps. Topics include row and column operations and their application to normal form, eigenvectors and eigenvalues of an endomorphism; characteristic polynomial and Jordan canonical form; multilinear algebra that covers tensor products, symmetric and exterior powers of vector spaces, and their universality properties; quadratic forms, reduction to diagonal form, and Sylvester theorem; hyperbolic spaces and Witt theorem; the orthogonal group and isotropic subspaces; antisymmetric forms and their reduction to canonical form; the symplectic group; and Pfaffian and affine geometry, and classification of conic sections. Requires permission of instructor and head advisor for undergraduate students.
MATH 5112. Algebra 2. 4 Hours.
Continues MATH 5111. Topics include groups, such as subgroups, normal subgroups, homomorphism of groups, abelian groups, solvable groups, free groups, finite p-groups, Sylow theorem, permutation groups, and the sign homomorphism; rings, such as homomorphism, ideals, quotient rings, integral domains, extensions of rings, unique factorization domain, Chinese remainder theorem, and Gauss’s lemma; and modules, such as homomorphism, submodules, quotient modules, exact sequence, and structure of finitely generated modules over principal ideal domains. Examples include abelian groups and Jordan canonical form. Also covers representations of finite groups, group rings and irreducible representations, Frobenius reciprocity, Maschke theorem and characters of finite groups, and dual groups. Requires permission of instructor and head advisor for undergraduate students.

MATH 5121. Topology 1. 4 Hours.
Provides an introduction to topology, starting with the basics of point set topology (topological space, continuous maps, homeomorphisms, compactness and connectedness, and identification spaces). Moves on to the basic notions of algebraic and combinatorial topology, such as homotopy equivalences, fundamental group, Seifert-VanKampen theorem, simplicial complexes, classification of surfaces, and covering space theory. Ends with a brief introduction to simplicial homology and knot theory. Requires permission of instructor and head advisor for undergraduate students.

MATH 5131. Introduction to Mathematical Methods and Modeling. 4 Hours.
Presents mathematical methods emphasizing applications. Uses ordinary and partial differential equations to model the evolution of real-world processes. Topics chosen illustrate the power and versatility of mathematical methods in a variety of applied fields and include population dynamics, drug assimilation, epidemics, spread of pollutants in environmental systems, competing and cooperating species, and heat conduction. Requires students to complete a math-modeling project. Requires undergraduate-level course work in ordinary and partial differential equations.