Mathematics

Chair

- Ryan D. Kinser

Undergraduate major: mathematics (BA, BS)

Undergraduate minor: mathematics

Graduate degrees: MS in mathematics; PhD in mathematics

Faculty: https://math.uiowa.edu/people/faculty

Website: https://math.uiowa.edu

Mathematics is a basic tool for understanding modern society as well as a crucial requirement for many careers in science, engineering, business, and the professions. Research in this living, dynamic subject is at the highest level in history.

An undergraduate degree in mathematics prepares students for a variety of careers in government and business, for secondary teaching, for graduate study, and with proper planning, for a variety of professional programs. Graduate study is advisable for some business and governmental positions and for college and university teaching and research. The department also offers a minor.

Programs

Undergraduate Programs of Study

Majors

- Major in Mathematics (Bachelor of Arts)
- Major in Mathematics (Bachelor of Science)

Minor

- Minor in Mathematics

Graduate Programs of Study

Majors

- Master of Science in Mathematics
- Doctor of Philosophy in Mathematics

Courses

Credit earned in MATH:0100 Basic Algebra I does not count toward graduation.

The sequences MATH:1850 Calculus I and MATH:1860 Calculus II, and MATH:1550 Engineering Mathematics I: Single Variable Calculus and MATH:1560 Engineering Mathematics II: Multivariable Calculus, are similar, but they cover the material in a different order and with different emphases. Students who have taken the first semester of one sequence must consult with their advisor before taking the second semester of the other sequence.

Students who consider taking MATH:1860 Calculus II after MATH:1350 Quantitative Reasoning for Business, MATH:1380 Calculus and Matrix Algebra for Business, or MATH:1460 Calculus for the Biological Sciences must consult with their advisor; they also must take a math placement test.

Graduate students may not earn graduate credit in courses numbered below 3000.

Graduate students in mathematics must have departmental approval to earn credit for any of the courses numbered between 3000 and 4999. Analysis and computation graduate students in mathematics may not earn credit for MATH:4010 Basic Analysis and MATH:4020 Basic Abstract Algebra. Graduate students in other disciplines may earn credit for any course numbered 3000 or above.

Mathematics Courses

MATH:0100 Basic Algebra I **3 s.h.**
Percents, ratio and proportion, algebraic expressions and operations, simple products, linear and quadratic equations, simultaneous equations, exponents and radicals; emphasis on verbal problems.

MATH:1000 First-Year Seminar **1 s.h.**
Small discussion class taught by a faculty member; topics chosen by instructor; may include outside activities (e.g., films, lectures, performances, readings, visits to research facilities). Requirements: first- or second-semester standing.

MATH:1005 College Algebra **4 s.h.**
Algebraic techniques, equations and inequalities, functions and graphs, exponential and logarithmic functions, systems of equations and inequalities. Prerequisites: MATH:0100 with a minimum grade of C- or ALEKS score of 30 or higher. Recommendations: it is strongly recommended that students whose math placement score is older than one year retake the math placement test for accurate placement and success in the course.

MATH:1010 Trigonometry **3 s.h.**
Trigonometric functions, solutions of right and oblique triangles, complex numbers. Prerequisites: MATH:1340 with a minimum grade of C- or MPT Level 3 score of 9 or higher or MATH:1005 with a minimum grade of C- or MATH:1380 with a minimum grade of C- or ALEKS score of 55 or higher. Recommendations: it is strongly recommended that students whose math placement score is older than one year retake the math placement test for accurate placement and success in the course.

MATH:1020 Elementary Functions **4 s.h.**
Functions, relations, coordinate systems; properties and graphs of algebraic, trigonometric, logarithmic, exponential functions; inverse trigonometric functions; properties of lines, conic sections. Prerequisites: MATH:1010 with a minimum grade of C- or MATH:1005 with a minimum grade of C- or MPT Level 3 score of 9 or higher or ALEKS score of 60 or higher or MATH:1340 with a minimum grade of C-. Recommendations: it is strongly recommended that students whose math placement score is older than one year retake the math placement test for accurate placement and success in the course. GE: Quantitative or Formal Reasoning.

MATH:1120 Logic of Arithmetic 4 s.h.
Mathematical and conceptual foundations of the natural numbers used in elementary school arithmetic teaching; multiple algorithmic approaches to arithmetic and its mathematical and contextual relationships, extensions to integers, rational and irrational numbers, multiple representations. Prerequisites: ALEKS score of 30 or higher or MATH:1460 with a minimum grade of C- or MATH:1010 with a minimum grade of C- or MATH:1550 with a minimum grade of C- or MATH:1340 with a minimum grade of C- or MATH:1860 with a minimum grade of C- or MATH:1005 with a minimum grade of C- or MATH:1020 with a minimum grade of C- or MPT Level 3 score of 9 or higher or MATH:1850 with a minimum grade of C- or MATH:1380 with a minimum grade of C- or MATH:1440 with a minimum grade of C- or MATH:0100 with a minimum grade of C-. Recommendations: it is strongly recommended that students whose math placement score is older than one year retake the math placement test for accurate placement and success in the course. GE: Quantitative or Formal Reasoning.

