

MATHEMATICS AND STATISTICS (MATH)

Degrees Offered: Ph.D., M.S., M.S.T., Graduate Certificate

This program is offered in Durham.

The mission of the Mathematics and Statistics program is twofold: to prepare students for a variety of exciting and rewarding career opportunities in business, industry, government and the teaching professions; and to advance forefront knowledge in the areas of pure mathematics, applied mathematics, statistics, and mathematics education through world-class cutting-edge research.

The Department of Mathematics and Statistics offers programs leading to a master of science for teachers (M.S.T.) in mathematics, master of science in mathematics, master of science in mathematics with an option in applied mathematics, and a master of science in mathematics with an option in statistics. Students in the master of science in applied mathematics may choose approved courses in the doctoral program in Integrated Applied Mathematics as part of their MS program.

The department also offers doctor of philosophy programs in mathematics, integrated applied mathematics, statistics, and mathematics education.

In general, the master's degree programs offer the student a high level of preparation for professional employment as well as appropriate preparation for programs leading to the Ph.D. The Ph.D. programs prepare the student primarily for a career in university teaching and research.

The graduate programs have limited enrollment, allowing students to work closely with faculty members in their areas of expertise. Research within the department is currently being conducted in many areas of the mathematical sciences, including: operator theory, Hilbert spaces, geometric function theory, complex analysis, ring theory, commutative algebra, homological algebra, quantum groups, tensor categories, combinatorics, topology, algebraic topology, category theory, nonlinear dynamics and chaos, data compression, chaotic prediction and control, spectral analysis, asymptotic analysis, mathematical control theory, environmental statistics, spatial and spatio-temporal statistics, Bayesian and computational statistics, wavelets in statistics, teaching and learning of K-12 mathematics and statistics, teaching and learning of undergraduate mathematics and statistics, mathematical curriculum and teacher education, and calculus learning.

Additionally, a graduate certificate in industrial statistics is offered.

Admission Requirements

Applicants for the M.S. and Ph.D. degrees must have completed significant undergraduate coursework in mathematics, preferably in algebra, analysis, and topology.

Applicants for the M.S. with applied mathematics option must have completed significant coursework in analysis or applied analysis.

Applicants for the M.S. with statistics option will typically have an undergraduate degree in the mathematical, physical, biological, or social sciences or in engineering. Applicants must have completed mathematical coursework at least through multivariate calculus, and

must have knowledge of basic statistics and basic linear algebra at the undergraduate level.

Applicants for the degree of master of science for teachers (M.S.T.) usually possess a background equivalent to at least a minor in mathematics and must have completed education courses sufficient for certification, or have three years teaching experience, or currently hold a full-time teaching position.

<http://ceps.unh.edu/mathematics-statistics>

Programs

- Applied Mathematics (Ph.D.) (<http://catalog.unh.edu/archives/2017-2018/graduate/programs-study/mathematics-statistics/applied-mathematics-phd>)
- Mathematics (Ph.D.) (<http://catalog.unh.edu/archives/2017-2018/graduate/programs-study/mathematics-statistics/mathematics-phd>)
- Mathematics Education (Ph.D.) (<http://catalog.unh.edu/archives/2017-2018/graduate/programs-study/mathematics-statistics/mathematics-education-phd>)
- Statistics (Ph.D.) (<http://catalog.unh.edu/archives/2017-2018/graduate/programs-study/mathematics-statistics/statistics-phd>)
- Mathematics (M.S.) (<http://catalog.unh.edu/archives/2017-2018/graduate/programs-study/mathematics-statistics/mathematics-ms>)
- Mathematics: Applied Mathematics (M.S.) (<http://catalog.unh.edu/archives/2017-2018/graduate/programs-study/mathematics-statistics/mathematics-applied-mathematics-ms>)
- Mathematics: Statistics (M.S.) (<http://catalog.unh.edu/archives/2017-2018/graduate/programs-study/mathematics-statistics/mathematics-statistics-ms>)
- Mathematics (M.S.T.) (<http://catalog.unh.edu/archives/2017-2018/graduate/programs-study/mathematics-statistics/mathematics-mst>)
- Industrial Statistics (Graduate Certificate) (<http://catalog.unh.edu/archives/2017-2018/graduate/programs-study/mathematics-statistics/industrial-statistics-certificate>)

