# MATHEMATICS (MATH)

**Courses primarily for undergraduates:**

**MATH 1010: Orientation in Mathematics**
Credits: Required. Contact Hours: Lecture 1.
A required orientation for all first-year and transfer students in mathematics. Provides information about campus resources and opportunities available to students, assists with transition to the University, and academic planning. Offered on a satisfactory/fail basis only. Offered on a satisfactory-fail basis only. (Typically Offered: Fall)

**MATH 1040: Introduction to Probability**
Credits: 3. Contact Hours: Lecture 3.
*Prereq: Satisfactory math placement test score (ALEKS 15+)*
Permutations, combinations, probability, expected value, and applications. Satisfactory placement scores can be found at https://math.iastate.edu/academics/undergraduate/aleks/placement/. Graduation Restriction: Either MATH 1040 or MATH 1500 may be counted toward graduation, but not both. (Typically Offered: Fall, Spring, Summer)

**MATH 1050: Introduction to Mathematical Ideas**
Credits: 3. Contact Hours: Lecture 3.
*Prereq: Satisfactory math placement test score (ALEKS 15+)*
Introduction to the use of basic mathematics to solve real-world problems in the areas of voting issues, measuring power in situations where people have different numbers of votes, apportionment, fair division, and elementary game theory. No prior background in politics or history is necessary for this course. Satisfactory placement scores can be found at https://math.iastate.edu/academics/undergraduate/aleks/placement/. (Typically Offered: Fall, Spring, Summer)

**MATH 1390: College Algebra Supplement**
Credits: 1. Contact Hours: Lecture 1.
*Prereq: Satisfactory math placement test score (ALEKS 15+)*
Math concepts to provide supplemental assistance with course topics of MATH 1400. Satisfactory placement scores can be found at https://math.iastate.edu/academics/undergraduate/aleks/placement/. Offered on a satisfactory-fail basis only. (Typically Offered: Fall, Spring)

**MATH 1400: College Algebra**
Credits: 3. Contact Hours: Lecture 2, Discussion 1.
*Prereq: Satisfactory math placement test score (ALEKS, 39+) or concurrent enrollment in MATH 139*
Coordinate geometry, quadratic and polynomial equations, functions, graphing, rational functions, exponential and logarithmic functions, inverse functions, quadratic inequalities, systems of linear equations. Satisfactory placement scores can be found at https://math.iastate.edu/academics/undergraduate/aleks/placement/. (Typically Offered: Fall, Spring, Summer)

**MATH 1430: Preparation for Calculus**
Credits: 4. Contact Hours: Lecture 2, Discussion 2.
*Prereq: Satisfactory performance on placement assessment or* MATH 1400
Preparation for MATH 1600 or MATH 1650. Functions, graphing, basic trigonometry, logarithms, exponentials. Emphasis on co-variational reasoning. Satisfactory placement scores can be found at https://math.iastate.edu/academics/undergraduate/aleks/placement/. Graduation Restriction: Only one of MATH 1430 and MATH 1450 may count toward graduation. (Typically Offered: Fall, Spring)

**MATH 1450: Applied Trigonometry**
Credits: 3. Contact Hours: Lecture 2, Discussion 1.
*Prereq: Satisfactory performance on placement assessment or* MATH 1400
Mathematical ideas regarding the conception of space. General trigonometry, with an emphasis on the calculation of lengths, areas, and angles. The Law of Sines and the Law of Cosines. Polar, cylindrical, and spherical coordinate systems. Conic sections and quadric surfaces. Satisfactory placement scores can be found at https://math.iastate.edu/academics/undergraduate/aleks/placement/. Graduation Restriction: Only one of MATH 1430 and MATH 1450 may count toward graduation. (Typically Offered: Fall, Spring)

**MATH 1490: Discrete Mathematics for Business and Social Sciences Supplement**
Credits: 1. Contact Hours: Lecture 1.
*Prereq: Satisfactory math placement test score (ALEKS 15+)*
Math concepts to provide supplemental assistance with course topics of MATH 1500. Satisfactory placement scores can be found at https://math.iastate.edu/academics/undergraduate/aleks/placement/. Offered on a satisfactory-fail basis only. (Typically Offered: Fall, Spring)

**MATH 1500: Discrete Mathematics for Business and Social Sciences**
Credits: 3. Contact Hours: Lecture 3.
*Prereq: Satisfactory math placement test score (ALEKS, 39+)*
Linear equations and inequalities, matrix algebra, linear programming, discrete probability. Satisfactory placement scores can be found at https://math.iastate.edu/academics/undergraduate/aleks/placement/. Graduation Restriction: Either MATH 1040 or MATH 1500 may be counted toward graduation, but not both. (Typically Offered: Fall, Spring, Summer)

**MATH 1510: Calculus for Business and Social Sciences**
Credits: 3. Contact Hours: Lecture 2, Discussion 1.
*Prereq: Satisfactory math placement test score (ALEKS, 51+)*
Differential calculus, applications to max-min problems, integral calculus and applications. Will not serve as prerequisite for MATH 2650 or MATH 2660. Satisfactory placement scores can be found at https://math.iastate.edu/academics/undergraduate/aleks/placement/. Graduation Restriction: Only one of MATH 1510, MATH 1600, or the sequence MATH 1650-MATH 1660 may be counted towards graduation. (Typically Offered: Fall, Spring, Summer)

**MATH 1600: Survey of Calculus**
Credits: 4. Contact Hours: Lecture 4.
*Prereq: Satisfactory performance on placement assessment or minimum of C- in (*MATH 1400 *or* MATH 1430*)*
Analytic geometry, derivatives and integrals of elementary functions, simple differential equations, and applications. Will not serve as a prerequisite for MATH 2650 or MATH 2660. Satisfactory placement scores can be found at https://math.iastate.edu/academics/undergraduate/aleks/placement/. Graduation Restriction: Only one of MATH 1510, MATH 1600, or the sequence MATH 1650-MATH 1660 may be counted towards graduation. (Typically Offered: Fall, Spring)

**MATH 1630X: Elements of Calculus**
Credits: 4. Contact Hours: Lecture 4.
Preparation for MATH 1600 and MATH 1650. Functions, graphing, basic trigonometry, logarithms, exponentials, limits, continuity, basics of differentiation. Graduation Restriction: Only one of MATH 1630 and MATH 1650 may count toward graduation. Also, only one of MATH 1430 and MATH 1630 may count toward graduation. (Typically Offered: Fall)