MATH:1140 Mathematical Basis of Elementary Geometry 3 s.h.
Points, lines, planes; measurement, two- and three-dimensional coordinate geometry, transformational geometry and vectors; applications of geometry to solve real-world problems. Prerequisites: MPT Level 3 score of 9 or higher or MATH:1850 with a minimum grade of C- or ALEKS score of 30 or higher or MATH:1010 with a minimum grade of C- or MATH:1005 with a minimum grade of C- or MATH:1380 with a minimum grade of C- or MATH:0100 with a minimum grade of C- or MATH:1440 with a minimum grade of C- or MATH:1460 with a minimum grade of C- or MATH:1340 with a minimum grade of C- or MATH:1860 with a minimum grade of C- or MATH:1020 with a minimum grade of C- or MATH:1550 with a minimum grade of C-. Requirements: elementary teacher certificate candidacy or certification. Recommendations: it is strongly recommended that students whose math placement score is older than one year retake the math placement test for accurate placement and success in the course.

MATH:1210 Diverse Perspectives in the Mathematical Sciences 3 s.h.
Exploration of the wide diversity of cultures and individuals who have contributed to mathematical sciences; experiences and cultural messages that have shaped our own mathematical attitudes; numerous mathematical contributions of women, people of color, and members of other underrepresented groups—their accomplishments, challenges they faced, and factors that led to their success; revisiting and revising our own attitudes toward mathematics in light of what is read to incorporate a larger vision of mathematics and of people who do mathematical work. GE: Diversity and Inclusion.

MATH:1250 Mathematics for Arts and Humanities 3 s.h.
Introduction to mathematical concepts via their applications in arts and humanities: mathematical patterns in nature; mathematics in ecology, religion, history, and linguistics; cryptology; modeling with mathematics; *The Matrix* directed by the Wachowskis; and *Star Wars* directed by George Lucas; students solve basic mathematical problems involving quadratic equation, exponential function, matrices, permutations, and combinatorics; application of mathematical logic to solve various mathematical games; application of mathematical concepts to real life problems (e.g., data interpretations); understanding the mathematics behind games, ciphers, and patterns. GE: Quantitative or Formal Reasoning.

MATH:1260 PokeMath: The Mathematics of Pokemon Go 3 s.h.
Use of mathematics to take Pokémon Go play to the next level; exposure to a range of topics central to applied mathematics including set theory, functions, probability and statistics, rates of change, and game theory; requires a mobile device with the game Pokémon Go. Pokémon Go is a registered trademark of the Pokémon Company. GE: Quantitative or Formal Reasoning.

MATH:1340 Mathematics for Business 4 s.h.
Algebraic techniques, functions and functional models, exponential and logarithmic functions and models, linear programming, informal introduction to calculus; examples and applications from management, economic sciences, related areas. Prerequisites: MATH:1005 with a minimum grade of C- or MPT Level 3 score of 9 or higher or ALEKS score of 45 or higher. Recommendations: it is strongly recommended that students whose math placement score is older than one year retake the math placement test for accurate placement and success in the course. GE: Quantitative or Formal Reasoning.

MATH:1350 Quantitative Reasoning for Business 4 s.h.
Algebraic techniques and modeling; quantitative methods for treating problems that arise in management and economic sciences; topics include algebra techniques, functions and functional models, exponential and logarithmic functions and models, and a thorough introduction to differential calculus; examples and applications from management, economic sciences, and related areas; for students planning to major in business. Prerequisites: MATH:1005 with a minimum grade of C- or MATH:1340 with a minimum grade of C- or ALEKS score of 55 or higher or MPT Level 3 score of 9 or higher. GE: Quantitative or Formal Reasoning.

MATH:1380 Calculus and Matrix Algebra for Business 4 s.h.
Quantitative methods for treating problems arising in management, economic sciences, related areas; introduction to differential and integral calculus, systems of linear equations and matrix operations. Prerequisites: MATH:1340 with a minimum grade of C- or MPT Level 3 score of 9 or higher or MATH:1020 with a minimum grade of C- or ALEKS score of 65 or higher or MATH:1440 with a minimum grade of C- or MATH:1005 with a minimum grade of C-. Recommendations: it is strongly recommended that students whose math placement score is older than one year retake the math placement test for accurate placement and success in the course. GE: Quantitative or Formal Reasoning.