Courses

Mathematics & Statistics (MATH)

MATH 801 - Exploring Mathematics for Teachers I
Credits: 3

Provides prospective elementary teachers with the opportunity to explore and master concepts involving number systems and operations, data analysis and probability. Additional topics may include geometry, measurement, and algebraic thinking. Mathematical reasoning, problem solving, and the use of appropriate manipulatives and technology are integrated throughout the course. Readings, class discussions, and assignments focus on mathematics content as well as applicable theories of learning, curriculum resources, and state and national recommendations. The course models instructional techniques that can be adapted to the elementary curricula. Prereq: EDUC 500 or EUDC 935; or permission. Credit offered only to M.Ed. and M.A.T., certificate students, and in-service teachers. (Not offered for credit if credit is received for MATH 821 or MATH 823.)

MATH 821 - Number Systems for Teachers**Credits:** 3

Ways of representing numbers, relationships between numbers, number systems, the meanings of operations and how they relate to one another, and computation with number systems as a foundation for algebra; episodes in history and development of the number system; and examination of the developmental sequence and learning trajectory as children learn number concepts. Credit offered only to M.Ed., M.A..T., Elementary Math Specialist certificate only students, and in-service teachers. Prereq: permission. Not offered for credit if credit received for MATH 621.

MATH 822 - Geometry for Teachers**Credits:** 3

Explorations of the foundations of informal measurement and geometry in one, two and three dimensions. The van Hiele model for geometric learning is used as a framework for how children build their understanding of length, area, volume, angles and geometric relationships. Visualization, spatial reasoning and geometric modeling are stressed. As appropriate, transformational geometry, congruence, similarity and geometric constructions will be discussed. Credit offered only to M.Ed., M.A..T., Elementary Math Specialist certificate only students, and in-service teachers. Prereq: permission. Not offered for credit if credit received for MATH 622.

MATH 823 - Statistics and Probability for Teachers**Credits:** 3

An introduction to probability, descriptive statistics and data analysis; exploration of randomness, data representation and modeling. Descriptive statistics will include measures of central tendency, dispersion, distributions and regression. Analysis of experiments requiring hypothesizing, experimental design and data gathering. Credit offered only to M.Ed., M.A..T., Elementary Math Specialist certificate only students, and in-service teachers. Prereq: MATH 621 or MATH 821, permission. Not offered for credit if credit received for MATH 623.

MATH 825 - Algebra and Functions for K-8 Mathematics Teachers**Credits:** 3

Representation and analysis of mathematical situations and structures using generalization and algebraic symbols and reasoning. Attention is given to the transition from arithmetic to algebra, working with quantitative change, and the description and prediction of change. Credit offered only to M.Ed., M.A..T., Elementary Math Specialist certificate only students, and in-service teachers. Prereq: MATH 621 or MATH 821, permission. Not offered for credit if credit received for MATH 625.

MATH 826 - Rational Numbers and Proportional Reasoning for K-8 Mathematics Teachers**Credits:** 3

Goal of this course is to prepare the K-8 mathematics teachers with sufficient mathematical knowledge for effective teaching of rational numbers and proportional reasoning. Attention is given to developing connections among a range of mathematical topics related to proportional reasoning, and the learning to assess elementary students' thinking about these topics. Credit offered only to M.Ed., M.A..T., Elementary Math Specialist certificate only students, and in-service teachers. Prereq: MATH 621 or MATH 821, permission.

MATH 831 - Mathematics for Geodesy**Credits:** 3

A survey of topics from undergraduate mathematics designed for graduate students in engineering and science interested in applications to geodesy and Earth Sciences. Topics include essential elements from analytic geometry, geometry of surfaces, linear algebra and statistics, Fourier analysis, discrete Fourier transforms and software, filtering applications to tidal data. Prereq: MATH 645, or the equivalent; MATH majors not allowed.

MATH 835 - Statistical Methods for Research**Credits:** 3

This course provides a solid grounding in modern applications of statistics to a wide range of disciplines by providing an overview of the fundamental concepts of statistical inference and analysis, including t-tests and confidence intervals. Additional topics include: ANOVA, multiple linear regression, analysis of cross classified categorical data, logistic regression, nonparameteric statistics and data mining using CART. The use of statistical software, such as JMP, S PLUS, or R, is fully integrated into the course.