**MATH 1640X: Advanced Elements of Calculus**
Credits: 3. Contact Hours: Lecture 4.
Advanced differentiation, applications of the derivative, introduction to integral calculus.Graduation Restriction: Only one of MATH 1510 or MATH 1600 or MATH 1640 or MATH 1650 may be counted towards graduation. (Typically Offered: Spring)

**MATH 1650: Calculus I**
Credits: 4. Contact Hours: Lecture 3, Discussion 1.
*Prereq: Minimum C- in* MATH 1430 *or satisfactory score on placement exam*
Differential calculus, applications of the derivative, introduction to integral calculus. Satisfactory placement scores can be found at https://math.iastate.edu/academics/undergraduate/aleks/placement/.Graduation Restriction: Only one of MATH 1510, MATH 1600, or the sequence MATH 1650-MATH 1660 may be counted towards graduation. (Typically Offered: Fall, Spring, Summer)

**MATH 1660: Calculus II**
Credits: 4. Contact Hours: Lecture 3, Discussion 1.
*Prereq:* MATH 1650 *or satisfactory placement on Calculus II placement exam (by department permission)*
Integral calculus, applications of the integral, parametric curves and polar coordinates, power series and Taylor series. Satisfactory placement scores can be found at https://math.iastate.edu/academics/undergraduate/aleks/placement/. Graduation Restriction: Only one of MATH 1510, MATH 1600, or the sequence MATH 1650-MATH 1660 may be counted towards graduation. (Typically Offered: Fall, Spring, Summer)

**MATH 1660H: Calculus II: Honors**
Credits: 4. Contact Hours: Lecture 4.
*Prereq:* MATH 1650 *or satisfactory placement on Calculus II placement exam (by department permission)*
Integral calculus, applications of the integral, parametric curves and polar coordinates, power series and Taylor series. Additional material of a theoretical, conceptual, computational, or modeling nature. Some of the work may require more ingenuity than is required for MATH 1660. Preference will be given to students in the University Honors Program. Satisfactory placement scores can be found at https://math.iastate.edu/academics/undergraduate/aleks/placement/. Graduation restriction: Only one of MATH 1510 or MATH 1600, or the sequence MATH 1650-MATH 1660 may be counted towards graduation. (Typically Offered: Fall)

**MATH 1950: Mathematics for Elementary Education I**
Credits: 3.
*Prereq: Satisfactory performance on placement assessment; Early or Elementary Education major*
Whole number operations through analysis of properties, theoretical and hands-on models, mathematical analysis of elementary students' thinking; standard and non-standard algorithms; structure of the decimal system; linear measurement; two- and three-dimensional measurement, shapes and spatial sense; number theory; algebra as it relates to elementary curricula/teaching profession. Satisfactory placement scores can be found at https://math.iastate.edu/academics/undergraduate/aleks/placement/. Graduation Restriction: Students in the College of Liberal Arts and Sciences may not count MATH 1950 toward General Education Requirements. (Typically Offered: Fall, Spring)

**MATH 1960: Mathematics for Elementary Education II**
Credits: 3.
*Prereq: Minimum of C- in* MATH 1950 *and enrollment in elementary education or early childhood education.*
Integer, fraction and decimal operations through analysis of properties, theoretical and hands-on models, mathematical analysis of elementary students' thinking; standard and non-standard algorithms; continuation of two- and three-dimensional measurement, shapes and spatial sense; probability and statistics; proportional reasoning; algebra as it relates to elementary curricula/teaching profession. (Typically Offered: Fall, Spring)

**MATH 2010: Introduction to Proofs**
Credits: 3. Contact Hours: Lecture 3.
*Prereq:* MATH 1660 *or* MATH 1660H
Transition to advanced mathematics. Communicating mathematics. Logical arguments; techniques of proofs regarding sets, numbers (natural and real), functions, relations, and limits. (Typically Offered: Fall, Spring)

**MATH 2020: Career Development in Math and Statistics**
(Cross-listed with STAT 2020).
Credits: 1. Contact Hours: Laboratory 2.
Career development in the mathematics and statistics disciplines with an emphasis on contemporary social issues. Presentations by professionals in STEM fields about occupations, decision-making strategies, and career goal implementation; development of job searching, resume writing, negotiating, and interviewing techniques. Offered on a satisfactory-fail basis only. (Typically Offered: Spring)

**MATH 2070: Matrices and Linear Algebra**
Credits: 3. Contact Hours: Lecture 3.
*Prereq:* MATH 1660 *or* MATH 1660H
Systems of linear equations, determinants, vector spaces, linear transformations, orthogonality, least-squares methods, eigenvalues and eigenvectors. Emphasis on applications and techniques.Graduation Restriction: Only one of MATH 2070 and MATH 3170 may be counted toward graduation. (Typically Offered: Fall, Spring, Summer)

**MATH 2300: Discrete Computational Structures**
(Cross-listed with COMS 2300).
Credits: 3. Contact Hours: Lecture 3, Discussion 1.
*Prereq: Minimum of C- in* COMS 2270 *and* MATH 1650*;* ENGL 1500
Concepts in discrete mathematics as applied to computer science. Logic, set theory, functions, relations, cardinality of sets, combinatorics, graph theory and number theory. Proof techniques, induction and recursion. (Typically Offered: Fall, Spring, Summer)

**MATH 2400: Mathematics of Investment and Credit**
Credits: 3. Contact Hours: Lecture 3.
*Prereq:* MATH 1660 *or* MATH 1660H
Interest rates, time value of money, annuities. Loans, bonds, yield rates. Term structure of interest rates, asset and liability management. Duration, convexity, immunization. (Typically Offered: Fall, Spring)

**MATH 2650: Calculus III**
Credits: 4. Contact Hours: Lecture 3, Discussion 1.
*Prereq: Minimum of C- in* MATH 1660 *or* MATH 1660H
Geometry of space and vectors, multivariable differential calculus, multivariable integral calculus, vector calculus. (Typically Offered: Fall, Spring, Summer)

**MATH 2650H: Calculus III: Honors**
Credits: 4. Contact Hours: Lecture 4.
*Prereq: Permission of the instructor; and minimum of C- in MATH 1660 or MATH 1660H*
Geometry of space and vectors, multivariable differential calculus, multivariable integral calculus, vector calculus. Additional material of a theoretical, conceptual, computational, or modeling nature. Some of the work may require more ingenuity than is required in MATH 2650. Preference will be given to students in the University Honors Program. (Typically Offered: Fall, Spring)