MATH:1440 Mathematics for the Biological Sciences 4 s.h.
Relations, functions, coordinate systems, graphing, polynomials, trigonometric functions, logarithmic and exponential functions; discrete mathematics, probability; examples and applications from biological sciences. Prerequisites: MATH:1005 with a minimum grade of C- or MATH:1340 with a minimum grade of C- or ALEKS score of 55 or higher or MATH:1010 with a minimum grade of C- or MPT Level 3 score of 9 or higher. Recommendations: it is strongly recommended that students whose math placement score is older than one year retake the math placement test for accurate placement and success in the course. GE: Quantitative or Formal Reasoning.

MATH:1460 Calculus for the Biological Sciences 4 s.h.
One-semester survey of calculus for students in biological or life sciences; nontheoretical treatment of differential and integral calculus; brief introduction to differential equations and probability with calculus, with applications to the life sciences. Prerequisites: MATH:1440 with a minimum grade of C- or MATH:1020 with a minimum grade of C- or (MATH:1005 with a minimum grade of C- and MATH:1010 with a minimum grade of C-) or ALEKS score of 70 or higher or (ALEKS score of 55 or higher and MATH:1010 with a minimum grade of C-) or (MATH:1010 with a minimum grade of C- and MATH:1340 with a minimum grade of C-) or MPT Level 3 score of 9 or higher. Recommendations: it is strongly recommended that students whose math placement score is older than one year retake the math placement test for accurate placement and success in the course. GE: Quantitative or Formal Reasoning.

MATH:1550 Engineering Mathematics I: Single Variable Calculus 4 s.h.
Limits, derivatives, max/min, other applications, mean-value theorem, approximating functions, concavity, curve sketching, exponential models; Riemann sums, fundamental theorem; integration techniques, improper integrals, approximations. Prerequisites: (MATH:1010 with a minimum grade of C- and MATH:1005 with a minimum grade of C-) or MPT Level 3 score of 9 or higher or ALEKS score of 75 or higher or (MATH:1380 with a minimum grade of C- and MATH:1010 with a minimum grade of C-) or MATH:1020 with a minimum grade of C- or MATH:1460 with a minimum grade of C- or (MATH:1010 with a minimum grade of C- and ALEKS score of 55 or higher) or (MATH:1340 with a minimum grade of C- and MATH:1010 with a minimum grade of C-). Recommendations: it is strongly recommended that students whose math placement score is older than one year retake the math placement test for accurate placement and success in the course. GE: Quantitative or Formal Reasoning.

MATH:1560 Engineering Mathematics II: Multivariable Calculus 4 s.h.
Vector geometry; functions of several variables; polar coordinates; partial derivatives, gradients, directional derivatives; tangent lines and planes; max/min/parametric curves, curvilinear motion; multiple integrals; vector fields, flows; integration on curves, work; divergence, flux, Green's theorem. Prerequisites: MATH:1550 with a minimum grade of C- or MATH:1850 with a minimum grade of C- or MPT Level 3 score of 15 or higher. Requirements: score of 4 or higher on AP Calc (AB) exam, or score of 4 or higher on AP Calc (BC) exam.

MATH:1850 Calculus I 4 s.h.
Fundamental concepts, limits, methods, and techniques of differential calculus of a single variable; definite and indefinite integrals, substitution rule, fundamental theorem of calculus; applications including graphing, extreme values, areas, and volumes. Prerequisites: (MATH:1010 with a minimum grade of C- and MATH:1380 with a minimum grade of C-) or MATH:1460 with a minimum grade of C- or ALEKS score of 75 or higher or MPT Level 3 score of 9 or higher or (ALEKS score of 55 or higher and MATH:1010 with a minimum grade of C-) or MATH:1020 with a minimum grade of C- or (MATH:1340 with a minimum grade of C- and MATH:1010 with a minimum grade of C-) or (MATH:1005 with a minimum grade of C- and MATH:1010 with a minimum grade of C-). Recommendations: it is strongly recommended that students whose math placement score is older than one year retake the math placement test for accurate placement and success in the course. GE: Quantitative or Formal Reasoning.

MATH:1860 Calculus II 4 s.h.
Techniques of integration including by-parts, trigonometric Integrals, trigonometric substitutions, partial fractions, improper integrals; applications (i.e., arclength), area surfaces of revolutions, application to physics; introduction to differential equations; parametric equations and polar coordinates; infinite sequences and series, convergence tests, power series, Taylor polynomials and series. Prerequisites: MATH:1550 with a minimum grade of C- or MATH:1850 with a minimum grade of C- or MPT Level 3 score of 15 or higher. Recommendations: it is strongly recommended that students whose math placement score is older than one year retake the math placement test for accurate placement and success in the course.

MATH:2150 Foundations of Geometry 3 s.h.
Axiomatic development of common foundation for Euclidean, non-Euclidean geometry; constructions of non-Euclidean models, independence of parallel postulate. Prerequisites: MATH:1860 or MATH:1560.