MATH 836 - Advanced Statistical Methods for Research**Credits:** 3

An introduction to multivariate statistical methods, including principal components, discriminant analysis, cluster analysis, factor analysis, multidimensional scaling, and MANOVA. Additional topics include generalized linear models, general additive models, depending on the interests of class participants. This course completes a solid grounding in modern applications of statistics used in most research applications. The use of statistical software, such as JMP, S PLUS, or R, is fully integrated into the course. Prereq: MATH 835 or MATH 839.

MATH 837 - Statistical Methods for Quality Improvement and Design**Credits:** 3

Six Sigma is a popular, data-focused methodology used worldwide by organizations to achieve continuous improvement of their existing processes, products and services or to design new ones. This course provides a thorough introduction to the Six Sigma principles, methods, and applications for continuous improvement (DMAIC process) and an overview of Design for Six Sigma (DFSS). Both manufacturing and non-manufacturing (transactional Six Sigma) applications will be included. Emphasis is placed on the use of case studies to motivate the use of, as well as the proper application of, the Six Sigma methodology. Formal Six Sigma Green Belt certification from UNH may be attained by successfully completing TECH 696. Prereq: MATH 539, MATH 644; or permission.

MATH 838 - Data Mining and Predictive Analytics**Credits:** 3

An introduction to supervised and unsupervised methods for exploring large data sets and developing predictive models. Unsupervised methods include: market basket analysis, principal components, clustering, and variables clustering. Important statistical and machine learning methods (supervised learning) include: Classification and Regression Trees (CART), Random Forests, Neural Nets, Support Vector Machines, Logistic Regression and Penalized Regression. Additional topics focus on metamodeling, validation strategies, bagging and boosting to improve prediction or classification, and ensemble prediction from a set of diverse models. Required case studies and projects provide students with experience in applying these techniques and strategies. The course necessarily involves the use of statistical software and programming languages. Prereq: MATH 539 (or MATH 644); or permission.

MATH 839 - Applied Regression Analysis**Credits:** 3

Statistical methods for the analysis of relationships between response and input variables: simple linear regression, multiple regression analysis, residual analysis model selection, multi-collinearity, nonlinear curve fitting, categorical predictors, introduction to analysis of variance, analysis of covariance, examination of validity of underlying assumptions, logistic regression analysis. Emphasizes real applications with use of statistical software. Prereq: basic introductory statistics.

MATH 840 - Design of Experiments I**Credits:** 3

First course in design of experiments with applications to quality improvement in industrial manufacturing, engineering research and development, or research in physical and biological sciences. Experimental factor identification, statistical analysis and modeling of experimental results, randomization and blocking, full factorial designs, random and mixed effects models, replication and sub-sampling strategies, fractional factorial designs, response surface methods, mixture designs, and screening designs. Focuses on various treatment structures for designed experimentation and the associated statistical analyses. Use of statistical software. Prereq: basic introductory statistics; permission.

MATH 841 - Survival Analysis**Credits:** 3

Explorations of models and data-analytic methods used in medical, biological, and reliability studies. Event-time data, censored data, reliability models and methods, Kaplan-Meier estimator, proportional hazards, Poisson models, loglinear models. The use of statistical software, such as SAS, JMP, or R, is fully integrated into the course. Prereq: MATH 839. (Offered in alternate years.)

MATH 843 - Time Series Analysis**Credits:** 3

An introduction to univariate time series models and associated methods of data analysis and inference in the time domain and frequency domain. Topics include: Auto regressive (AR), moving average (MA), ARMA and ARIMA processes, stationary and non-stationary processes, seasonal ARIMA processes, auto-correlation and partial auto-correlation functions, identification of models, estimation of parameters, diagnostic checking of fitted models, forecasting, spectral density function, periodogram and discrete Fourier transform, linear filters. parametric spectral estimation, dynamic Fourier analysis. Additional topics may include wavelets and long memory processes (FARIMA) and GARCH Models. The use of statistical software, such as JMP, or R, is fully integrated in to the course. Prereq: MATH 835 or MATH 839. Offered in alternate years in the spring.