**MATH 2660: Elementary Differential Equations**
Credits: 3. Contact Hours: Lecture 3.
*Prereq: Minimum of C- in* MATH 1660 *or* MATH 1660H
Solution methods for ordinary differential equations. First order equations, linear equations, constant coefficient equations. Eigenvalue methods for systems of first order linear equations. Introduction to stability and phase plane analysis. Graduation Restriction: Credit for either MATH 2670 or the MATH 2660, 2680 pair of courses, but not both, may be applied toward graduation. Credit for only one of the following courses may be applied toward graduation: MATH 2670, MATH 2660, MATH 2690. (Typically Offered: Fall, Spring, Summer)

**MATH 2670: Elementary Differential Equations and Laplace Transforms**
Credits: 4. Contact Hours: Lecture 3, Discussion 1.
*Prereq: Minimum of C- in* MATH 1660 *or* MATH 1660H
Same as MATH 2660 but also including Laplace transforms and power series solutions to ordinary differential equations. Graduation Restriction: Credit for either MATH 2670 or the MATH 2660, 2680 pair of courses, but not both, may be applied toward graduation. Credit for only one of the following courses may be applied toward graduation: MATH 2670, MATH 2660, MATH 2690. (Typically Offered: Fall, Spring, Summer)

**MATH 2680: Laplace Transforms**
Credits: 1. Contact Hours: Lecture 1.
*Prereq:* MATH 2660*; Department Permission*
Laplace transforms and power series solutions to ordinary differential equations. Graduation Restriction: Credit for either MATH 2670 or the MATH 2660, 2680 pair of courses, but not both, may be applied toward graduation. (Typically Offered: Fall, Spring, Summer)

**MATH 2690: Systems of Differential Equations**
Credits: 1. Contact Hours: Lecture 1.
*Prereq: Department Permission for Course*
Systems portion of MATH 2660 and MATH 2670: Eigenvalue methods for systems of first order linear equations. Introduction to stability and phase plane analysis. For students supplementing transfer courses in differential equations in order to earn credit in MATH 2660 or 2670. Familiarity with ordinary differential equations of first and second order required. Graduation Restriction: Students with credit in MATH 2660 or MATH 2670 may not earn credit in MATH 2690. (Typically Offered: Fall, Spring, Summer)

**MATH 2900: Independent Study**
Credits: 1-3. Repeatable.
*Prereq: Instructor Permission for Course*
Independent study.

**MATH 2900H: Independent Study: Honors**
Credits: 1-3. Repeatable.
*Prereq: Instructor Permission for Course*
Independent study.

**MATH 2970: Intermediate Topics for School Mathematics**
Credits: 3.
*Prereq: Minimum of C- in* MATH 1960*; Early or Elementary Education major*
Mathematical reasoning and topics in Euclidean and non-Euclidean geometry, including transformations, congruence, and similarity; exploration of probability with simulations; linearity and connections to Calculus; fractals and fractal dimension. (Typically Offered: Fall)

**MATH 3010: Abstract Algebra I**
Credits: 3. Contact Hours: Lecture 3.
*Prereq:* MATH 1660 *or* MATH 1660H*,* MATH 3170*, and grade of C- or better in* MATH 2010
Basic properties of integers, divisibility and unique factorization. Polynomial rings over a field. Congruence. Introduction to abstract rings, homomorphisms, ideals. Roots and irreducibility of polynomials. Introduction to groups. Emphasis on proofs. (Typically Offered: Fall, Spring)

**MATH 3040: Combinatorics**
Credits: 3. Contact Hours: Lecture 3.
*Prereq:*
*(MATH 1660 or* MATH 1660H*); (MATH 2010 or COMS 2300 or CPRE 3100)*
Enumeration strategies involving permutations, combinations, partitions, binomial coefficients, inclusion-exclusion principle, recurrence relations, generating functions. Additional topics selected from probability, algebraic combinatorics, and applications. (Typically Offered: Fall)

**MATH 3140: Graph Theory**
Credits: 3. Contact Hours: Lecture 3.
*Prereq:*
*(MATH 1660 or* MATH 1660H*); (MATH 2010 or COMS 2300 or CPRE 3100)*
Structure and extremal properties of graphs. Topics are selected from: trees, networks, colorings, paths and cycles, connectivity, planarity, directed graphs, matchings, Ramsey theory, forbidden structures, enumeration, applications. (Typically Offered: Spring)

**MATH 3170: Theory of Linear Algebra**
Credits: 4. Contact Hours: Lecture 4.
*Prereq: Credit or concurrent enrollment in* MATH 2010 *or* COMS 2300 *or* CPRE 3100
Systems of linear equations, determinants, vector spaces, inner product spaces, linear transformations, eigenvalues and eigenvectors. Emphasis on writing proofs and results. Graduation Restriction: Only one of MATH 2070 and MATH 3170 may be counted toward graduation. (Typically Offered: Fall, Spring)

**MATH 3410: Introduction to the Theory of Probability and Statistics I**
(Cross-listed with STAT 3410).
Credits: 4. Contact Hours: Lecture 3, Laboratory 2.
*Prereq: MATH 2650 or MATH 2650H*
Probability; distribution functions and their properties; classical discrete and continuous distribution functions; multivariate probability distributions and their properties; moment generating functions; transformations of random variables; simulation of random variables and use of the R statistical package. Graduation Restriction: Credit for only one of the following courses may be applied toward graduation: STAT 3410, STAT 3470, STAT 4470, or STAT 5880. (Typically Offered: Fall, Spring)

**MATH 3420: Introduction to the Theory of Probability and Statistics II**
(Cross-listed with STAT 3420).
Credits: 4. Contact Hours: Lecture 3, Laboratory 2.
*Prereq: (*MATH 2070 *or* MATH 3170*); (*STAT 1010 *or* STAT 1040 *or STAT 1050 or* STAT 2010 *or* STAT 2260 *or* STAT 2310 *or* STAT 3050 *or* STAT 3220 *or* STAT 3300*);* STAT 3410
Sampling distributions; confidence intervals and hypothesis testing; theory of estimation and hypothesis tests; linear model theory; resampling methods; introduction to Bayesian inference; use of the R statistical package for simulation and data analysis. (Typically Offered: Fall, Spring)

