MATHEMATICS

College of Science and Engineering

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Program Scope

The Bachelor of Arts is offered for students with a general interest in mathematics; Bachelor of Science programs in applied mathematics and statistics are also offered. Courses are offered in mathematics education for prospective elementary and secondary teachers. Copies of program requirements are available in the mathematics department office.

Bachelor of Arts in Mathematics

The Bachelor of Arts in Mathematics has three concentrations:

- Liberal Arts
- Teaching
- Advanced Study

The **Liberal Arts concentration** is for students who desire a broad liberal arts education with an emphasis in mathematics.

The **Teaching concentration** is for students whose goal is to teach mathematics in middle school or high school. These students will obtain a solid understanding of the mathematics needed for teaching and classroom experience as volunteers in local public schools. They will also have the opportunity to develop the mathematical skills, flexibility, and perceptiveness to help future students cultivate wonderful, fruitful ideas, and to help students connect their thinking to formal mathematical structures. Students who complete this concentration will have satisfied the early field experience requirement and the subject matter competency requirement for a single subject credential in mathematics.

The **Advanced Study concentration** is for students who plan to pursue a masters or doctoral degree in mathematics. Students who choose this concentration will obtain a solid foundation in the cornerstones of advanced mathematics: linear algebra, abstract algebra, vector analysis, real analysis, and complex analysis.

Bachelor of Science in Applied Mathematics

The Bachelor of Science in Applied Mathematics responds to the needs of business and industry for applied mathematical scientists. The program also responds to the needs of those students who enjoy mathematics for its own sake but who also have interests in other fields to which mathematics is applied. Applied mathematicians and statisticians are employed in such areas as operations research, systems analysis, computing, data analysis, biological sciences (for example, doing research on DNA topology, mathematical cancer biology, or meeting the special needs of Biostatistics), communications research, and in the management sciences.

The primary aim of applied mathematics is to elucidate scientific concepts and to describe and predict scientific phenomena through the use of mathematics. The applied mathematician is at once a mathematical specialist and a systems analyst, whose task it is to confront highly complex real-world situations with mathematical analysis. In industry, the applied mathematician has an opportunity to test both background and training in solving problems of a practical nature. It is necessary to have not only a grasp of the mathematical theories involved, but also an appreciation for the specific science or technology concerned. In this way, one can arrive at usable mathematical formulations of scientific and engineering problems.

The applied mathematics program prepares students in several areas. First, students acquire a broad knowledge of the techniques and methods of applied mathematics. These techniques include differential equations, optimization, statistics, numerical analysis, computer programming, and operations research. Second, students learn to model scientific phenomena and complex real-world systems, (Mathematical Modeling, Applied Mathematics Project) and to use these models to understand and predict the behavior of these systems. Finally, they learn how to communicate these results to other scientists and managerial decision makers.

Bachelor of Science in Statistics

he Bachelor of Science in Statistics is for students who are planning careers as statisticians in industry, business, government, or biomedical research. Statistics is basic to quantitative research in the biological, physical, and social sciences. Because its methods are based on mathematics, it requires a firm understanding of mathematical methods as well as an appreciation of scientific method, computation, and practical problems. To give the student both breadth and depth and to introduce the student to a variety of fields where statistics may be applied, three emphases are offered: science, business, and economics.

Master of Arts in Mathematics

The Master of Arts in Mathematics is offered with the purpose of extending students' experience in mathematics. A student's goal may be to prepare for a career in government, industry, or community college teaching, to enhance competency as an elementary or secondary school teacher, or to prepare for further graduate study.

Master of Science in Statistical Data Science

The M.S. in Statistical Data Science offers a comprehensive curriculum in the fields of statistics and data science.

The program prepares students with diverse backgrounds (including statistics, mathematics, computer science, engineering, and other quantitative fields) for the data science workforce.

The expected completion time for the program is two years. After graduation, students are expected to seek employment as data scientists/analysts in the San Francisco Bay Area's technology, pharmaceutical, and financial industries.

Minor in Mathematics

The Minor in Mathematics is available for students desiring a program of study in mathematics that is coherent but not as extensive as the B.A. program. It could provide an excellent background for prospective secondary school teachers who want to be able to teach in mathematics as well as in their major area, or for students majoring in a science such as biology or economics who want to emphasize the quantitative aspects of their major.

Career Outlook

The degree programs in mathematics and statistics prepare students for additional graduate work; teaching careers; and work in business, industry, and government that apply mathematical and statistical concepts. In addition, specific careers in actuarial science, investment firms, computer industry, biomedical research and the government sector (such as NASA and the NSA) are especially attractive.

Professor

Federico Ardila (2005), *Professor in Mathematics*. Ph.D. Massachusetts Institute of Technology.

Matthias Beck (2004), *Professor in Mathematics*. Ph.D. Temple University.

Arek Goetz (1999), *Professor in Mathematics*. Ph.D. University of Illinois, Chicago.

Shandy Hauk (2019), *Professor in Mathematics*. Ph.D. University of California, Irvine.

Serkan Hosten (2000), *Professor in Mathematics*. Ph.D. Cornell University.

Eric Hsu (2001), *Professor in Mathematics*. Ph.D. University of California, Berkeley.

Mohammed R. Kafai (1989), *Professor in Mathematics*. Ph.D. University of California, Santa Barbara.

Shidong Li (1996), *Professor in Mathematics*. Ph.D. University of Maryland.

Alexandra Piryatinska (2006), *Professor in Mathematics*. Ph.D. Case Western Reserve University.