MATH 844 - Design of Experiments II**Credits:** 3

Second course in design of experiments, with applications in quality improvement and industrial manufacturing, engineering research and development, research in physical and biological sciences. Covers experimental design strategies and issues that are often encountered in practice complete and incomplete blocking, partially balanced incomplete blocking (PBIB), partial confounding, intra and inter block information, split plotting and strip plotting, repeated measures, crossover designs, Latin squares and rectangles, Youden squares, crossed and nested treatment structures, variance components, mixed effects models, analysis of covariance, optimizations, space filling designs, and modern screening design strategies. Prereq: MATH 840; or permission.

MATH 845 - Foundations of Applied Mathematics I**Credits:** 3

An introduction to Partial Differential Equations (PDEs) and associated mathematical methods and the analytical foundation for applied mathematics. Topics include: PDE classification, superposition, separation of variables, orthonormal functions, completeness, convergence, Fourier Series, Sturm-Liouville eigenvalue problems, and eigenfunctions. Methods are introduced for the analysis and solution of boundary value problems, in particular, the Heat, Wave, and Laplace equations. Prereq: Multi-dimensional calculus and ordinary differential equations.

MATH 846 - Foundations of Applied Mathematics II**Credits:** 3

An introduction to special functions, asymptotic analysis, and transform methods applied to partial differential equations. Topics include: Boundary value problems in cylindrical coordinates, the Bessel equation and Bessel functions, Fourier-Bessel expansions in cylindrically symmetric spatial domains, the Fourier Transform, the Hilbert Transform, Cosine and Sine Transforms, problems on semi-infinite intervals, and Asymptotic Analysis. Prereq: Multi-dimensional calculus and ordinary differential equations.

MATH 847 - Introduction to Nonlinear Dynamics and Chaos**Credits:** 3

An introduction to the mathematics of chaos and nonlinear dynamics. Topics include: linear and nonlinear systems of ordinary differential equations; discrete maps; chaos; phase plane analysis; bifurcations; and computer simulations. Prereq: elementary differential equations; linear algebra; and multidimensional calculus. (Not offered every year.)

MATH 853 - Introduction to Numerical Methods**Credits:** 3

Introduction to mathematical algorithms and methods of approximation. A wide survey of approximation methods are examined including, but not limited to, polynomial interpolation, root finding, numerical integration, approximation of differential equations, and techniques used in conjunction with linear systems. Included in each case is a study of the accuracy and stability of a given technique, as well as its efficiency and complexity. It is assumed that the student is familiar and comfortable with programming a high-level computer language. (Also offered as CS 853.)

MATH 855 - Probability with Applications**Credits:** 3

Introduces the theory, methods, and applications of randomness and random processes. Probability concepts, random variable, expectation, discrete and continuous probability distributions, joint distributions, conditional distributions; moment-generating functions, convergence of random variables.

MATH 856 - Principles of Statistical Inference**Credits:** 3

Introduces the basic principles and methods of statistical estimation and model fitting. One- and two-sample procedures, consistency and efficiency, likelihood methods, confidence regions, significance testing, Bayesian inference, nonparametric and re-sampling methods, decision theory. Prereq: MATH 855; or permission.

MATH 859 - Introduction to the R software**Credits:** 1

This course provides a basic introduction to the open-sources statistical software R for students who have never used this software or have never formally learned the basics of it. Topics include: Numeric calculations, simple and advanced graphics, object management and work-flow, RStudio, user-contributed packages, basic programming, writing of functions, statistical modeling and related graphs, distributed computing, reproducible research and document production via markup language.

MATH 861 - Abstract Algebra**Credits:** 3

This course establishes the axiomatic framework that underlies number systems and similar mathematical structures, investigating basic properties of groups, rings, fields and their homomorphisms.

MATH 862 - Linear Algebra**Credits:** 3

Abstract vector spaces, linear transformations, and matrices. Determinants, eigenvalues, and eigenvectors. Prereq: MATH 861.

MATH 863 - Abstract Algebra II**Credits:** 3

This course extends the investigations of MATH 861 into more specialized situations related to old and new problems in mathematics, such as the nature of solutions of polynomial equations. It presents advanced properties of groups, rings, fields and their applications. Prereq: MATH 861.

MATH 865 - Introduction to Commutative Algebra and Algebraic Geometry**Credits:** 3

Methods of determining solution sets of polynomial systems; affine varieties and their ideals; the 'algebra-geometry correspondence'; theory and applications of Grobner bases.

MATH 867 - One-Dimensional Real Analysis**Credits:** 3

Theory of limits, continuity, differentiability, integrability.