**MATH 3500: Number Theory**
(Cross-listed with COMS 3500).
Credits: 3. Contact Hours: Lecture 3, Discussion 1.
*Prereq:* COMS 2300 *or* CPRE 3100 *or* MATH 2010
Divisibility, integer representations, primes and divisors, linear diophantine equations, congruences, and multiplicative functions. Applications to cryptography. Additional topics, chosen at the discretion of the instructor. (Typically Offered: Spring)

**MATH 3650: Complex Variables with Applications**
Credits: 3. Contact Hours: Lecture 3.
*Prereq:* MATH 2650
Functions of a complex variable, including differentiation, integration, series, residues, and conformal mappings. (Typically Offered: Spring)

**MATH 3730: Introduction to Scientific Computing**
Credits: 3. Contact Hours: Lecture 3.
*Prereq:* MATH 2650
Vector and matrix programming and graphing in MATLAB for scientific applications. Polynomial interpolation and approximation. Systems of linear equations and numerical linear algebra. Numerical differentiation and integration. Root-finding methods for solving nonlinear equations and optimization in one and several variables. Fast Fourier transform. Emphasis on effective use of mathematical software and understanding of its strengths and limitations. (Typically Offered: Fall)

**MATH 3850: Introduction to Partial Differential Equations**
Credits: 3. Contact Hours: Lecture 3.
*Prereq:* MATH 2650 *and one of* MATH 2660*,* MATH 2670
Method of separation of variables for linear partial differential equations, including heat equation, Poisson equation, and wave equation. Topics from Fourier series, Sturm-Liouville theory, Bessel functions, spherical harmonics, and method of characteristics. (Typically Offered: Fall, Spring)

**MATH 3920X: Mathematical Communication**
Credits: 3. Contact Hours: Lecture 3.
Principles of mathematical communication. How to create convincing logical arguments in written, oral, and visual formats. Using LaTeX for document preparation. (Typically Offered: Fall)

**MATH 3970: Teaching Secondary Mathematics Using University Mathematics**
Credits: 3.
*Prereq:* MATH 2010 *and* MATH 3010
Coursework in university mathematics including calculus, abstract algebra, discrete mathematics, geometry, and other topics as it relates to teaching mathematics in grades 5-12. (Typically Offered: Spring)

**MATH 3980: Cooperative Education**
Credits: Required. Repeatable, maximum of 2 times.
*Prereq: Permission of Department Cooperative Education Coordinator; Junior classification*
Required of all cooperative education students. Students must register for this course prior to commencing each work period. (Typically Offered: Fall, Spring, Summer)

**MATH 4030: Intermediate Abstract Algebra**
(Dual-listed with MATH 5030).
Credits: 3. Contact Hours: Lecture 3.
*Prereq: C or better in* MATH 3010
Properties of groups and rings, subgroups, ideals, and quotients, homomorphisms, structure theory for finite groups. PIDs, UFDs, and Euclidean Domains. Field extensions and finite fields. Selected applications. (Typically Offered: Spring)

**MATH 4070: Applied Linear Algebra**
(Dual-listed with MATH 5070).
Credits: 3. Contact Hours: Lecture 3.
*Prereq:* MATH 3170 *or (*MATH 2070*;* MATH 2010*)*
Advanced topics in applied linear algebra including eigenvalues, eigenvalue localization, singular value decomposition, symmetric and Hermitian matrices, nonnegative and stochastic matrices, matrix norms, canonical forms, matrix functions. Applications to mathematical and physical sciences, engineering, and other fields. (Typically Offered: Fall)

**MATH 4140: Analysis I**
Credits: 3. Contact Hours: Lecture 3.
*Prereq: Minimum of C- in COMS 2300 or CPRE 3100 or MATH 2010*
A rigorous development of calculus of functions of one real variable: real number properties and topology, limits, continuity, differentiation, integration, series. (Typically Offered: Fall, Spring, Summer)

**MATH 4150: Analysis II**
Credits: 3. Contact Hours: Lecture 3.
*Prereq:* MATH 4140*;* MATH 2650*; and* MATH 3170 *or* MATH 4070
Sequences and series of functions of a real variable, uniform convergence, power series, metric spaces, calculus of functions of two or more real variables. (Typically Offered: Spring)

**MATH 4210: Logic for Mathematics and Computer Science**
(Cross-listed with COMS 4210).
Credits: 3. Contact Hours: Lecture 3.
*Prereq:* COMS 2300 *or* CPRE 3100 *or* MATH 2070 *or* MATH 3010 *or* MATH 3170
Propositional and predicate logic. Topics selected from Horn logic, equational logic, resolution and unification, foundations of logic programming, reasoning about programs, program specification and verification, model checking and binary decision diagrams, temporal logic and modal logic.

**MATH 4220X: Mathematical Principles of Data Science**
(Cross-listed with DS 4220X).
Credits: 3. Contact Hours: Lecture 3.
Mathematical foundations of algorithms in data science. Topics include Riemann-Stieltjes integration, Riesz-Markov theorem, Stone-Weierstrass theorem, Universal Approximation theorem, reproducing kernel Hilbert spaces, Cauchy and Fourier kernels, convergence of clustering algorithms, and topological persistence. (Typically Offered: Spring)

**MATH 4230: Mathematical Modeling in Biology**
(Cross-listed with BCBIO 4230).
Credits: 3. Contact Hours: Lecture 3.
*Prereq:* MATH 2660 *or* MATH 2670
Introduction to mathematical techniques for modeling and simulation, parameter identification, and analysis of biological systems. Applications drawn from many branches of biology and medicine. Apply differential equations, difference equations, and dynamical systems theory to a wide array of biological problems. MATH 2650 or equivalent recommended. (Typically Offered: Fall)

**MATH 4240: Introduction to High Performance Computing**
(Cross-listed with COMS 4240/ CPRE 4240).
Credits: 3.
*Prereq: (*MATH 2650*; [*MATH 2070 *OR* MATH 3170*]) or permission of instructor*
Unix, serial programming of scientific applications, OpenMP for shared-memory parallelization. No Unix, Fortran or C experience required. (Typically Offered: Fall)