MATH:2550 Engineering Mathematics III: Matrix Algebra 2 s.h.
Applications, computers for matrix calculations; matrix, vector arithmetic; linear independence, basis, subspace (in R2, R3); systems of equations, matrix reduction; rank, dimension; determinants, applications; eigenvalues, eigenvectors; diagonalization, principal axis theorem. Prerequisites: MATH:1850 or MATH:1550 or MATH:1860 or MATH:1560 or MPT Level 3 score of 15 or higher.

MATH:2560 Engineering Mathematics IV: Differential Equations 3 s.h.
Ordinary differential equations and applications; first-order equations; higher order linear equations; systems of linear equations, Laplace transforms; introduction to nonlinear equations and systems, phase plane, stability. Prerequisites: (MATH:1560 or MATH:1860) and (MATH:2700 or MATH:2550).

MATH:2700 Introduction to Linear Algebra 4 s.h.
Vector algebra and geometry of three-dimensional Euclidean space and extensions to n-space and vector spaces; lines and planes, matrices, linear transformations, systems of linear equations, reduction to row echelon form, dimension, rank, determinants, eigenvalues and eigenvectors, diagonalization, Principal Axis Theorem. Prerequisites: MATH:1850 or MATH:1550 or MATH:1860 or MATH:1560 or MPT Level 3 score of 15 or higher.

MATH:2850 Calculus III 4 s.h.
Multivariable calculus; vector functions, total differentials, gradient, implicit functions, coordinate systems, Taylor's expansion, extrema, multiple integrals, vector fields, line integrals, surface integrals, and Green's, Stokes', and divergence theorems. Prerequisites: MATH:1860 with a minimum grade of C- or MATH:1560 with a minimum grade of C-.

MATH:2995 Introduction to Research Opportunities 1 s.h.
Modern mathematics research areas and activities; seminar. Prerequisites: (MATH:2700 or MATH:2550) and (MATH:1560 or MATH:1860).

MATH:3550 Engineering Mathematics V: Vector Calculus 3 s.h.
Partial derivatives, max-min problems, integrals along curves, surfaces and solids, vector fields and conservation of energy; curl, divergence, Stokes' theorem and the divergence theorem; the classical partial differential equations and qualitative behavior of their solutions. Prerequisites: MATH:1560 and (MATH:2550 or MATH:2700). Corequisites: MATH:2560.

MATH:3600 Introduction to Ordinary Differential Equations 2-3 s.h.
First-order ordinary differential equations; second-order linear differential equations; series solutions; higher-order linear and matrix differential equations; existence and uniqueness theorems; may include introduction to basic partial differential equations (PDE) or Laplace Transforms. Prerequisites: (MATH:1560 or MATH:1860) and (MATH:2550 or MATH:2700). Corequisites: MATH:2850 (if not taken as a prerequisite). Requirements: prior or concurrent enrollment in MATH:2850.

MATH:3700 Introduction to Matrix Theory 3 s.h.
Vector algebra and geometry of three-dimensional Euclidean space and extensions to n-space and vector spaces; lines and planes, matrices, linear transformations, systems of linear equations, reduction to row-echelon form, dimension, rank, determinants, eigenvalues and eigenvectors, diagonalization, Principal Axis Theorem. Requirements: graduate standing.

MATH:3720 Introduction to Abstract Algebra I 4 s.h.
Basic logic, proof methods, sets, functions, relations, mathematical induction; gradual transition from familiar number systems to abstract structures—division algorithm, unique factorization theorems; groups, subgroups, quotient groups, homomorphisms. Prerequisites: MATH:2700 or MATH:2550.

MATH:3750 Classical Analysis 4 s.h.
Multivariable calculus; vector functions, total differentials, gradient, implicit functions, coordinate systems, Taylor's expansion, extrema, multiple integrals, vector fields, line integrals, surface integrals, and Green's, Stokes', and divergence theorems. Requirements: graduate standing and one year of calculus.

MATH:3770 Fundamental Properties of Spaces and Functions I 4 s.h.
Elementary topological and analytic properties of real numbers; emphasis on ability to handle definitions, theorems, proofs. Prerequisites: MATH:1560 or MATH:1860. Corequisites: MATH:2700. Requirements: second-semester calculus.

MATH:3800 Introduction to Numerical Methods 3 s.h.
Computer arithmetic, root finding, polynomial approximation, numerical integration, numerical linear algebra, numerical solution of differential equations; use of a higher-level computer language such as Matlab, Python, or Julia. Prerequisites: (MATH:2550 or MATH:2700) and (MATH:1560 or MATH:1860). Same as CS:3700.

MATH:3900 Introduction to Mathematics Research 3 s.h.
Research experience; students study an elementary topic of active research, then work in groups under faculty supervision. Prerequisites: (MATH:2700 or MATH:2550) and (MATH:1860 or MATH:1560).