MATH 868 - Real Analysis II**Credits:** 3**MATH 869 - Introduction to Differential Geometry****Credits:** 3

Introduction to the study of the geometric properties of curves and surfaces in 3-dimensional space.

MATH 870 - Foundations of Number Theory**Credits:** 3

Factorization and prime numbers, arithmetic functions, congruences, reciprocity laws, quadratic forms, Diophantine equations, computational number theory. Offered in alternate years.

MATH 872 - Combinatorics**Credits:** 3

Graph theory (including planar graphs, graph coloring, Hamiltonian circuits, trees); counting principles (including permutations, combinations, pigeonhole principle, inclusion-exclusion principle); and related topics.

MATH 876 - Logic**Credits:** 3

Induction and recursion; sentential logic; first-order logic; completeness, consistency, and decidability; recursive function. (Not offered every year.)

MATH 883 - Set Theory**Credits:** 3

Axiomatic set theory, including its history, Zermelo-Fraenkel axioms, ordinal and cardinal numbers, consistency, independence, and undecidability. (Not offered every year.)

MATH 884 - Topology**Credits:** 3

Open sets, closure, base, and continuous functions. Connectedness, compactness, separation axioms, and metrizable.

MATH 888 - Complex Analysis**Credits:** 3

Complex functions, sequences, limits, differentiability and Cauchy-Riemann equations, elementary functions, Cauchy's theorem and formula, Taylor's and Laurent's series, residues, conformal mapping. Prereq: MATH 867.

MATH 896 - Topics in Mathematics and Statistics**Credits:** 1-4

New or specialized courses not covered in regular course offerings. Prereq: permission of instructor. May be repeated.

MATH 898 - Master's Project**Credits:** 1-6

May be repeated to a maximum of 6 credits. IA (continuous grading). Cr/F.

MATH 899 - Master's Thesis**Credits:** 1-6

May be repeated up to a maximum of 6 credits. Cr/F.

MATH 900 - Bridges from the Classroom to Mathematics**Credits:** 1

An introduction to the goals of the MST program. Students have the opportunity to explore mathematical problems; to complete activities that make connections between several areas of mathematics, including the mathematical content in the MST degree program and the secondary school mathematics classroom; and to participate in readings/on-line discussion on the nature of mathematics. Permission required. Cr/F.

MATH 902 - Classroom Mathematics Practicum**Credits:** 1

A follow-up course to the six core mathematics content courses of the MST degree program. During the course, students choose a mathematical topic and/or set of concepts learned in one of the core MST courses and develop and teach a unit based on these concepts at the middle school or secondary school level. Permission required. Cr/F.

MATH #903 - Algebraic Structures**Credits:** 3

An exploration of the structural similarities between and among seemingly disparate number systems, beginning with counting numbers, and progressing to integers, the rational numbers, the real numbers, and the complex numbers; and leading to a discussion of polynomials as an integer analogue and to fields as polynomial "quotients" through the basic concepts of splitting fields and Galois Theory. Permission required.

MATH 905 - Euclidean and non-Euclidean Geometries from a Synthetic Perspective**Credits:** 3

An axiomatic development of geometry, beginning with finite geometries; emphasis is given to the fundamental concepts of Euclidean and non-Euclidean geometries from a synthetic perspective. Permission required.

MATH 906 - Analytic and Transformational Geometry**Credits:** 3

Fundamental concepts of transformational, projective geometry, and inversive geometry, including properties of conics and quadratic surfaces. Permission required.

MATH #907 - Real Analysis**Credits:** 3

An introduction to the fundamental concepts in real analysis that provide the mathematical foundation for calculus. Content focuses on properties of sequences and series; properties of functions, including continuity, the derivative and the Riemann integral. Permission required.

MATH 909 - Probability and Statistics for Teachers**Credits:** 3

Permutations and combinations; finite sample spaces; random variables; binomial distributions; statistical applications.

MATH 910 - Selected Topics in Mathematics Education for Teachers**Credits:** 1-4

Current developments and issues in mathematics education; content, curricula, methods, and psychology of teaching mathematics. Can be repeated for credit.

MATH 913 - Graph Theory and Topics in Discrete Mathematics**Credits:** 3

Key theoretical and computational aspects of graph theory and related areas of discrete mathematics. Applications of graph theory as well as current "open" problems are explored. Permission required.