**MATH 4350: Geometry I**
Credits: 3. Contact Hours: Lecture 3.
*Prereq: (COMS 2300 or CPRE 3100 or MATH 2010); (MATH 2070 or* MATH 3170*)*
Euclidean geometry of triangles, circles, and parallelograms, studied from several points of view, chosen from: synthetic, analytic, axiomatic, transformational, complex numbers, or vector methods. Possible and impossible constructions with compass and straightedge. (Typically Offered: Fall)

**MATH 4360: Geometry II**
Credits: 3. Contact Hours: Lecture 3.
*Prereq: (COMS 2300 or CPRE 3100 or MATH 2010); (MATH 2070 or* MATH 3170*)*
Foundations of Euclidean geometry and the axiomatic method, including the use of models. The history, logical consistency, and basic theorems of non-Euclidean geometries, such as hyperbolic, elliptic, and projective geometry. (Typically Offered: Spring)

**MATH 4410: Life Contingencies I**
Credits: 3. Contact Hours: Lecture 3.
*Prereq:* MATH 2400*, credit or coenrollment in* MATH 2650
Topics in life insurance for the Actuarial Sciences I: single life annuities, benefits premiums and reserves. (Typically Offered: Fall)

**MATH 4420: Life Contingencies II**
Credits: 3. Contact Hours: Lecture 3.
*Prereq:* MATH 4410
Topics in life insurance for the Actuarial Sciences II: multiple life functions, multiple decrement models, pension plan valuation, insurance models, applications. (Typically Offered: Spring)

**MATH 4690: Introduction to Discrete Mathematics**
(Dual-listed with MATH 5690).
Credits: 3. Contact Hours: Lecture 3.
*Prereq: MATH 2070 or MATH 3170; and MATH 3040 or* MATH 3140
Combinatorial counting, double-counting, generating functions, graph structure, planar graphs, probabilistic proofs, points in general positions, polytopes, Farkas lemma, linear programming and duality. (Typically Offered: Spring)

**MATH 4810: Numerical Methods for Differential Equations**
(Cross-listed with COMS 4810).
Credits: 3. Contact Hours: Lecture 3.
*Prereq:* MATH 2650 *and one of* MATH 2660*,* MATH 2670
First order Euler method, high order Runge-Kutta methods, and multistep methods for solving ordinary differential equations. Finite difference and finite element methods for solving partial differential equations. Local truncation error, stability, and convergence for finite difference method. Numerical solution space, polynomial approximation, and error estimate for finite element method. Computer programming required. (Typically Offered: Spring)

**MATH 4900: Independent Study**
Credits: 1-3. Repeatable, maximum of 9 credits.
*Prereq: Instructor Permission for Course*
Graduation Restriction: No more than 9 credits of MATH 4900 or MATH 4900H may be counted toward graduation.

**MATH 4900H: Independent Study: Honors**
Credits: 1-3. Repeatable, maximum of 9 credits.
*Prereq: Instructor Permission for Course*
Graduation Restriction: No more than 9 credits of MATH 4900 or MATH 4900H may be counted toward graduation.

**MATH 4910: Undergraduate Thesis**
Credits: 2-3.
Writing and presenting a formal mathematics paper. Upon approval by the department, the paper will satisfy the departmental advanced English requirement.

**MATH 4920: Undergraduate Seminar**
Credits: 2. Contact Hours: Lecture 2.
*Prereq:* MATH 3170 *or* MATH 4070
Introduction to independent mathematical thought, with emphasis on oral communication of an advanced topic. Seminar content varies. (Typically Offered: Fall, Spring)

**MATH 4950: Special Topics**
Credits: 1-30. Contact Hours: Lecture 30.
Repeatable, maximum of 9 credits.
*Prereq: Instructor Permission for Course*
Topics of current interest.

**MATH 4970: Teaching Secondary School Mathematics**
(Cross-listed with EDUC 4970).
Credits: 3. Contact Hours: Lecture 3.
Develop an understanding of instructional planning, lesson implementation, and assessment in grades 5-12 mathematics, with a focus on reform-based mathematics, equity, and conceptual understanding. (Typically Offered: Fall)

**Courses primarily for graduate students, open to qualified undergraduates:**

**MATH 5010: Introduction to Real Analysis**
Credits: 3. Contact Hours: Lecture 3.
A development of the real numbers. Study of metric spaces, completeness, compactness, sequences, and continuity of functions. Differentiation and integration of real-valued functions, sequences of functions, limits and convergence, equicontinuity. (Typically Offered: Fall)

**MATH 5020: Topology**
Credits: 3. Contact Hours: Lecture 3.
Introduction to general topology. Topological spaces, continuous functions, connectedness, compactness. Topics selected from countability and separation axioms, metrization, and complete metric spaces. Topics in algebraic topology. (Typically Offered: Spring)

**MATH 5030: Intermediate Abstract Algebra**
(Dual-listed with MATH 4030).
Credits: 3. Contact Hours: Lecture 3.
Properties of groups and rings, subgroups, ideals, and quotients, homomorphisms, structure theory for finite groups. PIDs, UFDs, and Euclidean Domains. Field extensions and finite fields. Selected applications. (Typically Offered: Spring)

**MATH 5040: Abstract Algebra I**
Credits: 3. Contact Hours: Lecture 3.
Algebraic systems and their morphisms, with emphasis on groups and rings. (Typically Offered: Fall)

**MATH 5050: Abstract Algebra II**
Credits: 3. Contact Hours: Lecture 3.
Continuation of MATH 5040. Algebraic systems and their morphisms, with emphasis on modules and fields. (Typically Offered: Spring)

**MATH 5070: Applied Linear Algebra**
(Dual-listed with MATH 4070).
Credits: 3. Contact Hours: Lecture 3.
Advanced topics in applied linear algebra including eigenvalues, eigenvalue localization, singular value decomposition, symmetric and Hermitian matrices, nonnegative and stochastic matrices, matrix norms, canonical forms, matrix functions. Applications to mathematical and physical sciences, engineering, and other fields. (Typically Offered: Fall)

**MATH 5100: Linear Algebra**
Credits: 3. Contact Hours: Lecture 3.
Advanced topics in linear algebra including canonical forms; unitary, normal, Hermitian and positive-definite matrices; variational characterizations of eigenvalues. (Typically Offered: Spring)