Alexander Schuster (2000), *Professor in Mathematics*. Ph.D. University of Michigan.

Associate Professor

Henry A. Boateng (2019), *Associate Professor in Mathematics*. Ph.D. University of Michigan.

Emily Clader (2016), *Associate Professor in Mathematics*. Ph.D. University of Michigan.

Tao He (2015), *Associate Professor in Mathematics*. Ph.D. Michigan State University.

Chun-Kit Lai (2014), *Associate Professor in Mathematics*. Ph.D. The Chinese University of Hong Kong.

Dustin Ross (2016), *Associate Professor in Mathematics*. Ph.D. Colorado State University.

Kimberly Seashore (2015), *Associate Professor in Mathematics*. Ph.D. University of California, Berkeley.

Assistant Professor

Luella Fu (2018), *Assistant Professor in Mathematics*. Ph.D. University of Southern California.

Anandamayee Majumdar (2023), *Assistant Professor in Mathematics*. Ph.D. University of Connecticut.

Ornella Mattei (2019), *Assistant Professor in Mathematics*. Ph.D. University of Brescia.

Majors

- Bachelor of Arts in Mathematics: Concentration in Mathematics for Advanced Study (http://bulletin.sfsu.edu/colleges/science-engineering/mathematics/ba-mathematics-concentration-mathematics-for-advanced-study/)
- Bachelor of Arts in Mathematics: Concentration in Liberal Arts (http://bulletin.sfsu.edu/colleges/science-engineering/mathematics/ba-mathematics-concentration-liberal-arts/)
- Bachelor of Arts in Mathematics: Concentration in Teaching (http://bulletin.sfsu.edu/colleges/science-engineering/mathematics/ba-mathematics-concentration-teaching/)
- Bachelor of Science in Applied Mathematics (http://bulletin.sfsu.edu/colleges/science-engineering/mathematics/bs-applied-mathematics/)
- Bachelor of Science in Statistics (http://bulletin.sfsu.edu/colleges/science-engineering/mathematics/bs-statistics/)

Minor

- Minor in Mathematics (http://bulletin.sfsu.edu/colleges/science-engineering/mathematics/minor-mathematics/)

Masters

- Master of Arts in Mathematics (http://bulletin.sfsu.edu/colleges/science-engineering/mathematics/ma-mathematics/)
- Master of Science in Statistical Data Science (http://bulletin.sfsu.edu/colleges/science-engineering/mathematics/ms-statistical-data/)

MATH 107 Mathematics for Business Calculus I (Units: 3)
Prerequisite: First-Year Math Advising Module; Category III* or IV* placement for QR/Math.

Introduction of the necessary business vocabulary. Review of numbers and operations, exponents and radicals, functions in general, and linear, quadratic, polynomial, rational, exponential, and logarithmic functions in particular, in the context of business, finance, and economy. Introduction to the mathematics of finance: simple and compound interest, annuities, amortization.

MATH 108 Mathematics for Business Calculus II (Units: 3)
Prerequisite: MATH 107 with a grade of C or better.

Derivatives and integrals. Applications of differentiation and integration, including optimization. Problems involving business, finance, and economics.
(Note: Successful completion of MATH 107 and MATH 108 will culminate in satisfying the Quantitative Reasoning requirement (GE Area B4). For this course to satisfy General Education, students must earn a grade of C- or CR or higher.)
Course Attributes:

- B4: Math/QR

MATH 110 Business Calculus (Units: 3)
Prerequisite: First-Year Math Advising Module. For students who wish to take business calculus in one semester.

Functions, derivatives, and integrals. Applications of differentiation and integration, including optimization and moving averages. Problems involving business, finance, and economics. Elements of basic calculus. (Note: In order for this course to satisfy General Education, students must earn a C- or CR or higher grade if taken fall 2014 or later.)
Course Attributes:

- B4: Math/QR

MATH 111 Support for College Mathematics (Units: 2)
Prerequisites: First-Year Math Advising Module. Concurrent enrollment in PHIL 111* or CSC 110*.

Review of numbers and operations, exponents, and radicals. Linear, quadratic, polynomial, and rational functions. Exponential and logarithmic functions as needed. Develop and practice strategies for proficiency in quantitative reasoning through problem-solving, communication, and interpretation of data and graphs. [Formerly MATH 112]

MATH 112 Quantitative Reasoning for Civic Engagement (Units: 3)
Prerequisites: First-Year Math Advising Module.

Participation in civic society requires not only understanding principles of governance, but also problem-solving. Develop the mathematical concepts and skills relevant to the challenges and issues facing individuals and societies. Enables both quantitative understanding and decision-making about aspects of work, life, and civic participation. (Plus-minus ABC/NC, CR/NC allowed)
(Note: For this course to satisfy General Education, students must earn a grade of C- or CR or better.)
(This course is offered as LCA 112/PHIL 112/PLSI 112/HIST 112/I R 112/MATH 112. Students may not repeat the course under an alternate prefix.)
Course Attributes:

- B4: Math/QR
- Social Justice

MATH 122 Mathematics for Statistical Quantitative Reasoning (Units: 2)
Prerequisites: First-Year Math Advising Module. Concurrent enrollment in ISED 160* or PSY 171 required.

Review of mathematics in the context of elementary statistics: numbers, fractions, decimals, percentages; units; rounding; formulas and scientific notation; order of operations; algebra of equations; graphs and plots; sets; principals of counting.

MATH 123 Mathematics for Elementary Statistics (Unit: 1)
Prerequisites: First-year math advising module. Concurrent enrollment in MATH 124*, PSY 171* or ISED 160*.