MATH 914 - Topology for Teachers**Credits:** 3

Fundamental concepts of elementary topology; network and map problems; sets, spaces, and transformations.

MATH 915 - Algebraic Structures**Credits:** 3

An exploration of the structural similarities between and among seemingly disparate number systems, beginning with counting numbers, and progressing to integers, the rational numbers, the real numbers, and the complex numbers; and leading to a discussion of polynomials as an integer analogue and to fields as polynomial "quotients" through the basic concepts of splitting fields and Galois Theory. Permission required.

MATH 916 - Theory of Numbers for Teachers**Credits:** 3

Divisibility and primes; congruences; quadratic reciprocity; number theoretic functions; Diophantine equations; perfect and amicable numbers.

MATH 917 - Mathematical Proof and Problem Solving**Credits:** 3

Introduction to abstract mathematics with an emphasis on problem solving and proof structure, methods and techniques. Content includes logic, set theory and basic number theory.

MATH 918 - Analysis of Real Numbers**Credits:** 3

An introduction to the fundamental concepts in real analysis that provide the mathematical foundation for calculus. Content focuses on properties of sequences and series; properties of functions, including continuity, the derivative and the Riemann integral. Permission required.

MATH 920 - History of Mathematics**Credits:** 3

A problem-study approach to mathematical problems from the period of Greek mathematics until the modern era.

MATH 925 - Problem Solving Seminar**Credits:** 3

A study of variety of problem solving strategies and techniques in the context of solving mathematical problems. Problems will emphasize the connections between the core areas of algebra, geometry and analysis. Other mathematical topics may be included. Typically taken in conjunction with the Concluding Experience Problem Set. Cr/F.

MATH 928 - Selected Topics in Mathematics for Teachers**Credits:** 1-3

New or specialized topics not covered in the regular course offerings. May be repeated for credit.

MATH 929 - Directed Reading**Credits:** 1-3

A directed reading project on a selected topic in mathematics or mathematics education, planned in collaboration with a faculty member. May be repeated up to 6 credits.

MATH 931 - Mathematical Physics**Credits:** 3

Complex variables, differential equations, asymptotic methods, integral transforms, special functions, linear vector spaces and matrices, Green's functions, and additional topics selected from integral equations, variational methods, numerical methods, tensor analysis, and group theory. Prereq: differential equations; linear algebra; multidimensional calculus. (Also offered as PHYS 931.)

MATH 941 - Bayesian and Computational Statistics**Credits:** 3

Current approaches to Bayesian modeling and data analysis and related statistical methodology based on computational simulation. Fundamentals of Bayesian estimation and hypothesis testing. Multi-level and hierarchical Bayesian modeling for correlated data. Introduction to Markov chain Monte Carlo based estimation approaches such as the Gibbs sampler and the Metropolis-Hastings algorithm. Prereq: knowledge of intermediate statistics: distributions, discrete and continuous random variables, transformation of variables (calculus based), bivariate and multivariate normal distribution, maximum likelihood estimation; working knowledge of linear regression and analysis of variance; basic linear algebra: vectors and matrices, linear spaces, matrix multiplication, inverse of a matrix, positive definiteness. Matrix-vector notation for linear regression and ANOVA.

MATH 944 - Spatial Statistics**Credits:** 3

Frequentist and Bayesian methods for estimation of characteristics measured in space (usually 2-dimensional Euclidean space). Spatial averaging. Spatial point processes: models for clustering and inhibition. Cluster detection. Point referenced data: variogram estimation, Kriging, spatial regression. Lattice based data: spatial auto-regression, Markov random field models. Spatial regression models. Non-Gaussian response variables. Hierarchical Bayesian spatial models and Markov chain Monte Carlo methods. Multivariable spatial models. Prereq: Intermediate statistics including basics of maximum likelihood estimation; linear regression modeling including familiarity with matrix notation, basic concepts of calculus including partial derivatives.

MATH 945 - Advanced Theory of Statistics I**Credits:** 3

Introduction to the theory and practice of statistical modeling and inference. Basic multivariate analysis: covariance and expectation, multivariate-normal and non-central chi-squared distributions, linear and quadratic forms. Basic inequalities for probabilities and expectations: Markov, Chebyshev, Jensen, and Cauchy-Schwartz. Basic decision theory, sufficiency, minimal sufficiency, ancillarity and completeness, Point estimation: method of moments, maximum likelihood, Bayesian procedures, likelihood procedures and information inequalities. Measures of performance, notions of optimality, and construction of optimal procedures in simple situations. Convergence in distribution and in probability. Prereq: MATH 856; or permission.

