Mathematics

Undergraduate Study

For the undergraduate curriculum in liberal arts and sciences, major in mathematics, leading to the degree bachelor of science, see Liberal Arts and Sciences, Curriculum.

The program in mathematics offers training suitable for students planning to enter secondary school teaching, to work in mathematics and computation for industry or government, or to continue their studies in graduate school. Students may satisfy the major requirements in several ways, suitable for various career objectives. Graduates can construct rigorous arguments to demonstrate mathematical facts. They can communicate their mathematical methods to others and can justify their assumptions. The traditional program of study for mathematics majors gives students a thorough grounding in mathematics. Graduates understand a broad range of mathematical topics and are familiar with a broad range of mathematical models. They have skills for solving problems in diverse situations. The program allows flexibility for specialization, and students are encouraged to steer their education according to career objectives. This traditional program of study requires:

MATH 101	Orientation in Mathematics	1
MATH 165	Calculus I	4
MATH 166	Calculus II	4
MATH 201	Introduction to Proofs	3
MATH 265	Calculus III	4
MATH 317	Theory of Linear Algebra	3-4
or MATH 407	Applied Linear Algebra	
MATH 301	Abstract Algebra I	3
MATH 414	Analysis I	3
MATH 266	Elementary Differential Equations	3-4
or MATH 267	Elementary Differential Equations and Laplace Transforms	
Mathematics courses at the 300 level or above		15
One of the following:		2
MATH 492	Undergraduate Seminar	
C I 480C	Field Experience for Secondary Teaching Preparation: Mathematics *	
Total Credits		45-47

* C I 480C is available only for students seeking secondary school certification

The courses listed above must include one of the sequences:

MATH 301 & MATH 302	Abstract Algebra I and Abstract Algebra II	6
MATH 414 & MATH 415	Analysis I and Analysis II	6
MATH 435 & MATH 436	Geometry I and Geometry II	6
MATH 373 & MATH 481	Introduction to Scientific Computing and Numerical Methods for Differential Equations and Interpolation	6

Communication Proficiency requirement:

ENGL 150	Critical Thinking and Communication **	3
One of the following:		3
ENGL 250	Written, Oral, Visual, and Electronic Composition **	
ENGL 250H	Written, Oral, Visual, and Electronic Composition: Honors **	
One of the following:		3
MATH 491	Undergraduate Thesis	
ENGL 302	Business Communication	
ENGL 305	Creative Writing--Nonfiction	
ENGL 314	Technical Communication	
JL MC 201	Reporting and Writing for the Mass Media	

** The department requires a grade of C- or better

The department strongly recommends that each student majoring in mathematics include in the program substantial supporting work beyond the minimum general education requirement of the college in one or more areas of application of mathematics, such as other mathematical sciences, engineering, natural science, or social science. In particular, it recommends that each student take:

COM S 207	Fundamentals of Computer Programming	3
COM S 208	Intermediate Computer Programming	3
PHYS 221	Introduction to Classical Physics I	5
PHYS 222	Introduction to Classical Physics II	5
STAT 341	Introduction to the Theory of Probability and Statistics I	3
STAT 342	Introduction to the Theory of Probability and Statistics II	3

It also recommends that students contemplating graduate study in mathematics acquire a reading knowledge of French, German, or Russian.

Credits earned in the following cannot be counted toward graduation by mathematics majors:

MATH 104	Introduction to Probability and Matrices	3
MATH 105	Introduction to Mathematical Ideas	3
MATH 140	College Algebra	3
MATH 141	Trigonometry	2
MATH 142	Trigonometry and Analytic Geometry	3
MATH 150	Discrete Mathematics for Business and Social Sciences	3
MATH 151	Calculus for Business and Social Sciences	3
MATH 160	Survey of Calculus	4
MATH 181	Calculus and Mathematical Modeling for the Life Sciences I	4
MATH 182	Calculus and Mathematical Modeling for the Life Sciences II	4
MATH 195	Mathematics for Elementary Education I	3
MATH 196	Mathematics for Elementary Education II	3

The Mathematics Plus option is for students who wish to establish a clear strength in a field of application of mathematics. They obtain the mathematics major by pursuing study of mathematics, through the upper division level, complementary to their application area. This program makes double majors more feasible and is appropriate for students who plan on employment or graduate study in the application field. It is not intended for students who plan on graduate study in mathematics. For more information, see the mathematics department web site or consult an adviser in mathematics.

Minor in Mathematics

MATH 201	Introduction to Proofs	3
MATH 265	Calculus III	4
MATH 301	Abstract Algebra I	3
One of the following		
MATH 266	Elementary Differential Equations	3
MATH 267	Elementary Differential Equations and Laplace Transforms	4
One of the following		
MATH 317	Theory of Linear Algebra	4
MATH 407	Applied Linear Algebra	3

Graduate Study

The department offers programs leading to a master of science or doctor of philosophy degree in mathematics or applied mathematics, as well as minor work for students whose major is in another department. The department also offers a program leading to the degree of master of school mathematics (M.S.M.).

Students desiring to undertake graduate work leading to the M.S. or Ph.D. degree should have at least 12 semester credits of work in mathematics beyond calculus. It is desirable that these credits include advanced calculus and abstract algebra.

The M.S. degree requires at least 30 credits and students must write a creative component or thesis and pass a comprehensive oral examination over their coursework and their creative component or thesis. See the department handbook for specific requirements.