Support development of quantitative reasoning at the college level in the context of data visualization, data analysis, probability theory, and statistics. Development of sense-making skills and computational understanding. Activity. (CR/NC grading only)

MATH 124 Elementary Statistics (Units: 3)
Prerequisites: First-Year Math Advising Module. Students who elect to take additional support should concurrently enroll in MATH 123.

Data analysis, probability, and statistical inference. For students in any field where statistics is a means of communication and a tool for decision making.
Course Attributes:

- B4: Math/QR

MATH 165 Concepts of the Number System (Units: 3)
Prerequisite: Satisfactory completion of ELM requirement or any QR/Math placement category.

Designed for prospective multiple subjects credential candidates. Understanding operations with whole numbers, fractions and decimals. Problem-solving strategies, numeration systems and elementary number theory.

MATH 197 Prelude to Calculus I (Units: 3)
Prerequisite: First-Year Math Advising Module; Category III* and IV* placement for QR/Math.

Review of numbers and operations, exponents, and radicals. Linear, quadratic, polynomial, and rational functions. Exponential growth and exponential functions. Logarithmic functions. The transcendental number e and natural logarithms. The first semester of a year-long stretch pre-calculus course.

MATH 198 Prelude to Calculus II (Units: 3)
Prerequisite: MATH 197 with a grade of C or better.

Trigonometry, trigonometric identities, trigonometric and inverse trigonometric functions, sequences and series, and limits.
(Note: Note: Successful completion of MATH 197 and MATH 198 will culminate in satisfying the Quantitative Reasoning requirement (GE Area B4). For this course to satisfy General Education, students must earn a grade of C- or CR or higher.)
Course Attributes:

- B4: Math/QR

MATH 199 Pre-Calculus (Units: 4)
Prerequisite: First-Year Math Advising Module. For students who want to take pre-calculus in one semester.

Functions, graphing techniques, exponentials and logarithms, trigonometry.
Course Attributes:

- B4: Math/QR

MATH 209 Mathematical Computing (Units: 3)
Prerequisite: MATH 226 with a grade of C or better or permission of the instructor.

Introduces basic sequential programming constructs in scientific computing using the Python Language. Uses programming projects to review and reinforce material from Calculus and Linear Algebra. Introduces essential modeling and programming concepts. [Formerly MATH 309]

MATH 225 Introduction to Linear Algebra (Units: 3)
Prerequisites: MATH 198* or MATH 199* or MATH 226* with a grade of C or better.

Introduction to the solution to system of linear equations using Gaussian elimination, matrix algebra, subspaces of R^n and their bases, matrix transformations, eigenvalues and eigenvectors, diagonalization and applications, dot product, orthogonality, orthogonal bases, Gram-Schmidt orthogonalization, and using MATLAB to solve linear algebra problems.

MATH 226 Calculus I (Units: 4)
Prerequisite: One of the following: MATH 198 or MATH 199 or equivalent with a grade of C or better; or MATH 226 or equivalent with a grade of C- or lower; or high school pre-calculus with B or better; or high school calculus with a grade of C or better.

Graphs. Differentiation: theory, techniques, and applications. Integration: Fundamental Theorem of Calculus and applications. Transcendental functions. Lecture, 3 units; laboratory, 1 unit.
Course Attributes:

- B4: Math/QR

MATH 227 Calculus II (Units: 4)
Prerequisite: MATH 226* with a grade of C or better.

Techniques of integration, analytic geometry, polar coordinates, vectors, improper integrals. Sequences and series.

MATH 228 Calculus III (Units: 4)
Prerequisite: MATH 227* with a grade of C or better.

Three-dimensional analytic geometry, partial differentiation, multiple integrals, vector calculus. Lecture, 3 units; laboratory, 1 unit.

MATH 245 Elementary Differential Equations and Linear Algebra (Units: 3)
Prerequisite: MATH 228 with a grade of C or better.

First and second order linear differential equations, Laplace transform methods, Fourier series, matrix algebra.

MATH 265 Advanced Number Systems (Units: 3)
Prerequisite: MATH 165 with a grade of C or better.

Designed for prospective multiple subject credential candidates, continues work done in MATH 165 with decimals and percents. Introduces operations with negative numbers. Additional topics include problem-solving and elementary number theory.

MATH 300GW History of Mathematics - GWAR (Units: 3)
Prerequisites: GE Area A2; MATH 227 or equivalent with a grade of C or higher.

Survey of the history of mathematics focusing on topics of interest to secondary mathematics teachers. Emphasis on telling the story of mathematics through research and writing an expository paper. (ABC/NC grading only)
Course Attributes:

- Graduation Writing Assessment

MATH 301GW Exploration and Proof - GWAR (Units: 3)
Prerequisites: GE Area A2; MATH 226* with a grade of C or higher.

Informal exploration and proofs in mathematics. Basic concepts of advanced mathematics courses. Exploratory thinking, elementary logic, sets, mathematical induction, the integers, relations, and functions. (ABC/NC grading only)
Course Attributes:

- Graduation Writing Assessment

MATH 310 Elementary Number Theory (Units: 3)
Prerequisites: MATH 227 and MATH 301GW with grades of C or better.

Divisibility, congruencies, power residues, quadratic reciprocity, diophantine equations. Number theoretic functions, continued fractions and rational approximation, partitions.

MATH 324 Probability and Statistics with Computing (Units: 3)
Prerequisites: MATH 227* with a grade of C or better; computer experience that meets the approval of the instructor; basic concepts of probability and statistics.