MATH:3995 Topics in Mathematics 3 s.h.
Varied topics. Recommendations: junior, senior, or graduate standing in mathematics, classics, or related fields.

MATH:3996 Individual Study and Honors in Mathematics arr.

MATH:3997 Readings in Mathematics arr.

MATH:4010 Basic Analysis 3 s.h.
Elementary topological and analytical properties of real numbers; emphasis on ability to handle definitions, theorems, proofs; same material as MATH:3770 for non-mathematics graduate students. Requirements: graduate standing, one year of calculus, and one semester of linear algebra.

MATH:4020 Basic Abstract Algebra 3 s.h.
Basic logic, proof methods, sets, functions, relations, mathematical induction; gradual transition from familiar number systems to abstract structures (division algorithm, unique factorization theorems); groups, subgroups, quotient groups, homomorphisms; same material as MATH:3720; for non-mathematics graduate students. Requirements: graduate standing, one year of calculus, and one semester of linear algebra.

MATH:4040 Matrix Theory 3 s.h.
Vector spaces, linear transformations, matrices, equivalence of matrices, eigenvalues and eigenvectors, canonical forms, similarity, orthogonal transformations, bilinear and quadratic forms. Prerequisites: MATH:2700 or MATH:3700.

MATH:4050 Introduction to Discrete Mathematics 3 s.h.
Basic methods of enumerative combinatorics, inclusion-exclusion and generating functions, applications of group theory (Polya-Burnside theorem). Offered fall semesters. Prerequisites: (MATH:1860 or MATH:1560) and (MATH:2550 or MATH:2700).

MATH:4060 Discrete Mathematical Models 3 s.h.
Basic combinatorics and graph theory, their applications (which may include scheduling, matching, optimization); Eulerian and Hamiltonian paths, spanning trees. Offered spring semesters. Prerequisites: MATH:2700 or MATH:2550.

MATH:4080 Number Theory and Cryptography 3 s.h.
Elementary theory of numbers and its applications in public key cryptography. Prerequisites: MATH:1860 and MATH:2700.

MATH:4090 A Rigorous Introduction to Abstract Algebra 3 s.h.
Rigorous review of groups including homomorphisms and quotient groups; group actions; Sylow's theorems; rigorous review of rings; ideals, ring homomorphisms, quotient rings; polynomial rings; vector spaces and linear transformations; basic field theory; serves as a bridge between MATH:3720 and MATH:5000. Prerequisites: MATH:3720. Requirements: MATH:3720 or graduate standing.

MATH:4095 Rigorous Introduction to Module Theory and Galois Theory 4 s.h.
Rigorous review of vector spaces and linear transformations; introduction to module theory, including finitely generated modules over principal ideal domains; rigorous introduction to field theory, including existence of algebraic closure and splitting fields; introduction to Galois theory, including solvability by radicals. Prerequisites: MATH:4090 or MATH:5000.

MATH:4120 History of Mathematics 3 s.h.
May include numerical systems; Babylonian, Egyptian, and Greek mathematics; mathematics of other cultures; calculus; 19th- and 20th-century mathematics. Prerequisites: (MATH:2700 or MATH:2550) and (MATH:1560 or MATH:1860). Requirements: two semesters of calculus and one semester of linear algebra.

MATH:4200 Complex Variables 3 s.h.
Geometry of complex plane, analytic functions; Cauchy-Goursat theorem, applications; Laurent series, residues, elementary conformal mapping. Prerequisites: MATH:2850 or MATH:1560 or MATH:3750.

MATH:4220 Fourier Analysis and Applications 3 s.h.
Study of functions or noisy data by decomposing them into a series of trigonometric functions or sine waves. Prerequisites: (MATH:1560 or MATH:1860) and (MATH:2550 or MATH:2700).

MATH:4250 Introduction to Financial Mathematics 3 s.h.
Financial mathematics; option pricing and portfolio optimization, stochastic integration, methods due to Ito and Feynman-Kac, Monte-Carlo simulation. Prerequisites: MATH:2850 or STAT:3120.

MATH:4500 Introduction to Differential Geometry I 3 s.h.
Space curves, Frenet frames, intrinsic and extrinsic geometry of surfaces, first and second fundamental forms, isometries, Gauss map, Gaussian curvature, Theorema Egregium, geodesics, covariant differentiation; may include global theory of curves and Gauss-bonnet theorem. Prerequisites: (MATH:3550 or MATH:2850) and (MATH:2700 or MATH:2550).

MATH:4510 Introduction to Differential Geometry II 3 s.h.
Continuation of MATH:4500; geometry of surfaces in Euclidean space, Gauss-Bonnet theorem and its applications, minimal surfaces, abstract surfaces; may include Riemannian manifolds, connections, elementary Lie groups, applications of differential geometry to other disciplines (physics, engineering). Prerequisites: MATH:4500.