The Ph.D. degree requires a student to take 48 hours of coursework in addition to research hours, pass written qualifying examinations, pass an oral preliminary exam, and perform an original research project culminating in a dissertation

which is defended by an oral exam. Ph.D. candidates must have at least one year of supervised teaching experience. See the on-line Mathematics Graduate Handbook for specific requirements.

The M.S.M. degree is primarily for inservice secondary mathematics teachers. Students desiring to pursue the M.S.M degree should present some undergraduate work in mathematics beyond calculus. Candidates for the M.S.M. degree must write an approved creative component and pass a comprehensive oral examination over their course work and their creative component.

Courses primarily for undergraduates:

MATH 010. High School Algebra.
(4-0) Cr. arr. F.S.SS.
For students who do not have adequate facility with topics from high school algebra or do not meet the algebra admission requirement. The course is divided into tracks of one- and two-semester lengths. For most students a diagnostic exam will determine which track must be taken. Students will receive a grade in MATH 25 or MATH 30 respectively depending on the level of material covered. Satisfactory completion of MATH 30 is recommended for students planning to take MATH 140 or MATH 151, while MATH 25 is sufficient for MATH 104, MATH 105, MATH 150, MATH 195, STAT 101 or STAT 105. Students must complete MATH 30 to remove a deficiency in the algebra admission requirement. Topics include signed numbers, polynomials, rational and radical expressions, exponential and logarithmic expressions, and equations. Offered on a satisfactory-fail basis only.

MATH 025. High School Algebra.
(4-0) Cr. arr. F.S.SS.
Students should initially enroll in MATH 10. See description of MATH 10. Offered on a satisfactory-fail basis only.

MATH 030. High School Algebra.
(4-0) Cr. arr. F.S.SS.
Students should initially enroll in MATH 10. See description of MATH 10. Offered on a satisfactory-fail basis only.

MATH 101. Orientation in Mathematics.
(1-0) Cr. 1. F.S.
For new majors. Academic policies and procedures. Campus resources and opportunities available to students. Careers and programs of study in mathematics. Mathematical reasoning, culture and resources. Description of main branches of mathematics. Offered on a satisfactory-fail basis only.

MATH 104. Introduction to Probability and Matrices.
(3-0) Cr. 3. F.S. *Prereq: Satisfactory performance on placement exam, 2 years of high school algebra, 1 year of high school geometry*
Permutations, combinations, probability, binomial and multinomial theorems, matrices, expected value. Either MATH 104 or MATH 150 may be counted toward graduation, but not both.

MATH 105. Introduction to Mathematical Ideas.
(3-0) Cr. 3. F.S. *Prereq: Satisfactory performance on placement exam, 2 years of high school algebra, 1 year of high school geometry*
Topics from mathematics and mathematical applications with emphasis on their nontechnical content.

MATH 140. College Algebra.
(3-1) Cr. 3. F.S.SS. *Prereq: Satisfactory performance on placement exam, 2 years of high school algebra; 1 year of high school geometry*
Coordinate geometry, quadratic and polynomial equations, functions, graphing, rational functions, exponential and logarithmic functions, inverse functions, quadratic inequalities. Students in the College of Liberal Arts and Sciences may not count MATH 140, MATH 141, MATH 142, or MATH 195 toward Group III of the General Education Requirements.

MATH 141. Trigonometry.
(2-0) Cr. 2. F.S.SS. *Prereq: Satisfactory performance on placement exam, 2 years of high school algebra; 1 year of high school geometry, or enrollment in MATH 140*
May be taken concurrently with MATH 140. Trigonometric functions and their inverses, solving triangles, trigonometric identities and equations, graphing. Students in the College of Liberal Arts and Sciences may not count MATH 140, MATH 141, MATH 142, or MATH 195 toward Group III of the General Education Requirements. Only one of MATH 141, MATH 142 may count toward graduation.

MATH 142. Trigonometry and Analytic Geometry.
(2-1) Cr. 3. F.S.SS. *Prereq: Satisfactory performance on placement exam, 2 years of high school algebra, 1 year of high school geometry, or enrollment in MATH 140*
May be taken concurrently with MATH 140. Trigonometric functions and their inverses, solving triangles, trigonometric identities and equations, graphing, polar coordinates, complex numbers, conic sections, parametric equations. Students in the College of Liberal Arts and Sciences may not count MATH 140, MATH 141, MATH 142, or MATH 195 toward Group III of the General Education Requirements. Only one of MATH 141, MATH 142 may count toward graduation.

MATH 150. Discrete Mathematics for Business and Social Sciences.
(2-1) Cr. 3. F.S.SS. *Prereq: Satisfactory performance on placement exam, 2 years of high school algebra, 1 year of high school geometry*
Linear equations and inequalities, matrix algebra, linear programming, discrete probability. Either MATH 104 or MATH 150 may be counted toward graduation, but not both.

MATH 151. Calculus for Business and Social Sciences.
(2-1) Cr. 3. F.S.SS. *Prereq: Satisfactory performance on placement exam, 2 years of high school algebra, 1 year of high school geometry*
Differential calculus, applications to max-min problems, integral calculus and applications. Will not serve as prerequisite for MATH 265 or MATH 266. Only one of MATH 151, MATH 160, the sequence MATH 165-MATH 166, or the sequence MATH 181-MATH 182 may be counted towards graduation.

MATH 160. Survey of Calculus.
(4-0) Cr. 4. F.S. *Prereq: Satisfactory performance on placement exam, 2 years of high school algebra, 1 year of geometry*
Analytic geometry, derivatives and integrals of elementary functions, partial derivatives, and applications. Will not serve as a prerequisite for MATH 265 or MATH 266. Only one of MATH 151, MATH 160, the sequence MATH 165-MATH 166, or the sequence MATH 181-MATH 182 may be counted towards graduation.