Data analysis, probability distributions, confidence intervals, and hypothesis testing. Students use computer software to do statistical analyses.

MATH 325 Linear Algebra (Units: 4)
Prerequisites: MATH 226* with a grade of C or better; concurrent enrollment in MATH 301GW recommended.

Examination of the solution of systems of linear equations, Gaussian elimination, matrix algebra, vector spaces, bases, linear transformations, inner products, orthogonal bases, orthogonalization, eigenvalues and eigenvectors, diagonalization and spectral factorization of symmetric matrices, and singular value decomposition.

MATH 335 Modern Algebra (Units: 3)
Prerequisites: MATH 301GW and either MATH 225 or MATH 325 all with a grade of C or better; or permission of the instructor.

Introduction to groups, rings, integral domains, fields, and ordering.

MATH 338 Introduction to SAS (Units: 3)
Prerequisites: MATH 209* or MATH 309* or CSC 210* or CSC 215* or CSC 309* with a grade of C or better or permission of the instructor.

Using SAS software for data management, presentation of data using graphs and reports, calculation of basic statistics such as mean, standard error, percentiles. Analysis of data using t-test, Chi-square test, regression, and analysis of variance.

MATH 350 Geometry (Units: 3)
Prerequisites: MATH 228 and MATH 301GW with grades of C or better.

Introduction to the origin and foundations of geometry: Euclidean, non-Euclidean geometries, more recent approaches. Quick survey of high school geometry. Classification and representation of motions and similarities. Projections, homogeneous coordinates.

MATH 370 Real Analysis I (Units: 3)
Prerequisites: MATH 227 and MATH 301GW* with grades of C or better.

Critical development of analysis: Bolzano-Weierstrass and Heine-Borel theorems; limits, continuity, differentiability, integrability.

MATH 375 Field Study for Secondary Teachers (Units: 3)
Prerequisite: MATH 301GW with a grade of C or better or permission of the instructor.

Completion of tuberculosis test and fingerprinting for work in the public schools. Opportunity for students to relate the mathematics they are learning to the teaching and learning of mathematics at the middle and high school levels; at the same time, fulfill the 45-hour field experience requirement for prospective teachers.

MATH 376 Ordinary Differential Equations I (Units: 3)
Prerequisites: MATH 228; MATH 225 or MATH 325; MATH 209 or CSC 309 or equivalent, all with grades of C or better.

First-order differential equations, second-order linear equations with constant coefficients, graphical and numerical methods, systems of differential equations and phase-plane analysis, existence and uniqueness theorems.

MATH 380 Introduction to Complex Analysis (Units: 3)
Prerequisites: MATH 228 and MATH 301GW* with grades of C or better.

Analytic functions of a complex variable. Cauchy's theorem, power series, Laurent series, singularities, residue theorem with applications to definite integrals.

MATH 400 Numerical Analysis (Units: 3)
Prerequisites: MATH 228; MATH 225 or MATH 325; and CSC 210 or CSC 215 or MATH 209 or MATH 309, all with grades of C or better.

Numerical solution of algebra and calculus problems. Interpolation and approximations; direct and iterative methods for solutions of linear equations. Gaussian elimination. Numerical differentiation and integration; solution of ordinary differential equations.

MATH 420 Combinatorics (Units: 3)
Prerequisite for MATH 720: Graduate Mathematics students or permission of the instructor.
Prerequisites for MATH 420: Upper-division standing; MATH 301GW; CSC 230 or MATH 310 or MATH 325; all with grades of C or better; GPA of 3.0 or higher; or permission of the instructor.

An introduction to fundamental combinatorial objects, their uses in other fields of mathematics and its applications, and their analysis. Does an object with certain prescribed properties exist? How many of them are there? What structure do they have?
(MATH 720/MATH 420 is a paired course offering. Students who complete the course at one level may not repeat the course at the other level.)

MATH 424 Introduction to Linear Models (Units: 3)
Prerequisite for MATH 724: Graduate Mathematics students or permission of the instructor.
Prerequisites for MATH 424: Upper-division standing; MATH 228*, MATH 325*, and MATH 440* all with grades of C or better; GPA of 3.0 or higher; or permission of the instructor.

Theory and applications of Linear Models, Multiple Regression, Analysis of Variance for Fixed and Random Effects, Nested and Crossed Treatments, and Experimental Design.
(MATH 724/MATH 424 is a paired course offering. Students who complete the course at one level may not repeat the course at the other level.)

MATH 425 Applied and Computational Linear Algebra (Units: 3)
Prerequisites: MATH 225 or MATH 325; and MATH 209 or MATH 309 or CSC 210 or CSC 215; all with grades of C or better.

Explore techniques for solving huge linear systems, covering both the theory behind the techniques and the computation. Review and further develop earlier concepts and use them to efficiently solve problems across the natural and social sciences. Problems are drawn from numerical analysis, mathematical biology, data analysis and machine learning, imaging and signal processing, chemistry, physics, economics, computer science, engineering, and other disciplines.

MATH 430 Mathematics of Optimization (Units: 3)
Prerequisite: MATH 325 with a grade of C or better.

Modeling and solution of optimization problems as linear, semidefinite, nonlinear, or integer programming problems. Analysis and interpretations of solutions to these problems.

MATH 435 Modern Algebra II (Units: 3)
Prerequisite for MATH 735: Graduate Mathematics students or permission of the instructor.
Prerequisites for MATH 435: Upper-division standing; MATH 335 with a grade of C or better; GPA of 3.0 or higher; or permission of the instructor.