MATH:4700 Partial Differential Equations and Applications 3 s.h.
Introduction to elliptic, parabolic, and hyperbolic partial differential equations and their applications to problems from science and engineering. Prerequisites: (MATH:1560 or MATH:2850) and (MATH:2560 or MATH:3600).

MATH:4740 Large Data Analysis 3 s.h.
Current areas that deal with problem of big data; techniques from computer science, mathematics, statistics; high performance and parallel computing, matrix techniques, cluster analysis, visualization; variety of applications including Google PageRank, seismology, Netflix-type problems, weather forecasting; fusion of data with simulation; projects. Prerequisites: (CS:1210 with a minimum grade of C- or ENGR:2730 with a minimum grade of C-) and (MATH:3800 or MATH:3800) and (STAT:3200 or STAT:3200 or STAT:3200). Same as CS:4740, IGPI:4740, STAT:4740.

MATH:4750 Introduction to Mathematical Biology 3 s.h.
Use and creation of mathematical models in biology, primarily those using continuous dynamical systems ordinary and partial differential equations; may include additional approaches (e.g., game theory, discrete models); modeling approaches—the model as representation—and canonical models in context of example systems drawn from a range of application areas including, but not limited to, neurobiology, electrophysiology, epidemiology, ecology, evolution, demography, and spatiotemporal pattern formation including morphogenesis. Prerequisites: MATH:3600 or MATH:2560.

MATH:4820 Optimization Techniques 3 s.h.
Basic theory of optimization, use of numerical algorithms in solution of optimization problems; linear and nonlinear programming, sensitivity analysis, convexity, optimal control theory, dynamic programming, calculus of variations. Prerequisites: (MATH:2700 or MATH:2550) and (ME:4111 or MATH:3800 or CS:3700) and (MATH:1560 or MATH:2850). Same as CS:4720.

MATH:4840 Mathematics of Machine Learning 3 s.h.
Mathematical aspects of machine learning; regression methods and related issues of overfitting, generalization error, cross-validation; matrix methods for dimension reduction; optimization for support vector machines and neural networks, including convex duality and "kernel trick" for support vector machines; training of neural networks using backpropagation and gradients; reliability of optimization methods for nonconvex optimization; approximation properties of neural networks; convolutions for handling sound and image data; game theory for adversarial networks. Prerequisites: (MATH:2550 or MATH:2700) and (MATH:1560 or MATH:2850 or MATH:3550).

MATH:4860 High Performance and Parallel Computing 3 s.h.
Parallel algorithms presented and implemented with different approaches and libraries (e.g., OpenMP, MPI); various platforms including Message Passing Clusters, Multicore and GPUs, MapReduce (Hadoop), and related current topics; scientific computing and large data analysis projects. Prerequisites: (CS:2210 with a minimum grade of C- or MATH:4050) and CS:2230 with a minimum grade of C-. Same as CS:4700.

MATH:5000 Abstract Algebra I 3 s.h.
Groups and homomorphisms, Sylow Theorems, rings, finitely generated modules over a PID, Galois theory, vector spaces, linear transformations and matrices, canonical forms. Prerequisites: MATH:3720.

MATH:5010 Abstract Algebra II 3 s.h.
Continuation of MATH:5000. Prerequisites: MATH:5000.

MATH:5200 Introduction to Analysis I 3 s.h.
Real numbers, fundamentals of limits and continuity in the context of metric spaces; Lebesque theory of functions of one real variable. Prerequisites: MATH:3770 or MATH:4220. Requirements: MATH:3770 or graduate standing.

MATH:5210 Introduction to Analysis II 3 s.h.
Local theory of analytic functions of one complex variable, power series, classical transcendental functions; spaces of functions. Prerequisites: MATH:5200.

MATH:5400 Fundamental Groups and Covering Spaces 3 s.h.
Homotopy, homotopy equivalence, homotopy extension property, fundamental group, Van Kampen's theorem, free products of groups, covering spaces, lifting properties, classification of covering spaces, deck transformations and group actions, cell complexes, applications to cell complexes, graphs and free groups; may include simplicial homology and point-set topology topics. Prerequisites: MATH:3770 or MATH:4220.

MATH:5410 Introduction to Smooth Manifolds 3 s.h.
Calculus on smooth manifolds; smooth functions, mean value theorem, chain rule, smooth manifolds, tangent vectors, tangent spaces, inverse and implicit functions theorems, submersions and immersions, vector fields, flows, multilinear algebra, differential forms, Stokes theorem. Prerequisites: MATH:2700 and MATH:2850 and MATH:5400.