MATH 165. Calculus I.
(4-0) Cr. 4. F.S.SS. *Prereq: Satisfactory performance on placement exam, 2 years of high school algebra, 1 year of geometry, 1 semester of trigonometry or enrollment in MATH 141 or MATH 142*
Differential calculus, applications of the derivative, introduction to integral calculus. Only one of Math 151 or 160 or the sequence MATH 165-MATH 166, or the sequence MATH 181-MATH 182 may be counted towards graduation.

MATH 166. Calculus II.
(4-0) Cr. 4. F.S.SS. *Prereq: Grade of C- or better in MATH 165 or high math placement scores*
Integral calculus, applications of the integral, infinite series. Only one of MATH 151, MATH 160, the sequence MATH 165-MATH 166, or the sequence MATH 181-MATH 182 may be counted towards graduation.

MATH 166H. Calculus II, Honors.
(4-0) Cr. 4. F. *Prereq: Permission of instructor and MATH 165 or high math placement scores*
Integral calculus, applications of the integral, infinite series. Additional material of a theoretical, conceptual, computational, or modeling nature. Some of the work may require more ingenuity than is required for MATH 166. Preference will be given to students in the University Honors Program. Only one of MATH 151 or MATH 160, the sequence MATH 165-MATH 166, or the sequence MATH 181-MATH 182 may be counted towards graduation.

MATH 181. Calculus and Mathematical Modeling for the Life Sciences I.
(4-0) Cr. 4. F.S. *Prereq: Satisfactory performance on placement exam, 2 years of high school algebra, 1 year of high school geometry, 1 semester of trigonometry or enrollment in MATH 141 or MATH 142*
Exponential and logarithm functions, difference equations, derivatives, and applications of the derivative. Examples taken from biology. Only one of MATH 151, MATH 160, the sequence MATH 165- MATH 166, or the sequence MATH 181-MATH 182 may be counted towards graduation.

MATH 182. Calculus and Mathematical Modeling for the Life Sciences II.
(4-0) Cr. 4. S. *Prereq: MATH 181*
Integration, first and second order differential equations, applications of the definite integral, introduction to multivariable calculus. Examples taken from biology. Only one of MATH 151, MATH 160, the sequence MATH 165-MATH 166, or the sequence MATH 181-MATH 182 may be counted towards graduation.

MATH 195. Mathematics for Elementary Education I.
(2-2) Cr. 3. F.S. *Prereq: Satisfactory performance on placement exam, 2 years high school algebra, 1 year of high school geometry, enrollment in elementary education or early childhood education*
Theoretical and hands-on models, mathematical analysis of: elementary students? thinking, standard and non-standard algorithms, and properties related to whole numbers and whole number operations; linear measurement, and two- and three-dimensional geometric shapes and spatial sense; algebra as it relates to elementary curricula. Students in the College of Liberal Arts and Sciences may not count MATH 140, MATH 141, MATH 142, or MATH 195 toward Group III of the General Education Requirements.

MATH 196. Mathematics for Elementary Education II.
(2-2) Cr. 3. F.S. *Prereq: Grade of C- or better in MATH 195 and enrollment in elementary education or early childhood education.*
Two- and three-dimensional measurement; probability, statistics, algebra as it relates to elementary curricula; theoretical and hands-on models, mathematical analysis of: elementary students' thinking, standard and non-standard algorithms, and properties related to integer, fraction, and decimal operations.

MATH 201. Introduction to Proofs.
(3-0) Cr. 3. F.S. *Prereq: MATH 166 or MATH 166H*
Logic and techniques of proof including induction. Communicating mathematics. Writing proofs about sets, functions, real numbers, limits, sequences, infinite series and continuous functions.

MATH 207. Matrices and Linear Algebra.
(3-0) Cr. 3. F.S.SS. *Prereq: 2 semesters of calculus*
Systems of linear equations, determinants, vector spaces, linear transformations, orthogonality, least-squares methods, eigenvalues and eigenvectors. Emphasis on methods and techniques. Only one of MATH 207, MATH 307, MATH 317 may be counted toward graduation.

MATH 265. Calculus III.
(4-0) Cr. 4. F.S.SS. *Prereq: Grade of C- or better in MATH 166 or MATH 166H*
Analytic geometry and vectors, differential calculus of functions of several variables, multiple integrals, vector calculus.

MATH 265H. Calculus III, Honors.
(4-0) Cr. 4. F.S. *Prereq: Permission of the instructor; and MATH 166 or MATH 166H*
Analytic geometry and vectors, differential calculus of functions of several variables, multiple integrals, 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 265. Preference will be given to students in the University Honors Program.

MATH 266. Elementary Differential Equations.
(3-0) Cr. 3. F.S.SS. *Prereq: Grade of C- or better in MATH 166 or MATH 166H*
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.

MATH 267. Elementary Differential Equations and Laplace Transforms.
(4-0) Cr. 4. F.S.SS. *Prereq: Grade of C- or better in MATH 166 or MATH 166H*
Same as MATH 266 but also including Laplace transforms and series solutions to ordinary differential equations.

MATH 268. Laplace Transforms.
(1-0) Cr. 1. S. *Prereq: MATH 266*
Laplace transforms and series solutions to ordinary differential equations. Together, MATH 266 and MATH 268 are the same as MATH 267.

MATH 290. Independent Study.
Cr. 1-3. Repeatable.