Group actions, conjugacy classes, and Sylow's Theorem. Rings, modules, vector spaces, and finitely generated modules over PIDs. Field extensions and finite fields.
(MATH 735/MATH 435 is a paired course offering. Students who complete the course at one level may not repeat the course at the other level.)

MATH 440 Probability and Statistics I (Units: 3)
Prerequisites: MATH 228* with a grade of C or better (may be taken concurrently); or permission of the instructor.

Probability spaces, elementary combinatorics, random variables, independence, expected values, moment generating functions, selected probability distributions, limit theorems, and applications.

MATH 441 Probability and Statistics II (Units: 3)
Prerequisite for MATH 741: Graduate Mathematics students or permission of the instructor.
Prerequisites for MATH 441: Upper-division standing; MATH 228*, MATH 325*, and MATH 440* all with grades of C or better; GPA of 3.0 or higher; or permission of the instructor.

Sampling distributions, estimation of parameters, hypothesis testing, goodness-of-fit tests, linear regression, and selected non-parametric methods.
(MATH 741/MATH 441 is a paired course offering. Students who complete the course at one level may not repeat the course at the other level.)

MATH 442 Probability Models (Units: 3)
Prerequisites: MATH 228*, MATH 325*, and MATH 440* all with grades of C or better, or permission of the instructor.

Advanced topics in probability theory: discrete and continuous-time Markov chains, Poisson process, queuing systems, and applications.

MATH 443 Introduction to Time Series Analysis (Units: 3)
Prerequisites: MATH 228*, MATH 325*, and MATH 440* all with grades of C or better; or permission of the instructor.

Introduction to the theory and practice of time series analysis. Topics include time series regression and exploratory data analysis, stationary processes, ARMA/ARIMA models, Spectral analysis, and Multivariate time series analysis: Multivariate ARMA. The analyses will be performed using R/Python software.

MATH 447 Design and Analysis of Experiments (Units: 3)
Prerequisites: MATH 325 and MATH 440* with grades of C or better or permission of the instructor.

Learn how to plan, design, and conduct experiments and analyze the resulting data.
(MATH 747/MATH 447 is a paired course offering. Students who complete the course at one level may not repeat the course at the other level.)

MATH 448 Introduction to Statistical Learning and Data Mining (Units: 3)
Prerequisites: MATH 228*, MATH 325*, and MATH 440* all with grades of C or better; or permission of the instructor.

Modern techniques in the statistical analysis of data, including regression, classification, regularization methods, model selection, non-parametric methods, dimensionality reduction, and clustering; employ statistical software to analyze real data using advanced methods from statistics, machine learning, data mining, and pattern recognition.

MATH 449 Categorical Data Analysis (Units: 3)
Prerequisites: MATH 228*, MATH 325*, and MATH 440* all with grades of C or better; or permission of the instructor.

Exploration of descriptive and inferential methods for contingency tables, generalized linear models for discrete data, logistic regression for binary responses, multi-category logistic models for nominal and ordinal responses, log-linear models, and inference for matched-pairs and correlated clustered data.

MATH 450 Topology (Units: 3)
Prerequisite: MATH 370 with a grade of C or better.

Rigorous development of the theory of metric spaces and topological spaces. Concepts covered include open, closed sets, interior, closure, boundary of sets; connects sets, compact sets, continuous functions defined on metric and topological spaces.

MATH 451 Introduction to Differential Geometry (Units: 3)
Prerequisites: MATH 228 and MATH 325 with grades of C or better; MATH 370 or MATH 450; or permission of the instructor.

Study of intrinsic surface along with a topological invariant known as the Euler characteristic. The aim is to prove that the Euler characteristic of a compact orientated surface is numerically equal to the total index of any vector field with isolated zeroes (Poincare-Hopf Index theorem), the total Gaussian curvature (Gauss-Bonnet-Chern theorem), and the algebraic total of the number of non-degenerate critical points (Morse theorem).

MATH 460 Mathematical Modeling (Units: 3)
Prerequisites: MATH 225 or MATH 325; MATH 245 or MATH 376; all with grades of C or better.

Deterministic and stochastic techniques used in mathematical modeling, illustrated and developed through problems originating in industry and applied research.

MATH 462 Dynamical Systems with Applications (Units: 3)
Prerequisites: CSC 210 or CSC 215 or MATH 209 or MATH 309; MATH 227 and MATH 301GW; all with grades of C or better; or permission of the instructor.

An introduction to the study of iterations (repeated composition) of a function in most basic contexts, including linear and continuous functions of one variable, number-theoretic functions, geometric functions, and Markov chains. Using mathematical software as an investigative tool, explore applications chosen from piecewise linear systems, fractals, chaos, number theory, cryptography, complex networks, and mathematical modeling.

MATH 470 Real Analysis II: Several Variables (Units: 3)
Prerequisite for MATH 770: Graduate Mathematics students or permission of the instructor.
Prerequisites for MATH 470: Upper-division standing; MATH 370 with a grade of C or better; GPA of 3.0 or higher; or permission of the instructor.

Sequences and series of functions, uniform convergence, real-analytic functions, metric spaces, open and closed sets, compact and connected sets, and continuous functions.
(MATH 770/MATH 470 is a paired course offering. Students who complete the course at one level may not repeat the course at the other level.)

MATH 471 Fourier Analysis and Applications (Units: 3)
Prerequisites for MATH 771: Graduate standing; MATH 370 with a grade of C or better; or permission of the instructor.
Prerequisites for MATH 471: Upper-division standing; MATH 370 with a grade of C or better; GPA of 3.0 or higher; or permission of the instructor.