MATH 946 - Advanced Theory of Statistics II**Credits:** 3

Asymptotic statistical inference: consistency, asymptotic normality and efficiency. Hypothesis testing: Neyman-Pearson lemma, uniformly most powerful test, generalized likelihood ratio tests, Chi squared goodness-of-fit tests, Wald tests and related confidence intervals, pivotal quantities, optimality properties. Modern likelihood methods (quasi, pseudo and composite). Algorithmic inference: Gibbs sampling, bootstrapping, simultaneous inferences in high-dimensional data and functional data. Nonparametric and semiparametric estimation methods, asymptotic estimation theory and large sample tests. Prereq: MATH 945; or permission.

MATH 951 - Algebra I**Credits:** 3

Groups and their homomorphisms, products and sums, structure of groups; rings and their homomorphisms, ideals, factorization properties. Prereq: MATH 861.

MATH 952 - Algebra II**Credits:** 3

Field extensions; Galois theory; module theory. Prereq: MATH 951.

MATH 953 - Analysis I**Credits:** 3

Measurable spaces and functions, measures, Lebesgue integrals, convergence theorems. Prereq: MATH 867.

MATH 954 - Analysis II**Credits:** 3

Cauchy theory and local properties of analytic functions, Riemann mapping theorem, representation theorems, harmonic functions. Prereq: MATH 888.

MATH 955 - Topology I**Credits:** 3

Subspace, product, and quotient topologies; embedding; separation and countability axioms; connectedness; compactness and compactifications; paracompactness, metrization, and metric completions. Prereq: MATH 884.

MATH 956 - Topology II**Credits:** 3

Chain complexes; homology of simplicial complexes, singular homology and cohomology; axiomatic homology; cup and cap products. Prereq: MATH 861 and MATH 884.

MATH 958 - Foundations of Math Education**Credits:** 3

Topics will include: major issues, trends, and programs in mathematics education research, the research process, theoretical perspectives to guide research, the profession and infrastructure of mathematics education, cultural and historical aspects of mathematics education, and the research-practice interface. Examples span the K-16 spectrum. Prereq: permission.

MATH 961 - Topics in Algebra I**Credits:** 3

An introduction to topics chosen from algebra and number theory. Prereq: MATH 951-MATH 952. May be repeated.

MATH 964 - Topics in Analysis I**Credits:** 3

An introduction to topics in analysis. Prereq: permission. May be repeated.

MATH 965 - Topics in General Topology I**Credits:** 3

An introduction to topics in general topology. Prereq: MATH 955. May be repeated.

MATH 966 - Topics in Algebraic Topology I**Credits:** 3

An introduction to topics in algebraic topology. Prereq: MATH 956. May be repeated.

MATH #967 - Topics in Applied Mathematics I**Credits:** 3

An introduction to topics in applied mathematics. Prereq: permission. May be repeated.

MATH 968 - Topics in Mathematics Education I**Credits:** 3

A) The Teaching and Learning of Mathematics; B) Curriculum and History in Mathematics Education. Topics selected from: epistemologies of knowledge applied to mathematics; theories of learning and teaching mathematics; theoretical perspectives in research; mathematics education research programs K-16; research methods for studying mathematics teaching, learning, and curricula; theoretical frameworks for curriculum development, implementation of new curricula, and research on curricula; historical perspectives of research in mathematics education; the evolution and history of K-16 mathematics curricula both in United States and internationally. Versions A and B offered alternately. Prereq: MATH 958 or permission. May be repeated.

MATH 969 - Topics in Probability and Statistics I**Credits:** 3

Selected advanced topics from one or several of the following areas: probability, stochastic processes, design of experiments, biostatistics, Bayesian theory and methods, spatial and spatio-temporal statistics, time series analysis, nonparametric statistics. Prereq: permission. May be repeated.

MATH 971 - Topics in Algebra II**Credits:** 3

An introduction to advanced topics chosen from algebra and number theory. Prereq: MATH 951 - MATH 952; permission. May be repeated.

MATH 973 - Topics in Operator Theory**Credits:** 3

Selected topics in operator theory. Prereq: MATH 963. May be repeated.