MATH 290H. Independent Study, Honors.
Cr. 1-3. Repeatable.

MATH 297. Intermediate Topics for School Mathematics.
(2-2) Cr. 3. F. *Prereq: Enrollment in elementary education and grade of C- or better in MATH 196*
Mathematical reasoning, data fitting, and topics in Euclidean and non-Euclidean geometry. Discrete mathematics topics selected from graphs, networks, recurrence relations, probability, Markov chains. Use of technology to learn and teach mathematics.

MATH 298. Cooperative Education.
Cr. R. Repeatable, maximum of 2 times. F.S.SS. *Prereq: Permission of the department cooperative education coordinator; sophomore classification*
Required of all cooperative education students. Students must register for this course prior to commencing each work period.

MATH 301. Abstract Algebra I.
(3-0) Cr. 3. F.S. *Prereq: MATH 166 or MATH 166H, MATH 317 or MATH 407, and grade of C- or better in MATH 201*
Theory of groups. Homomorphisms. Quotient groups. Introduction to rings. Emphasis on writing proofs. Nonmajor graduate credit.

MATH 302. Abstract Algebra II.
(3-0) Cr. 3. S. *Prereq: MATH 301*
Theory of rings and fields. Introduction to Galois theory. Emphasis on writing proofs. Nonmajor graduate credit.

MATH 304. Introductory Combinatorics.
(3-0) Cr. 3. F. *Prereq: MATH 166 or MATH 166H; grade of C- or better in MATH 201 or experience with proofs; MATH 207 or MATH 317*
Permutations, combinations, binomial coefficients, inclusion-exclusion principle, recurrence relations, generating functions. Additional topics selected from probability, random walks, and Markov chains. Nonmajor graduate credit.

MATH 314. Graphs and Networks.
(3-0) Cr. 3. S. *Prereq: MATH 166 or MATH 166H; MATH 201 or experience with proofs*
Structure and extremal properties of graphs. Topics are selected from: trees, networks, colorings, paths and cycles, connectivity, planarity, Ramsey theory, forbidden structures, enumeration, applications. Nonmajor graduate credit.

MATH 317. Theory of Linear Algebra.
(4-0) Cr. 4. F.S. *Prereq: MATH 166; credit or enrollment in MATH 201*
Systems of linear equations, determinants, vector spaces, inner product spaces, linear transformations, eigenvalues and eigenvectors. Emphasis on writing proofs and results. Nonmajor graduate credit. Only one of MATH 207, MATH 307, MATH 317 may be counted toward graduation.

MATH 331. Topology.
(3-0) Cr. 3. *Prereq: MATH 317 or MATH 407*
Topological properties of metric spaces, including Euclidean n-space, continuous functions, homeomorphisms, and topological invariants. Examples from surfaces, knots, links, and three-dimensional manifolds. Nonmajor graduate credit.

MATH 341. Introduction to the Theory of Probability and Statistics I.
(Cross-listed with STAT). (3-0) Cr. 3. F.S. *Prereq: MATH 265 (or MATH 265H)*
Probability; distribution functions and their properties; classical discrete and continuous distribution functions; multivariate probability distributions and their properties; moment generating functions; simulation of random variables and use of the R statistical package. Credit for both Stat 341 and 447 may not be applied toward graduation.

MATH 342. Introduction to the Theory of Probability and Statistics II.
(Cross-listed with STAT). (3-0) Cr. 3. F.S. *Prereq: STAT 341; MATH 307 or MATH 317*
Transformations of random variables; sampling distributions; confidence intervals and hypothesis testing; theory of estimation and hypothesis tests; linear model theory; use of the R statistical package for simulation and data analysis.

MATH 350. Number Theory.
(Cross-listed with COM S). (3-0) Cr. 3. S. *Prereq: MATH 166*
Divisibility, integer representations, primes and divisors, linear diophantine equations, congruences, and multiplicative functions. Applications to cryptography. Nonmajor graduate credit.

MATH 365. Complex Variables with Applications.
(3-0) Cr. 3. S. *Prereq: MATH 265*
Functions of a complex variable, including differentiation, integration and series expansions, residues, evaluation of integrals, conformal mapping. Nonmajor graduate credit.

MATH 373. Introduction to Scientific Computing.
(3-0) Cr. 3. F. *Prereq: MATH 265*
Vector, matrix, and graphics programming in MATLAB for scientific applications. Polynomial interpolation and approximation. Systems of linear equations and numerical linear algebra. Numerical differentiation and integration. Newton methods 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. Nonmajor graduate credit.

MATH 385. Introduction to Partial Differential Equations.
(3-0) Cr. 3. F.S. *Prereq: MATH 265 and one of MATH 266, MATH 267*
Separation of variables methods for elliptic, parabolic, and hyperbolic partial differential equations. Fourier series, Sturm-Liouville theory, Bessel functions, and spherical harmonics. Nonmajor graduate credit.

MATH 397. Teaching Secondary Mathematics Using University Mathematics.
(2-2) Cr. 3. S. *Prereq: MATH 201, MATH 301*
Coursework in university mathematics including calculus, abstract algebra, discrete mathematics, geometry, and other topics as it relates to teaching mathematics in grades 7-12.

MATH 398. Cooperative Education.
Cr. R. Repeatable, maximum of 2 times. F.S.SS. *Prereq: Permission of the department cooperative education coordinator; junior classification*
Required of all cooperative education students. Students must register for this course prior to commencing each work period.