**MATH 5110: Functions of a Single Complex Variable**
Credits: 3. Contact Hours: Lecture 3.
Theory of analytic functions, integration, topology of the extended complex plane, singularities and residue theory, maximum principle, conformal mapping, meromorphic functions, argument principle. (Typically Offered: Spring)

**MATH 5150: Real Analysis I**
Credits: 3. Contact Hours: Lecture 3.
Lebesgue measure and Lebesgue integral, one variable differentiation theory, Fubini and Tonelli theorems in R^n, Lp spaces. (Typically Offered: Fall)

**MATH 5160: Real Analysis II**
Credits: 3. Contact Hours: Lecture 3.
Metric spaces, topological spaces, compactness, abstract theory of measure and integral, differentiation of measures, Banach spaces. (Typically Offered: Spring)

**MATH 5170: Finite Difference Methods**
Credits: 3. Contact Hours: Lecture 3.
Finite difference methods for partial differential equations. Methods for elliptic equations; explicit and implicit methods for parabolic and hyperbolic equations; stability, accuracy, and convergence theory, including von Neumann analysis, modified equations, and the Courant-Friedrichs-Lewy condition. (Typically Offered: Spring)

**MATH 5180: Mathematical Modeling and Differential Equations**
Credits: 3. Contact Hours: Lecture 3.
Basic theory of ordinary differential equations, existence and uniqueness theorems, linear systems, linearization and stability, mathematical models in biology and physics, modeling with ordinary and partial differential equations, dynamical systems techniques. (Typically Offered: Spring)

**MATH 5190: Methods of Applied Mathematics I**
Credits: 3. Contact Hours: Lecture 3.
Techniques of classical and functional analysis with applications to differential equations and integral equations. Vector spaces, metric spaces, Hilbert and Banach spaces, Sobolev spaces and other function spaces, contraction mapping theorem, distributions, Fourier series and Fourier transform. (Typically Offered: Fall)

**MATH 5200: Methods of Applied Mathematics II**
Credits: 3. Contact Hours: Lecture 3.
Continuation of MATH 5190. Linear operators, spectral theory of differential and integral operators, Green's functions and boundary value problems, weak solutions of partial differential equations and variational methods, calculus in Banach spaces and applications. (Typically Offered: Spring)

**MATH 5220X: Mathematical Principles of Data Science**
Credits: 3. Contact Hours: Lecture 3.
Mathematical foundations of algorithms in data science. Topics include Riemann-Stieltjes integration, Riesz-Markov theorem, Stone-Weierstrass theorem, Universal Approximation theorem, reproducing kernel Hilbert spaces, Cauchy and Fourier kernels, convergence of clustering algorithms, and topological persistence. (Typically Offered: Spring)

**MATH 5230: Mathematical Modeling in Biology**
(Cross-listed with BCB 5230/ BCBIO 5230).
Credits: 3. Contact Hours: Lecture 3.
*Prereq:* MATH 2660 *or* MATH 2670 *or Graduate Classification*
Introduction to mathematical techniques for modeling and simulation, parameter identification, and analysis of biological systems. Applications drawn from many branches of biology and medicine. Apply differential equations, difference equations, and dynamical systems theory to a wide array of biological problems. MATH 2650 or equivalent recommended. (Typically Offered: Fall)

**MATH 5250: Numerical Analysis of High Performance Computing**
(Cross-listed with COMS 5250/ CPRE 5250).
Credits: 3. Contact Hours: Lecture 3.
Introduction to parallelization techniques and numerical methods for distributed memory high performance computers. A semester project in an area related to each student's research interests is required. (Typically Offered: Spring)

**MATH 5330: Cryptography**
(Cross-listed with CYBSC 5330/ CPRE 5330).
Credits: 3. Contact Hours: Lecture 3.
Basic concepts of secure communication, DES and AES, public-key cryptosystems, elliptic curves, hash algorithms, digital signatures, applications. Relevant material on number theory and finite fields. (Typically Offered: Spring)

**MATH 5350: Steganography and Digital Image Forensics**
(Cross-listed with CPRE 5350/ CYBSC 5350).
Credits: 3. Contact Hours: Lecture 3.
Basic principles of covert communication, steganalysis, and forensic analysis for digital images. Steganographic security and capacity, matrix embedding, blind attacks, image forensic detection and device identification techniques. Related material on coding theory, statistics, image processing, pattern recognition. (Typically Offered: Spring)

**MATH 5540: Stochastic Process Models**
(Cross-listed with STAT 5540).
Credits: 3. Contact Hours: Lecture 3.
Markov chains on discrete spaces in discrete and continuous time (random walks, Poisson processes, birth and death processes) and their long-term behavior. Optional topics may include branching processes, renewal theory, introduction to Brownian motion. (Typically Offered: Fall)

**MATH 5570: Ordinary Differential Equations and Dynamical Systems**
Credits: 3. Contact Hours: Lecture 3.
The initial-value problem, existence and uniqueness theorems, continuous dependence on parameters, linear systems, stability and asymptotic behavior of solutions, linearization, dynamical systems, bifurcations, and chaotic behavior. Offered irregularly. (Typically Offered: Fall)

**MATH 5610: Numerical Analysis I**
Credits: 3. Contact Hours: Lecture 3.
Approximation theory, including polynomial interpolation, spline interpolation and best approximation; numerical differentiation and integration; numerical methods for ordinary differential equations. (Typically Offered: Fall)

**MATH 5620: Numerical Analysis II**
Credits: 3. Contact Hours: Lecture 3.
Numerical linear algebra including LU factorization, QR factorization, linear least squares, singular value decomposition, eigenvalue problems, and iterative methods for large linear systems. (Typically Offered: Spring)

**MATH 5650: Continuous Optimization**
Credits: 3. Contact Hours: Lecture 3.
Theory and methods for constrained and unconstrained optimization. Steepest-descent, conjugate gradient, Newton and quasi-Newton, line search and trust-region, first and second order necessary and sufficient conditions, linear, quadratic and general nonlinear programming. (Typically Offered: Spring)

**MATH 5660: Discrete Optimization**
Credits: 3. Contact Hours: Lecture 3.
Algorithms for linear programming, integer and combinatorial optimization. Linear programming, duality theory, simplex algorithm; the solution of the shortest-path, minimum spanning tree, max-flow/min-cut, minimum cost flow, maximum matching, and traveling salesman problems; integer linear programming, branch-and-bound, local and global search algorithms; matroids and greedy algorithms. (Typically Offered: Fall)