Sequences and series of functions, modes of convergence, Fourier series and integrals, and wavelet analysis.
(MATH 771/MATH 471 is a paired course offering. Students who complete the course at one level may not repeat the course at the other level.)

MATH 475 Capstone Course for Secondary Teachers of Mathematics (Units: 3)
Prerequisites: MATH 335 with a grade of C or better and one of the following: concurrent enrollment in MATH 370 or permission of the instructor.

Builds on student's work in upper division mathematics to deepen understanding of the math taught in secondary school. Active exploration of topics in algebra, analysis, geometry and statistics.

MATH 477 Partial Differential Equations (Units: 3)
Prerequisite for MATH 777: Graduate Mathematics students or permission of the instructor.
Prerequisites for MATH 477: Upper-division standing; MATH 376 with a grade of C or better; GPA of 3.0 or higher; or permission of the instructor.

Study of partial differential equations in rectangular and polar coordinates. Initial and boundary value problems for the heat equation and wave equation. Study of Fourier series, Bessel series, harmonic functions, and Fourier transforms.
(MATH 777/MATH 477 is a paired course offering. Students who complete the course at one level may not repeat the course at the other level.)

MATH 490 Selected Topics in Mathematics (Units: 3)
Prerequisite: MATH 301 with a grade of C, or permission of the instructor.

Introduction to selected topics in mathematics. Topics to be specified in the Class Schedule. May be repeated for a total of 18 units when topics vary.
Topics:

a. Group Representations
b. Introduction to Actuarial Mathematics
c. Non-Parametric Statistics
d. Algebra, Geometry and Combinatorics
e. Analysis
f. Game Theory
g. Math Education
h. Mathematical Statistics
i. Introduction to Differential Geometry
j. Wavelets and Frames with Applications
k. Applied Mathematics

MATH 491 Game Theory (Units: 3)
Prerequisite: MATH 227 with a grade of C or better.

Normal, extensive and network forms. Strategy, bets reply and Nash equilibrium. Equilibrium path, information and beliefs, sequential rationality and perfect equilibria. Applications to learning, signaling, screening and deterrence.

MATH 495 Introduction to Wavelets and Frames with Applications (Units: 3)
Prerequisites: MATH 325 or MATH 370 with grades of C or better, or permission of the instructor.

Fundamentals of wavelets, time frequency analysis, and frames, as well as applications in engineering and physics.

MATH 565 Concepts of Geometry, Measurement, and Probability (Units: 3)
Prerequisite: MATH 165 with a grade of C or better.

Designed for prospective multiple subjects credential candidates. Spatial relationships and inductive reasoning in geometry, measurement emphasizing the metric system, and elementary statistics and probability.

MATH 575 Mathematics in the Middle School Classroom (Units: 3)
Prerequisite: MATH 565 with a grade of C or better; or BA Math Concentration in Teaching majors; or permission of the instructor.

Designed for current or prospective middle school teachers of mathematics. Topics in algebra, number theory, and geometry. (Plus-minus letter grade only)

MATH 576 Math in Middle Schools II (Units: 3)
Prerequisite: MATH 565 with a grade of C or better; or BA Math Concentration in Teaching majors; or permission of the instructor.

Continues to prepare students with content knowledge needed to teach algebra in middle school. Begins work in probability and statistics.

MATH 577 Math in Middle School III (Units: 3)
Prerequisite: MATH 565 with a grade of C or better; or BA Math Concentration in Teaching majors; or permission of the instructor.

Continues the work begun in MATH 575 and MATH 576 to prepare students with content knowledge needed to teach algebra, geometry, and probability and statistics in middle school.

MATH 696 Applied Mathematics Project I (Unit: 1)
Prerequisite: MATH 460 with a grade of C or better. May be replaced by permission of the instructor.

Preparation under faculty guidance of feasibility study and outline of a project in applied mathematics.

MATH 697 Applied Mathematics Project II (Units: 2)
Prerequisite: Successful completion of MATH 696 in a previous semester. May not be taken concurrently with MATH 696.

Completion of applied mathematics project. Presentation of oral and written report.

MATH 699 Independent Study (Units: 1-3)
Prerequisite: Approval of the department and permission of the instructor.

Special study of a particular problem under the direction of a member of the department. The student must present a written report of the work accomplished to the department. May be repeated for a total of 6 units.

MATH 700 Graduate Teaching Workshop (Units: 3)
Prerequisite: Graduate Teaching Assistant status.

Discussion and analysis of teaching techniques, peer evaluation, peer classroom observations, guided groups, and self-analysis of videotapes; group project developing and studying common lesson materials.

MATH 710 Measure and Integration (Units: 3)
Prerequisite: Graduate standing and MATH 770 with a grade of C or better or permission of the instructor; or upper-division standing and MATH 470.

Outer measure, Lebesgue measure and integration; convergence theorems; bounded variation, absolute continuity, and Lebesgue's theory of differentiation.

MATH 711 Functional Analysis (Units: 3)
Prerequisites: MATH 710 and MATH 725 with grades of B- or better or permission of the instructor.

Banach and Hilbert spaces, bounded linear operators, dual spaces; the Hahn-Banach, closed graph, and open mapping theorems with applications; functional analysis topics.

MATH 720 Combinatorics (Units: 3)
Prerequisite for MATH 720: Graduate Mathematics students or permission of the instructor.
Prerequisites for MATH 420: Upper-division standing; MATH 301GW; CSC 230 or MATH 310 or MATH 325; all with grades of C or better; GPA of 3.0 or higher; or permission of the instructor.