MATH 407. Applied Linear Algebra.
(Dual-listed with MATH 507). (3-0) Cr. 3. F. *Prereq: MATH 207 or MATH 317*
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 and engineering. Nonmajor graduate credit.

MATH 414. Analysis I.
(3-0) Cr. 3. F.S.SS. *Prereq: grade of C- or better in MATH 201; MATH 265*
Introduction to properties and basic topology of the real numbers. A careful development of calculus of functions of a real variable: limits, continuity, differentiation, integration, series. Nonmajor graduate credit.

MATH 415. Analysis II.
(3-0) Cr. 3. S. *Prereq: MATH 414; and MATH 317 or MATH 407*
Sequences and series of functions of a real variable, uniform convergence, power series and Taylor series, Fourier series, topology of n-dimensional space, implicit function theorem, calculus of the plane and 3-dimensional space. Additional topics may include metric spaces or Stieltjes or Lebesgue integration. Nonmajor graduate credit.

MATH 421. Logic for Mathematics and Computer Science.
(Cross-listed with MATH). (3-0) Cr. 3. S. *Prereq: MATH 301 or MATH 317 or COM S 330*
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. Nonmajor graduate credit.

MATH 435. Geometry I.
(3-0) Cr. 3. F. *Prereq: MATH 307 or MATH 317*
Euclidean geometry. Points, lines, circles, triangles, congruence, similarity, properties invariant under rigid motions. Synthetic, analytic, and axiomatic methods. Nonmajor graduate credit.

MATH 436. Geometry II.
(3-0) Cr. 3. S. *Prereq: MATH 435*
Continuation of Euclidean geometry with topics from elliptic, projective, or hyperbolic geometry. Emphasis on analytic methods. Nonmajor graduate credit.

MATH 439. Mathematics of Fractals and Chaos.
(3-0) Cr. 3. *Prereq: MATH 265*
Iterated function systems; periodic points; algorithms for generation of fractals; fractal dimension; Julia sets and the Mandelbrot set; chaos. Nonmajor graduate credit.

MATH 471. Computational Linear Algebra and Fixed Point Iteration.
(Cross-listed with COM S). (3-0) Cr. 3. Alt. F., offered 2011.S. *Prereq: Math 265 and either Math 266, or 267; knowledge of a programming language*
Computational error, solutions of linear systems, least squares, similarity methods for eigenvalues, solution of nonlinear equations in one and several variables. Nonmajor graduate credit.

MATH 481. Numerical Methods for Differential Equations and Interpolation.
(Cross-listed with COM S). (3-0) Cr. 3. S. *Prereq: MATH 265 and either MATH 266 or MATH 267; knowledge of a programming language*
First order Euler method, high order Runge-Kutta method, and multistep method 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. Nonmajor graduate credit.

MATH 490. Independent Study.
Cr. 1-3. Repeatable, maximum of 9 credits. *Prereq: MATH 301 or MATH 317; 6 credits in mathematics*
No more than 9 credits of Math 490 may be counted toward graduation.

MATH 490H. Independent Study: Honors.
Cr. 1-3. Repeatable, maximum of 9 credits. *Prereq: MATH 301 or MATH 317; 6 credits in mathematics*
No more than 9 credits of Math 490 may be counted toward graduation.

MATH 491. Undergraduate Thesis.
Cr. 2-3.
Writing a formal mathematics paper. Upon approval by the department, the paper will satisfy the departmental advanced English requirement.

MATH 492. Undergraduate Seminar.
(2-0) Cr. 2. S. *Prereq: Consent of instructor*
Introduction to mathematics research, a participating seminar on advanced topics in mathematics. Mathematical literature search, reading a mathematical article with the guidance of the instructor, mathematical presentation. Seminar content varies.

MATH 497. Teaching Secondary School Mathematics.
(Cross-listed with C I). (3-0) Cr. 3. F. *Prereq: 15 credits in college mathematics and admission to a teacher licensure program, concurrent enrollment in C I 426 or C I 526; C I 480C*
Theory and methods for teaching mathematics in grades 7-12. Includes critical examination of instructional strategies, curriculum materials, learning tools, assessment methods, National Standards in Mathematics Education, and equity issues.

MATH 498. Cooperative Education.
Cr. R. Repeatable, maximum of 2 credits. F.S.SS. *Prereq: Permission of the department cooperative education coordinator; senior classification*
Required of all cooperative education students. Students must register for this course prior to commencing each work period.

Courses primarily for graduate students, open to qualified undergraduates:

MATH 501. Introduction to Real Analysis.
(3-0) Cr. 3. F. *Prereq: MATH 265 and (MATH 307 or MATH 317)*
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.

MATH 504. Abstract Algebra I.
(3-0) Cr. 3. F. *Prereq: MATH 302*
Algebraic systems and their morphisms, with emphasis on groups and rings.

MATH 505. Abstract Algebra II.
(3-0) Cr. 3. S. *Prereq: MATH 504*
Continuation of Math 504. Algebraic systems and their morphisms, with emphasis on modules and fields.

MATH 507. Applied Linear Algebra.
(Dual-listed with MATH 407). (3-0) Cr. 3. F. *Prereq: MATH 207 or MATH 317*
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 and engineering. Nonmajor graduate credit.

MATH 510. Linear Algebra.
(3-0) Cr. 3. F. *Prereq: MATH 307 or MATH 317*
Advanced topics in linear algebra including canonical forms; unitary, normal, Hermitian and positive-definite matrices; variational characterizations of eigenvalues.