MATH:5600 Nonlinear Dynamics with Numerical Methods 3 s.h.
Linear systems of differential equations (fundamental solutions, matrix exponentials, Floquet theory); nonlinear differential equations (theorem for existence and uniqueness, flows, attractors); local nonlinear theory (invariant manifolds, Hartman-Grobman theorem, Poincare maps); global nonlinear theory (Poincare-Bendixson criterion, Lyapunov functions, gradient systems, Hamiltonian systems); bifurcations (saddle-node, pitchfork, transcritical, Hopf); introduction to chaos theory (Lorenz equations); computational methods to solve numerically differential equations and to draw phase planes and trajectories. Prerequisites: MATH:3600 and (MATH:3770 or MATH:4220).

MATH:5700 Introduction to Partial Differential Equations 3 s.h.
Diffusion, Laplace, and wave equations; scalar conservation laws; weak solutions and energy methods. Prerequisites: MATH:2850 and MATH:3600 and (MATH:3770 or MATH:4220).

MATH:5750 Mathematical Biology I 3 s.h.
Topics in mathematical biology; canonical mathematical modeling and analysis of problems in the biological sciences; first of a two-semester sequence. Prerequisites: MATH:5600 and MATH:5700.

MATH:5760 Mathematical Biology II 3 s.h.
Topics in mathematical biology; canonical mathematical modeling and analysis of problems in the biological sciences; second of a two-semester sequence. Corequisites: MATH:5600 and MATH:5700, if not taken as prerequisites.

MATH:5800 Numerical Methods I 3 s.h.
Root finding for nonlinear equations; polynomial interpolation; polynomial approximation of functions; numerical integration. Prerequisites: MATH:2700 and (MATH:2850 or MATH:3550). Requirements: knowledge of computer programming. Same as CS:5710.

MATH:5810 Numerical Methods II 3 s.h.
Numerical methods for initial value problems for ordinary differential equations; direct and iterative methods for linear systems of equations; eigenvalue problems for matrices. Prerequisites: MATH:2700 and MATH:5800 and (MATH:2850 or MATH:3550) and (MATH:3600 or MATH:2560). Requirements: knowledge of computer programming. Same as CS:5720.

MATH:5900 First-Year Graduate Seminar 1 s.h.
Introduction to mathematics graduate program. Requirements: first-year graduate standing in mathematics.

MATH:5950 Qualifying Exam Preparation Seminars 0 s.h.
Exam preparation in pure and applied mathematics.

MATH:6000 Categories and Modules 3 s.h.
Introduction to categories and functors; emphasis on module categories, products and coproducts, hom functors and tensor product functors, exact sequences, projective/injective/flat modules, Noetherian and Artinian rings and modules, composition series and Jordan-Hölder theorem, Jacobson radical, Nakayama's lemma, semisimple rings and modules, and Artin-Wedderburn structure theorem. Prerequisites: MATH:5010.

MATH:6010 Commutative Algebra and Representation Theory 3 s.h.
Fundamental notions in commutative algebra and representation theory; specific topics may include Gröbner bases, associated primes, primary decomposition, valuation rings, affine and projective varieties, group representations, characters, orthogonality relations, and other branches of representation theory. Prerequisites: MATH:5010.

MATH:6200 Analysis I 3 s.h.
Lebesque measure and integral, fundamental theorem of calculus, abstract measures and integration, Fubini's theorem, Radon-Nikodym theorem, Riesz representation theorem, L-p spaces. Prerequisites: MATH:5210.

MATH:6210 Analysis II 3 s.h.
Hilbert space, Banach space techniques; Hahn-Banach theorem, open mapping theorem, principle of uniform boundedness; reflexivity, H-p spaces, Paley-Wiener theorem, space of functions analytic on the open unit disk. Prerequisites: MATH:6200.

MATH:6400 Algebraic Topology 3 s.h.
Singular homology, relative homology, homotopy invariance, exact sequences and excision, cellular homology, Mayer-Vietoris sequences, homology with coefficients, axioms for homology, Hurewicz theorem, cohomology groups, universal coefficient theorem, cup product, cohomology ring, fundamental class, Poincaré duality. Prerequisites: MATH:5400.

MATH:6410 Introduction to Differential Topology 3 s.h.
Manifolds, functions: tangent bundle, Morse-Sard theorem, transversality, submanifolds, tubular neighborhoods, normal bundles, vector fields, degree and intersection theory, fixed-point theory, Morse theory. Prerequisites: MATH:5410.

MATH:6500 Differential Geometry I 3 s.h.
Differentiable manifolds, forms, tensors, Riemannian metrics, isometries, connections, geodesics, curvature, related topics. Prerequisites: MATH:5410.

MATH:6510 Differential Geometry II 3 s.h.
Continuation of MATH:6500; varied topics, may include study of existence and uniqueness of solutions to differential equations and systems related to geometry, indefinite metrics, Lie groups, attributes of manifolds with particular curvature properties, global Riemannian geometry, Kahler geometry, applications of differential geometry to other disciplines. Prerequisites: MATH:6500.