**MATH 5670: Graph Theory**
Credits: 3. Contact Hours: Lecture 3.
Structural theory of graphs. Topics include basic structures (trees, paths, cycles and matchings), networks, colorings, connectivity, topological graph theory, Ramsey and Turan theory, spectral graph theory, introduction to probabilistic methods. (Typically Offered: Fall)

**MATH 5680: Enumerative Combinatorics and Ordered Sets**
Credits: 3. Contact Hours: Lecture 3.
Enumeration methods. Generating functions and sieve methods. Partially ordered sets, lattices, and Moebius inversion. Extremal set theory. (Typically Offered: Spring)

**MATH 5690: Introduction to Discrete Mathematics**
(Dual-listed with MATH 4690).
Credits: 3. Contact Hours: Lecture 3.
*Prereq: (*MATH 2070 *or* MATH 3170*) and (*MATH 3040 *or* MATH 3140*) or Graduate Classification*
Combinatorial counting, double-counting, generating functions, graph structure, planar graphs, probabilistic proofs, points in general positions, polytopes, Farkas lemma, linear programming and duality. (Typically Offered: Spring)

**MATH 5770: Linear Systems**
(Cross-listed with AERE 5770/ ME 5770/ EE 5770).
Credits: 3. Contact Hours: Lecture 3.
Linear algebra review. Least square method and singular value decomposition. State space modeling of linear continuous-time systems. Solution of linear systems. Controllability and observability. Canonical description of linear equations. Stability of linear systems. State feedback and pole placements. Observer design for linear systems. (Typically Offered: Fall)

**MATH 5780: Nonlinear Systems**
(Cross-listed with AERE 5780/ ME 5780/ EE 5780).
Credits: 3. Contact Hours: Lecture 3.
Linear vs nonlinear systems. Phase plane analysis. Bifurcation and center manifold theory. Lyapunov stability. Absolute stability of feedback systems. Input-output stability. Passivity theory and feedback linearization. Nonlinear control design techniques. (Typically Offered: Spring)

**MATH 5810: Numerical Methods for Differential Equations**
Credits: 3. Contact Hours: Lecture 3.
First order Euler method, high order Runge-Kutta methods, and multistep methods for solving ordinary differential equations. Finite difference and finite element methods for solving partial differential equations. Local truncation error, stability, and convergence for finite difference method. Numerical solution space, polynomial approximation, and error estimate for finite element method. Computer programming required. (Typically Offered: Spring)

**MATH 5900: Independent Study**
Credits: 1-30. Repeatable.
*Prereq: Instructor Permission for Course*

**MATH 5910: Orientation for Mathematics Graduate Students I**
Credits: 0.5. Contact Hours: Lecture 0.5.
Fall semester orientation seminar. Required for graduate students in Mathematics and Applied Mathematics. Topics include teaching at the university level and communication of mathematics. Offered on a satisfactory-fail basis only. (Typically Offered: Fall)

**MATH 5920: Orientation for Mathematics Graduate Students II**
Credits: 0.5. Contact Hours: Lecture 0.5.
Spring semester orientation seminar. Required for graduate students in Mathematics and Applied Mathematics. Topics include teaching at the university level and communication of mathematics. Offered on a satisfactory-fail basis only. (Typically Offered: Spring)

**MATH 5950: Special Topics**
Credits: 1-30. Repeatable.

**MATH 5990: Creative Component**
Credits: 1-30. Repeatable.
*Prereq: Instructor Permission for Course*

**Courses for graduate students:**

**MATH 6010: Mathematical Logic**
Credits: 3. Contact Hours: Lecture 3.
Model theory of propositional and predicate logic, the Soundness Theorem, the Compactness Theorem, the Goedel-Henkin Completeness Theorem, the Incompleteness Theorem, computability theory. As time permits: modal and temporal logic, set theory (the continuum hypothesis). Emphasis on the relationship between `provable' and `true' and the relationship between `computable' and `definable'. Offered odd-numbered years. (Typically Offered: Fall)

**MATH 6030: Mathematical Logic II**
Credits: 3. Contact Hours: Lecture 3.
Topics in model theory, computability theory, and set theory such as infinitary logic, non-standard models of arithmetic, ultraproducts, and independence results. Offered even-numbered years. (Typically Offered: Spring)

**MATH 6050: Design Theory and Association Schemes**
Credits: 3. Contact Hours: Lecture 3.
Combinatorial designs and algebraic codes. Construction methods including finite fields. Error-correcting codes. Adjacency matrices and algebraic combinatorics. Offered odd-numbered years. (Typically Offered: Spring)

**MATH 6080: Extremal Graph Theory**
Credits: 3. Contact Hours: Lecture 3.
Study of extremal graph problems and methods. Topics include probabilistic methods, generalizations of Turan’s theorem, Szemeredi's regularity lemma, random graph theory. Offered even-numbered years. (Typically Offered: Spring)

**MATH 6100: Seminar**
Credits: 1-30. Contact Hours: Lecture 30.
Repeatable.

**MATH 6170: Category Theory**
Credits: 3. Contact Hours: Lecture 3.
Categories and functors and their applications. Offered even-numbered years. (Typically Offered: Fall)

**MATH 6180: Representation Theory**
Credits: 3. Contact Hours: Lecture 3.
Representations of algebraic structures. Content varies by semester. Offered odd-numbered years. (Typically Offered: Spring)

**MATH 6190: Commutative Algebra**
Credits: 3. Contact Hours: Lecture 3.
Detailed study of commutative rings with applications to number theory and algebraic geometry, including prime ideals, Going Up and Going Down theorems, exact sequences, Ext and Tor, modules of fractions, primary decomposition, rings of integers, dimension theory. Offered odd-numbered years. (Typically Offered: Fall)

**MATH 6200: Lie Algebras and Their Representations**
Credits: 3. Contact Hours: Lecture 3.
Nilpotent and solvable Lie algebras. Root systems and the classification of finite- dimensional complex semi-simple Lie algebras. The universal enveloping algebra. Representation theory including Weyl's theorem, Verma modules, highest weight theory. Offered even-numbered years. (Typically Offered: Fall)