MATH 511. Functions of a Single Complex Variable.
(3-0) Cr. 3. S. *Prereq: MATH 414 or MATH 501*
Theory of analytic functions, integration, topology of the extended complex plane, singularities and residue theory, maximum principle.

MATH 515. Real Analysis I.
(3-0) Cr. 3. F. *Prereq: MATH 414 or MATH 501*
Lebesgue measure and Lebesgue integral, one variable differentiation theory, product integration, Lp spaces.

MATH 516. Real Analysis II.
(3-0) Cr. 3. S. *Prereq: MATH 515*
Metric spaces, topological spaces, compactness, abstract theory of measure and integral, differentiation of measures, Banach spaces.

MATH 517. Finite Difference Methods.
(3-0) Cr. 3. S. *Prereq: MATH 481 or MATH 561*
Finite difference methods for partial differential equations, with emphasis on parabolic and hyperbolic equations, and other partial differential equations from application areas. Topics include convergence, stability and implementation issues.

MATH 519. Methods of Applied Mathematics I.
(3-0) Cr. 3. F. *Prereq: MATH 414 or MATH 501*
Techniques of classical and functional analysis with applications to partial differential equations, 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, 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.

MATH 520. Methods of Applied Mathematics II.
(3-0) Cr. 3. S. *Prereq: MATH 519*
Continuation of Math 519.

MATH 525. Numerical Analysis of High Performance Computing.
(Cross-listed with COM S, CPR E). (3-0) Cr. 3. Alt. S., offered 2015. *Prereq: CPR E 308 or MATH 481; experience in scientific programming; knowledge of FORTRAN or C*
Introduction to parallelization techniques and numerical methods for state-of-the-art high performance computers. A major component will be a final project in an area related to each student's research interests.

MATH 533. Cryptography.
(Cross-listed with CPR E, INFAS). (3-0) Cr. 3. S. *Prereq: MATH 301 or CPR E 310 or COM S 330*
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.

MATH 535. Steganography and Digital Image Forensics.
(Cross-listed with CPR E, INFAS). (3-0) Cr. 3. S. *Prereq: E E 524 or MATH 307 or COM S 330*
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.

MATH 540. Seminar in Mathematics Education.
(1-0) Cr. 1. SS. *Prereq: Enrollment in the Master of School Mathematics program or professional studies in education*
Research studies in mathematics learning and teaching, exemplary practices in mathematics education, and current state and national trends in the mathematics curriculum in grades K-12. Topics are offered on a 3-year cycle.

MATH 540A. Seminar in Mathematics Education: Assessment, equity, and teaching of statistics..
(1-0) Cr. 1. Alt. SS., offered 2014. *Prereq: Enrollment in the Master of School Mathematics program or professional studies in education*
Research studies in mathematics learning and teaching, exemplary practices in mathematics education, and current state and national trends in the mathematics curriculum in grades K-12. Topics are offered on a 3-year cycle.

MATH 540B. Seminar in Mathematics Education: Geometry and discrete mathematics, and problem solving..
(1-0) Cr. 1. *Prereq: Enrollment in the Master of School Mathematics program or professional studies in education*
Offered on a 3-year cycle--Offered in 2015.Research studies in mathematics learning and teaching, exemplary practices in mathematics education, and current state and national trends in the mathematics curriculum in grades K-12.

MATH 540C. Seminar in Mathematics Education: Teaching of analysis, algebra, and the use of technology..
(1-0) Cr. 1. SS. *Prereq: Enrollment in the Master of School Mathematics program or professional studies in education*
Offered SS 2013, 2016. Research studies in mathematics learning and teaching, exemplary practices in mathematics education, and current state and national trends in the mathematics curriculum in grades K-12. Topics are offered on a 3-year cycle.

MATH 545. Intermediate Calculus.
(4-0) Cr. 4. *Prereq: 3 semesters of calculus and enrollment in the master of school mathematics program*
Offered on a 3-year cycle, offered SS. 2013. Further development of the fundamental concepts of calculus and their applications with an emphasis on a constructivist approach to learning, cooperative groups, problem solving, the use of technology.

MATH 546. Algorithms in Analysis and Their Computer Implementation.
(2-2) Cr. 3. *Prereq: 3 semesters in calculus or concurrent enrollment in 545 and enrollment in the master of school mathematics program*
Offered on a 3- year cycle, offered SS. 2013, 2016. The use of technology in secondary mathematics with an emphasis on the exploration and implementation of algorithms.

MATH 547. Discrete Mathematics and Applications.
(4-0) Cr. 4. *Prereq: Enrollment in the master of school mathematics program*
Offered on a 3-year cycle, offered SS. 2015. Applications of graph theory, game theory, voting methods, recursion, and combinatorics. Issues in integrating discrete topics into the secondary curriculum. Use of the computer to explore discrete mathematics.

MATH 549. Intermediate Geometry.
(3-0) Cr. 3. *Prereq: MATH 435 or equivalent and enrollment in the master of school mathematics program*
Offered on a 3-year cycle, offered SS. 2015. A study of geometry which includes metrics, the group of isometries, and the group of similarities. Specific spaces studied normally include the Euclidean plane, the 2-sphere, projective 2-space, and hyperbolic geometry. Emphasis on analytical methods. Incorporation of geometry software.

MATH 554. Introduction to Stochastic Processes.
(Cross-listed with STAT). (3-0) Cr. 3. F. *Prereq: STAT 542*
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.

MATH 557. Ordinary Differential Equations and Dynamical Systems.
(3-0) Cr. 3. F. *Prereq: MATH 415 or MATH 501*
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.