MATH:6600 Ordinary Differential Equations I 3 s.h.
Existence, uniqueness, continuous dependence of solutions to initial value problems, variational calculus, Lagrangian and Hamiltonian systems, differential inequalities, perturbation theory, normal forms, invariant manifolds, KAM theory, bifurcation theory, boundary value problems. Prerequisites: MATH:5210.

MATH:6610 Ordinary Differential Equations II 3 s.h.
Continuation of MATH:6600. Prerequisites: MATH:6600.

MATH:6700 Partial Differential Equations I 3 s.h.
Elliptic equations; potential theory, maximum principle, a priori estimate, Dirichlet problem; initial value problem for parabolic equations; hyperbolic equations; Duhamel's principle, Cauchy problem; nonlinear equations, characteristics, canonical form, first-order systems. Prerequisites: MATH:5210.

MATH:6710 Partial Differential Equations II 3 s.h.
Continuation of MATH:6700. Prerequisites: MATH:6700.

MATH:6850 Advanced Numerical Methods I 3 s.h.
Theoretical foundations of numerical analysis, within framework of functional analysis; application areas including approximation theory, numerical methods for partial differential equations, integral equations; introduction to functional analysis. Prerequisites: MATH:5200 and MATH:5210 and MATH:5800 and MATH:5810.

MATH:6860 Advanced Numerical Methods II 3 s.h.
Continuation of MATH:6850. Prerequisites: MATH:6850.

MATH:7000 Homological Algebra 2-3 s.h.
Fundamental notions in homological algebra, including derived functors (Ext and Tor); specific topics may include group cohomology, spectral sequences, and derived categories. Prerequisites: MATH:6000.

MATH:7020 Algebraic Number Theory 3 s.h.
Topics include integral elements, integrally closed rings, algebraic extensions, norms and traces, the discriminant; number fields and some analogues in positive characteristic, global fields; class groups, unit groups; valuations and local fields; adele ring and idele group attached to global fields; L-functions (including the Riemann zeta function) and class number formulas. Prerequisites: MATH:5000 and MATH:5010.

MATH:7030 Topics in Algebra 2-3 s.h.
May include algebraic number theory, groups, representation theory, algebras, ideal theory, lattice theory. Prerequisites: MATH:6010.

MATH:7070 Seminar: Algebra arr.

MATH:7080 Seminar: Commutative Ring Theory arr.

MATH:7090 Seminar: Representation Theory arr.

MATH:7200 Functional Analysis I 2-3 s.h.
Locally convex topological vector spaces, duality, tensor products and nuclear spaces; Krein-Millman theorem, Choquet's theory; geometry of Banach spaces, nonlinear functional analysis; operators on Hilbert spaces, spectral theorem, algebras of operators. Prerequisites: MATH:6210.

MATH:7210 Functional Analysis II 2-3 s.h.
Continuation of MATH:7200. Prerequisites: MATH:7200.

MATH:7250 Topics in Analysis 2-3 s.h.
Measure theory, integration, general topology.

MATH:7290 Seminar: Operator Theory arr.

MATH:7400 Current Geometry and Topology I 3 s.h.
Introduction to current topics in geometry and topology: Gromov-Witten theory, moduli spaces, Floer theory, mirror symmetry, geometric analysis, conformal geometry, knots and braids, topological data analysis, contact and symplectic topology, mapping class groups, categorification, Heegaard splittings of 3-manifolds, trisections of 4-manifolds, quantum topology, and Skein theory. Prerequisites: MATH:5400 and MATH:5410.

MATH:7450 Current Geometry and Topology II 2-3 s.h.
Introduction to current topics in geometry and topology: Gromov-Witten theory, moduli spaces, Floer theory, mirror symmetry, geometric analysis, conformal geometry, knots and braids, topological data analysis, contact and symplectic topology, mapping class groups, categorification, Heegaard splittings of 3-manifolds, trisections of 4-manifolds, quantum topology, and Skein theory. Prerequisites: MATH:5400 and MATH:5410.

MATH:7470 Seminar: Topology arr.

MATH:7570 Seminar: Differential Geometry arr.

MATH:7580 Seminar: Mathematical Physics arr.

MATH:7630 Topics in Mathematical Biology 2-3 s.h.
Application of mathematics to biology.

MATH:7660 Seminar: Nonlinear Dynamics and Differential Equations arr.

MATH:7670 Seminar: Mathematical Biology arr.

MATH:7730 Topics in Partial Differential Equations 2-3 s.h.
Regularity theory, nonlinear analysis in partial differential equations, fluid dynamics, harmonic analysis, conservation laws, other topics.

MATH:7770 Seminar: Partial Differential Equations arr.

MATH:7830 Topics in Applied Mathematics 3 s.h.
Application of mathematics to other disciplines.

MATH:7870 Seminar: Numerical Analysis arr.

MATH:7990 Reading Research arr.