**MATH 6240: Manifolds, Tensors and Differential Geometry**
Credits: 3. Contact Hours: Lecture 3.
Topics selected from: Geometry of curves and surfaces. Manifolds, coordinate systems. Tangent and cotangent vectors, vector fields. Tensors, differential forms, Riemannian metrics. Connections, covariant differentiation, curvature tensors. Applications to physics and engineering. Offered odd-numbered years. (Typically Offered: Spring)

**MATH 6310: Harmonic Analysis**
Credits: 3. Contact Hours: Lecture 3.
Fourier Series on an interval, approximate identities and summation, Gibb's phenomenon, Fourier transform on the line, uncertainty principle. Additional topics may include distributions, Hardy-Littlewood maximal function, boundedness of singular integral operators, arithmetic combinatorics, wavelet theory. Offered even-numbered years. (Typically Offered: Fall)

**MATH 6330: Functional Analysis**
Credits: 3. Contact Hours: Lecture 3.
Fundamental theory of normed linear spaces and algebras, such as topology and continuity, duality and spectral theory, emphasizing aspects that provide a framework for the study of the spectrum of an operator, analytic function theory, and modern operator theory. Offered odd-numbered years. (Typically Offered: Fall)

**MATH 6410: Foundations of Probability Theory**
(Cross-listed with STAT 6410).
Credits: 3. Contact Hours: Lecture 3.
*Prereq: MATH 4140 or MATH 5010 or Graduate Classification*
Sequences and set theory; Lebesgue measure, measurable functions. Absolute continuity of functions, integrability and the fundamental theorem of Lebesgue integration. General measure spaces, probability measure, extension theorem and construction of Lebesgue-Stieljes measures on Euclidean spaces. Measurable transformations and random variables, induced measures and probability distributions. General integration and expectation, Lp-spaces and integral inequalities. Uniform integrability and absolutecontinuity of measures. Probability densities and the Radon-Nikodym theorem. Product spaces and Fubini-Tonelli theorems. (Typically Offered: Fall)

**MATH 6420: Advanced Probability Theory**
(Cross-listed with STAT 6420).
Credits: 3. Contact Hours: Lecture 3.
Probability spaces and random variables. Kolmogorov's consistency theorem. Independence, Borel-Cantelli lemmas and Kolmogorov's 0 - 1 Law. Types and characterizations of convergence for random variables. Sums of independent random variables, empirical distributions, weak and strong laws of large numbers. Convergence in distribution and its formulations, tightness, characteristic functions, central limit theorems and Lindeberg-Feller conditions. Conditional probability and expectation, discrete parameter martingales. (Typically Offered: Spring)

**MATH 6450: Advanced Stochastic Processes**
(Cross-listed with STAT 6450).
Credits: 3. Contact Hours: Lecture 3.
Weak convergence. Random walks and Brownian motion. Martingales. Stochastic integration and Ito's Formula. Stochastic differential equations and applications. (Typically Offered: Spring)

**MATH 6460: Mathematical Modeling of Complex Physical Systems**
(Cross-listed with PHYS 6460).
Credits: 3. Contact Hours: Lecture 3.
Modeling of the dynamics of complex systems on multiple scales: Classical and dissipative molecular dynamics, stochastic modeling and Monte-Carlo simulation; coarse grained nonlinear dynamics, interface propagation and spatial pattern formation. (Typically Offered: Spring)

**MATH 6550: Partial Differential Equations I**
Credits: 3. Contact Hours: Lecture 3.
Study of model problems of elliptic, parabolic and hyperbolic types, first order equations, conservation laws, transform methods, introduction to linear partial differential equations of arbitrary order, fundamental solutions. (Typically Offered: Fall)

**MATH 6560: Partial Differential Equations II**
Credits: 3. Contact Hours: Lecture 3.
Sobolev spaces, general theory of second order linear elliptic, parabolic and hyperbolic partial differential equations, first order linear hyperbolic systems, variational methods, fixed point methods. (Typically Offered: Spring)

**MATH 6660: Finite Element Methods**
Credits: 3. Contact Hours: Lecture 3.
Weak and variational formulations of elliptic problems; weak derivatives and Sobolev spaces; Lax-Milgram theorem, Bramble-Hilbert lemma; examples of finite element spaces; polynomial approximation theory; error estimates for finite element methods; implementation issues; mixed finite element methods for Stokes problems; applications. Offered even-numbered years. (Typically Offered: Fall)

**MATH 6670: Computational Methods for Hyperbolic Partial Differential Equations (PDE)**
Credits: 3. Contact Hours: Lecture 3.
Mathematical theory of weak/entropy solutions of nonlinear hyperbolic conservation laws; shock speed and Riemann problems; numerical methods for scalar equations and systems including Euler equations; conservative methods; approximate Riemann solvers; total variation stability; DG method. Offered odd-numbered years. (Typically Offered: Fall)

**MATH 6800A: Advanced Topics: Algebra**
Credits: 3. Contact Hours: Lecture 3.
Repeatable.

**MATH 6800B: Advanced Topics: Analysis**
Credits: 3. Contact Hours: Lecture 3.
Repeatable.

**MATH 6800C: Advanced Topics: Applied Mathematics**
Credits: 3. Contact Hours: Lecture 3.
Repeatable.

**MATH 6800D: Advanced Topics: Combinatorics**
Credits: 3. Contact Hours: Lecture 3.
Repeatable.

**MATH 6800E: Advanced Topics: Differential Equations**
Credits: 3. Contact Hours: Lecture 3.
Repeatable.

**MATH 6800F: Advanced Topics: Linear Algebra**
Credits: 3. Contact Hours: Lecture 3.
Repeatable.

**MATH 6800G: Advanced Topics: Logic and Foundations**
Credits: 3. Contact Hours: Lecture 3.
Repeatable.

**MATH 6800H: Advanced Topics: Number Theory**
Credits: 3. Contact Hours: Lecture 3.
Repeatable.

**MATH 6800I: Advanced Topics: Numerical Analysis**
Credits: 3. Contact Hours: Lecture 3.
Repeatable.

**MATH 6800J: Advanced Topics: Optimization**
Credits: 3. Contact Hours: Lecture 3.
Repeatable.

**MATH 6800K: Advanced Topics: Probability**
Credits: 3. Contact Hours: Lecture 3.
Repeatable.

**MATH 6800L: Advanced Topics: Topology**
Credits: 3. Contact Hours: Lecture 3.
Repeatable.

**MATH 6990: Research**
Credits: 1-30. Repeatable.
*Prereq: Instructor Permission for Course*