MATH 561. Numerical Analysis I.
(3-0) Cr. 3. F. *Prereq: MATH 414 or MATH 501*
Approximation theory, including polynomial spline interpolation and best approximation; numerical differentiation and integration; numerical methods for ordinary differential equations.

MATH 562. Numerical Analysis II.
(3-0) Cr. 3. S. *Prereq: MATH 317*
Numerical linear algebra including eigenvalue problems; numerical solution of nonlinear equations and optimization problems.

MATH 565. Continuous Optimization.
(3-0) Cr. 3. S. *Prereq: MATH 265 and one of MATH 317, 507, 510*
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, quadratic and general nonlinear programming.

MATH 566. Discrete Optimization.
(3-0) Cr. 3. F. *Prereq: MATH 317 or MATH 507 or MATH 510*
Algorithms for linear programming, integer and combinatorial optimization. Linear programming, duality theory, simplex algorithm; the solution of the shortest-path, minimal spanning tree, max-flow/min-cut, minimal cost flow, maximum matching, and traveling salesman problems; integer linear programming, branch-and-bound, local and global search algorithms.

MATH 573. Random Signal Analysis and Kalman Filtering.
(Cross-listed with E E, AER E, M E). (3-0) Cr. 3. F. *Prereq: E E 324 or AER E 331 or M E 370 or M E 411 or MATH 341*
Elementary notions of probability. Random processes. Autocorrelation and spectral functions. Estimation of spectrum from finite data. Response of linear systems to random inputs. Discrete and continuous Kalman filter theory and applications. Smoothing and prediction. Linearization of nonlinear dynamics.

MATH 574. Optimal Control.
(Cross-listed with AER E, E E, M E). (3-0) Cr. 3. S. *Prereq: E E 577*
The optimal control problem. Variational approach. Pontryagin's principle, Hamilton-Jacobi equation. Dynamic programming. Time-optimal, minimum fuel, minimum energy control systems. The regulator problem. Structures and properties of optimal controls.

MATH 575. Introduction to Robust Control.
(Cross-listed with E E, AER E, M E). (3-0) Cr. 3. *Prereq: E E 577*
Introduction to modern robust control. Model and signal uncertainty in control systems. Uncertainty description. Stability and performance robustness to uncertainty. Solutions to the H2, Hoo, and l1 control problems. Tools for robustness analysis and synthesis.

MATH 576. Digital Feedback Control Systems.
(Cross-listed with AER E, E E, M E). (3-0) Cr. 3. F. *Prereq: E E 475 or AER E 432 or M E 411 or 414 or MATH 415; and MATH 267*
Sampled data, discrete data, and the z-transform. Design of digital control systems using transform methods: root locus, frequency response and direct design methods. Design using state-space methods. Controllability, observability, pole placement, state estimators. Digital filters in control systems. Microcomputer implementation of digital filters. Finite wordlength effects. Linear quadratic optimal control in digital control systems. Simulation of digital control systems.

MATH 577. Linear Systems.
(Cross-listed with AER E, E E, M E). (3-0) Cr. 3. F. *Prereq: E E 324 or AER E 331 or MATH 415; and MATH 307*
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.

MATH 578. Nonlinear Systems.
(Cross-listed with AER E, E E, M E). (3-0) Cr. 3. S. *Prereq: E E 577*
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.

MATH 590. Independent Study.
Cr. arr. Repeatable.

MATH 591. Orientation for Mathematics Graduate Students I.
(0.5-0) Cr. 0.5. F.
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.

MATH 592. Orientation for Mathematics Graduate Students II.
(0.5-0) Cr. 0.5. S.
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.

MATH 595. Special Topics.
Cr. arr. Repeatable.

MATH 599. Creative Component.
Cr. arr.

Courses for graduate students:

MATH 601. Mathematical Logic I.
(3-0) Cr. 3. Alt. F., offered 2013. *Prereq: MATH 504*
First semester of full-year course. Completeness and compactness of propositional and predicate logic, incompleteness and undecidability of set theory and arithmetic, Goedel's theorems, recursive functions, computability, models, ultraproducts, and ultralimits.

MATH 602. Mathematical Logic II.
(3-0) Cr. 3. Alt. S., offered 2014. *Prereq: MATH 601*
Continuation of MATH 601.

MATH 605. Design Theory and Association Schemes.
(3-0) Cr. 3. Alt. F., offered 2014. *Prereq: MATH 504*
Combinatorial designs and Latin squares. Construction methods including finite fields. Error-correcting codes. Adjacency matrices and algebraic combinatorics.

MATH 606. Enumerative Combinatorics and Ordered Sets.
(3-0) Cr. 3. Alt. S., offered 2015. *Prereq: MATH 504*
Ordered sets and lattices. Generating functions. Moebius inversion and other enumeration methods.

MATH 607. Modern (Structural) Graph Theory.
(3-0) Cr. 3. Alt. F., offered 2013. *Prereq: MATH 504*
Structural and extremal theory of graphs. Topics include basic structures (trees, paths and cycles), networks, colorings, connectivity, topological graph theory, Ramsey theory, forbidden graphs and minors, introduction to random graphs, applications.

MATH 608. Extremal Graph Theory.
(3-0) Cr. 3. Alt. S., offered 2014. *Prereq: Math 607*
Study of extremal graph problems and methods. Topics include Szemeredi's regularity lemma, generalizations of the theorems of Turan and Ramsey, and the theory of random graphs.

MATH 610. Seminar.
Cr. arr.