An introduction to fundamental combinatorial objects, their uses in other fields of mathematics and its applications, and their analysis. Does an object with certain prescribed properties exist? How many of them are there? What structure do they have?
(MATH 720/MATH 420 is a paired course offering. Students who complete the course at one level may not repeat the course at the other level.)

MATH 724 Introduction to Linear Models (Units: 3)
Prerequisite for MATH 724: Graduate Mathematics students or permission of the instructor.
Prerequisites for MATH 424: Upper-division standing; MATH 228*, MATH 325*, and MATH 440* all with grades of C or better; GPA of 3.0 or higher; or permission of the instructor.

Theory and applications of Linear Models, Multiple Regression, Analysis of Variance for Fixed and Random Effects, Nested and Crossed Treatments, and Experimental Design.
(MATH 724/MATH 424 is a paired course offering. Students who complete the course at one level may not repeat the course at the other level.)

MATH 725 Advanced Linear Algebra (Units: 3)
Prerequisite: MATH 335 with a grade of C or better.

Vector spaces and linear maps on them. Inner product spaces and the finite-dimensional spectral theorem. Eigenvalues, the singular-value decomposition, the characteristic polynomial, and canonical forms.

MATH 729 Communicating Mathematics (Units: 3)
Prerequisite: Formal commitment to write an MA thesis or expository paper.

Practice of written and oral communication of advanced and research mathematics: prepare research article or monograph, design research poster, prepare and present short and long research talks, write a grant proposal.

MATH 730 Theory of Functions of a Complex Variable (Units: 3)
Prerequisites: Graduate standing and MATH 770 with a grade of C or better; or upper-division standing and MATH 470; and permission of the instructor.

Elementary topology of the Euclidean plane, analytic functions, power series, conformal mapping, Cauchy integral formula, residue theorems, power series, Laurent series, analytic continuation, normal families and Riemann mapping theorem.

MATH 735 Modern Algebra II (Units: 3)
Prerequisite for MATH 735: Graduate Mathematics students or permission of the instructor.
Prerequisites for MATH 435: Upper-division standing; MATH 335 with a grade of C or better; GPA of 3.0 or higher; or permission of the instructor.

Group actions, conjugacy classes, and Sylow's Theorem. Rings, modules, vector spaces, and finitely generated modules over PIDs. Field extensions and finite fields.
(MATH 735/MATH 435 is a paired course offering. Students who complete the course at one level may not repeat the course at the other level.)

MATH 741 Probability and Statistics II (Units: 3)
Prerequisite for MATH 741: Graduate Mathematics students or permission of the instructor.
Prerequisites for MATH 441: Upper-division standing; MATH 228*, MATH 325*, and MATH 440* all with grades of C or better; GPA of 3.0 or higher; or permission of the instructor.

Sampling distributions, estimation of parameters, hypothesis testing, goodness-of-fit tests, linear regression, and selected non-parametric methods.
(MATH 741/MATH 441 is a paired course offering. Students who complete the course at one level may not repeat the course at the other level.)

MATH 742 Advanced Probability Models (Units: 3)
Prerequisite: Graduate standing; upper-division standing with MATH 441 or equivalent; or permission of the instructor.

Advanced topics in probability theory including continuous-time Markov chains, renewal theory and applications, queuing systems, and reliability theory. Discussion of Brownian Motion and Stationary Processes.

MATH 747 Design and Analysis of Experiments (Units: 3)
Prerequisites: MATH 325 and MATH 440* with grades of C or better or permission of the instructor.

Learn how to plan, design, and conduct experiments and analyze the resulting data.
(MATH 747/MATH 447 is a paired course offering. Students who complete the course at one level may not repeat the course at the other level.)

MATH 748 Theory and Applications of Statistical and Machine Learning (Units: 3)
Prerequisites: Graduate standing; MATH 448; or permission of the instructor.

Study of the fundamental concepts of statistical and machine learning theory.

MATH 760 Multivariate Statistical Methods (Units: 3)
Prerequisite: Graduate standing; upper-division standing with MATH 441 or equivalent; or permission of the instructor.

Multivariate Statistical Methods are used to analyze the joint behavior of more than one random variable. There are a number of multivariate techniques available including Factor Analysis, Principle Component Analysis, Canonical Correlation, Multidimensional Scaling, MANOVA, and Discriminant Analysis.

MATH 761 Computational Statistics (Units: 3)
Prerequisite: Graduate standing; upper-division standing with MATH 441 or equivalent; or permission of the instructor.

Exploration of efficient methods for obtaining numerical solutions to statistically formulated problems. Emphasis on basic R programming, random variable generation, bootstrap, Jackknife and its applications, methods for variance reduction, Monte Carlo simulation and integration, optimization techniques, Newton-Raphson algorithm, EM algorithm, Metropolis-Hasting algorithm, and Gibbs samplers.

MATH 770 Real Analysis II: Several Variables (Units: 3)
Prerequisite for MATH 770: Graduate Mathematics students or permission of the instructor.
Prerequisites for MATH 470: Upper-division standing; MATH 370 with a grade of C or better; GPA of 3.0 or higher; or permission of the instructor.

Sequences and series of functions, uniform convergence, real-analytic functions, metric spaces, open and closed sets, compact and connected sets, and continuous functions.
(MATH 770/MATH 470 is a paired course offering. Students who complete the course at one level may not repeat the course at the other level.)