MATH 615. General Theory of Algebraic Structures I.
(3-0) Cr. 3. Alt. F., offered 2014. *Prereq: MATH 504*
First semester of full-year course. Subalgebras, homomorphisms, congruence relations, and direct products. Lattices and closure operators. Varieties and quasivarieties of algebras, free algebras, Birkhoff's theorems, clones, Mal'cev conditions. Advanced topics.

MATH 616. General Theory of Algebraic Structures II.
(3-0) Cr. 3. Alt. S., offered 2015. *Prereq: MATH 615*
Continuation of MATH 615.

MATH 617. Category Theory.
(3-0) Cr. 3. Alt. F., offered 2013. *Prereq: MATH 504*
Categories and functors and their applications.

MATH 618. Representation Theory.
(3-0) Cr. 3. Alt. S., offered 2014. *Prereq: MATH 504*
Representations of algebraic structures. Content varies by semester.

MATH 621. Topology.
(3-0) Cr. 3. Alt. F., offered 2014. *Prereq: Permission of instructor*
Introduction to general topology. Topological spaces, continuous functions, connectedness, compactness. Topics selected from countability and separation axioms, metrization, and complete metric spaces.

MATH 622. Algebraic Topology.
(3-0) Cr. 3. Alt. S., offered 2015. *Prereq: MATH 504*
Foundations of algebraic topology. The fundamental group, homology groups, relative homology groups, and long exact sequences.

MATH 624. Manifolds, Tensors and Differential Geometry.
(3-0) Cr. 3. Alt. S., offered 2015. *Prereq: MATH 501 or MATH 515*
Topics selected from: Geometry of curves and surfaces. Manifolds, coordinate systems. Tensors, differential forms, Riemannian metrics. Connections, covariant differentiation, curvature tensors.

MATH 633. Functional Analysis I.
(3-0) Cr. 3. Alt. F., offered 2013. *Prereq: MATH 515*
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 boundary-value problems, eigenvalue problems, harmonic analysis, analytic function theory, and modern operator theory.

MATH 634. Functional Analysis II.
(3-0) Cr. 3. Alt. S., offered 2014. *Prereq: MATH 633*
Continuation of MATH 633.

MATH 641. Foundations of Probability Theory.
(Cross-listed with STAT). (3-0) Cr. 3. F. *Prereq: MATH 414 or MATH 501 or equivalent course.*
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 absolute,continuity of measures. Probability densities and the Radon-Nikodym theorem. Product spaces and Fubini-Tonelli theorems.

MATH 642. Advanced Probability Theory.
(Cross-listed with STAT). (3-0) Cr. 3. S. *Prereq: STAT 641 or STAT 543 and MATH 514.*
Probability spaces and random variables. Kolmogorov's consistency theorem. Independence, Borel-Cantelli lemmas and Kolmogorov's 0 - 1 Law. Comparing types of convergence for random variables. Sums of independent random variables, empirical distributions, weak and strong laws of large numbers. Convergence in distribution and its characterizations, tightness, characteristic functions, central limit theorems and Lindeberg-Feller conditions. Conditional probability and expectation. Discrete parameter martingales and their properties and applications.

MATH 645. Advanced Stochastic Processes.
(Cross-listed with STAT). (3-0) Cr. 3. S.
Weak convergence. Random walks and Brownian motion. Martingales. Stochastic integration and Ito's Formula. Stochastic differential equations and applications.

MATH 646. Mathematical Modeling of Complex Physical Systems.
(Cross-listed with PHYS). (3-0) Cr. 3. S.
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.

MATH 655. Partial Differential Equations I.
(3-0) Cr. 3. F. *Prereq: MATH 515 or MATH 519*
First order equations and systems, conservation laws, general theory of linear partial differential equations of elliptic, parabolic and hyperbolic types, maximum principles, fundamental solutions, Sobolev spaces, variational and Hilbert space methods.

MATH 656. Partial Differential Equations II.
(3-0) Cr. 3. S. *Prereq: MATH 655*
Continuation of MATH 655.

MATH 666. Finite Element Methods.
(3-0) Cr. 3. F. *Prereq: MATH 516 or MATH 520 or MATH 561 or MATH 656*
Elements of functional analysis; Sobolev spaces; variational principles and weak formulations; approximation theory in finite element spaces; analysis of finite element methods; implementation issues; applications.

MATH 680. Advanced Topics.
Cr. 3. Repeatable.

MATH 680A. Advanced Topics: Algebra.
Cr. 3. Repeatable.

MATH 680B. Advanced Topics: Analysis.
Cr. 3. Repeatable.

MATH 680C. Advanced Topics: Applied Mathematics.
Cr. 3. Repeatable.

MATH 680D. Advanced Topics: Combinatorics.
Cr. 3. Repeatable.

MATH 680E. Advanced Topics: Differential Equations.
Cr. 3. Repeatable.

MATH 680F. Advanced Topics: Linear Algebra.
Cr. 3. Repeatable.

MATH 680G. Advanced Topics: Logic and Foundations.
Cr. 3. Repeatable.

MATH 680H. Advanced Topics: Number Theory.
Cr. 3. Repeatable.

MATH 680I. Advanced Topics: Numerical Analysis.
Cr. 3. Repeatable.

MATH 680J. Advanced Topics: Optimization.
Cr. 3. Repeatable.

MATH 680K. Advanced Topics: Probability.
Cr. 3. Repeatable.

MATH 680L. Advanced Topics: Topology.
Cr. 3. Repeatable.

MATH 699. Research.
Cr. arr. Repeatable.