MATH 771 Fourier Analysis and Applications (Units: 3)
Prerequisites for MATH 771: Graduate standing; MATH 370 with a grade of C or better; or permission of the instructor.
Prerequisites for MATH 471: Upper-division standing; MATH 370 with a grade of C or better; GPA of 3.0 or higher; or permission of the instructor.

Sequences and series of functions, modes of convergence, Fourier series and integrals, and wavelet analysis.
(MATH 771/MATH 471 is a paired course offering. Students who complete the course at one level may not repeat the course at the other level.)

MATH 777 Partial Differential Equations (Units: 3)
Prerequisite for MATH 777: Graduate Mathematics students or permission of the instructor.
Prerequisites for MATH 477: Upper-division standing; MATH 376 with a grade of C or better; GPA of 3.0 or higher; or permission of the instructor.

Study of partial differential equations in rectangular and polar coordinates. Initial and boundary value problems for the heat equation and wave equation. Study of Fourier series, Bessel series, harmonic functions, and Fourier transforms.
(MATH 777/MATH 477 is a paired course offering. Students who complete the course at one level may not repeat the course at the other level.)

MATH 790 Advanced Topics in Mathematics (Units: 3)
Prerequisite: Graduate standing or permission of the instructor.

Introduction to advanced topics in mathematics. Topics to be specified in the Class Schedule. May be repeated for a total of 24 units when topics vary. (Plus-minus letter grade only)
Topics:

a. Applied Mathematics
b. Mathematical Statistics
c. Analysis
d. Math Education
e. Algebraic Topology
f. Polytopes and Varieties
g. Advanced Frame Theory
h. Algebra, Geometry and Combinatorics

MATH 850 Algebra (Units: 3)
Prerequisite: MATH 435/MATH 735 with a grade of C or better or permission of the instructor.

Rings and modules; further material is selected from such topics as Wedderburn theory, Noetherian ring theory, field theory, and general algebraic systems.

MATH 852 Algebraic Topology (Units: 3)
Prerequisites: MATH 335* and MATH 450* with grades of C or better; or permission of the instructor.

The fundamental group of topological spaces, construction of surfaces, simplicial and singular homology and cohomology with basic calculations, exact sequences, and Mayer-Vietoris theorem.

MATH 881 Selected Topics in Combinatorics (Units: 3)
Prerequisites: Graduate standing; MATH 301GW and MATH 335; or permission of the instructor.

Review of fundamental combinatorial objects, addressing questions of existence, structure, and enumeration, then treating a well-established area of combinatorics in detail. May be repeated for a total of 6 units.

MATH 883 Polytopes and Varieties (Units: 3)
Prerequisites: Either MATH 435 with a grade of C or better and permission of the instructor or MATH 735 or MATH 850 with a grade of C or better.

Central concepts in polytope theory and simplicial complexes, elements of affine and projective algebraic geometry, commutative algebra of special ideals and related effective methods, applications to one of the following: discrete geometry, toric varieties, algebraic statistics, polytope theory, optimization. May be repeated for a total of 6 unit.

MATH 885 Advanced Frame Theory and Its Applications (Units: 3)
Prerequisites: MATH 471 or MATH 470; MATH 725 or MATH 770; or permission of the instructor.

Frames in Hilbert spaces, finite frame theory, frames vs. Riesz bases, particular frames structures including frames of translates, Gabor frames, wavelet frames, frame multi-resolution, compressed sensing and sampling theory, and applications.

MATH 892 Data Science Internship (Units: 3)
Prerequisites: Permission of the instructor and graduate adviser; and approval of Advancement to Candidacy (ATC) and Culminating Experience (CE) forms by Graduate Studies. ATC and Proposal for Culminating Experience Requirement forms must be approved by the Graduate Division before registration.

Field experience in Statistical Data Science offered in cooperation with a private, public profit, or non-profit organization that enables students to acquire competencies and experience required for fulfilling professional responsibilities under the supervision of a Statistics faculty member. [Formerly MATH 895]

MATH 895 Research Project (Units: 3)
Prerequisites: Permission of the instructor and graduate adviser; and approval of Advancement to Candidacy (ATC) and Culminating Experience (CE) forms by Graduate Studies. ATC and Proposal for Culminating Experience Requirement forms must be approved by the Graduate Division before registration.

Complete and present a Data Science project with a final exam in Probability and Statistics. [Formerly MATH 896]

MATH 896EXM Culminating Experience Examination (Units: 0-3)
Prerequisites: Permission of the instructor, committee chair, and approval of Advancement to Candidacy (ATC) and Culminating Experience (CE) forms by Graduate Studies. ATC and Proposal for Culminating Experience Requirement forms must be approved by the Graduate Division before registration.

Enrollment in 896EXAM required for students whose culminating experience consists of an examination only. Not for students enrolled in a culminating experience course numbered MATH 898 (or in some cases, MATH 890 - see program's graduate advisor for further information). (CR/NC, RP)

MATH 898 Master's Thesis (Units: 3)
Prerequisites: Permission of the instructor and graduate adviser; and approval of Advancement to Candidacy (ATC) and Culminating Experience (CE) forms by Graduate Studies. ATC and Proposal for Culminating Experience Requirement forms must be approved by the Graduate Division before registration.

(CR/NC grading only)

MATH 899 Independent Study (Units: 1-3)
Prerequisites: Approval of the department and permission of the instructor.

Special study of a particular problem under the direction of a member of the department. The student must present a written report of the work accomplished to the staff of the department. May be repeated.