MATH 977 - Topics in Applied Mathematics II**Credits:** 3

An exploration of an area of research in applied mathematics. Prereq: permission. May be repeated.

MATH 978 - Topics in Mathematics Education II**Credits:** 3

An exploration of an area of research in mathematics education. Prereq: permission. May be repeated.

MATH 979 - Research Topics in Statistics**Credits:** 3

An exploration of the main statistical issues and computational methods associated with research problems from such areas as survival analysis, reliability, latitudinal data, categorical data, spatio-temporal data, and industrial processes. Student term projects require: literature searches, presentation, use of modern statistical software, and written reports. Prereq: permission. May be repeated.

MATH 997 - Statistics Seminar**Credits:** 1

A seminar of weekly and bi-weekly meetings organized by the statistics Ph.D. students with supervision by a statistics faculty member. Informal presentations of faculty members, students, and outside guest presenters; also discussion of topics that are of mutual interest to its participants. Dissertation proposal presentations. Seminar presentations are open to the greater public. Statistics Ph.D. students are required to enroll for at least 3 semesters. Attendance is mandatory by those students who are enrolled in the seminar. Credits do not count towards the Master's degree. May be repeated to a maximum of 6 credits.

MATH 998 - Reading Courses**Credits:** 1-6

A) Algebra; B) Analysis; C) Operator Theory; D) Geometry; E) General Topology; F) Algebraic Topology; G) Applied Mathematics; H) Mathematics Education; I) Probability and Statistics. Prereq: permission.

MATH 999 - Doctoral Research**Credits:** 0

Cr/F.

Integrated Applied Mathematics (IAM)

IAM 830 - Graduate Ordinary Differential Equations**Credits:** 3

Course is a graduate-level course on ordinary differential equations. It is designed to be accessible to first-year graduate students from math, science or engineering backgrounds who have had a first undergraduate course in differential equations, along with a standard calculus sequence. The course is designed to begin with an intensive review of undergraduate differential equations and then will proceed to handle more advanced concepts, starting with multi-dimensional coupled systems of ordinary differential equations, exponential matrix solutions, using coordinate transformations for conversion to standard forms, nonlinear systems and transform-based solutions, using coordinate transformations for conversion to standard forms, nonlinear systems and transform-based techniques. The course will have an interdisciplinary and applied style and will cover the following topics: Intense review of undergraduate differential equations, Power Series and Fourier Series solutions, Multi-dimensional D.E.s, eigenvectors and Jordan forms, Numerical Methods, Nonlinear D.E.s Dynamical Systems and Chaos.

IAM 851 - Introduction to High-Performance Computing**Credits:** 3

Course gives an introduction to select areas of high-performance computing, providing a basis for writing and working with high-performance simulation codes. The three main topics are: 1) basic software engineering, 2) high-performance and parallel programming, and 3) performance analysis and modeling. Additional topics may include heterogeneous architectures like GPUs and data analysis/visualization. Prereq: Enrollment in a CEPS graduate program, MATH 753, working knowledge of a programming language (C or Fortran), or by permission of instructor.

IAM 932 - Graduate Partial Differential Equations**Credits:** 3

Graduate level introduction to the analysis of linear and nonlinear partial differential equations. topics include: separation of variables, Fourier series, weak and strong solutions, eigenfunction expansions, the Sturm-Liouville problem, Green's functions and fundamental solutions, method of characteristics, and conservation laws. Prereq: Ordinary Differential Equations and Linear Algebra.

IAM 933 - Applied Functional Analysis**Credits:** 3

Introduction to rigorous mathematical analysis from the perspective of applications. Topics include: metric and normed spaces; convergence; completeness; continuity; Lebesgue measure theory; convergence theorems; Banach, Hilbert, L_p , and Sobolev spaces; orthogonality, bases, and projections; Sturm-Liouville theory; spectral theory; distributions; and weak solutions. Applications including to differential and integral equations, are presented throughout. Prereq: real analysis or graduate introductory courses in mathematical physics or applied mathematics.

IAM 940 - Asymptotic and Perturbation Methods**Credits:** 3

Introduction to the asymptotic analysis of linear and nonlinear algebraic equations, ODEs, and PDEs and the asymptotic approximation of integrals arising as transform solutions to ODEs/PDEs. Topics include: algebraic equations and dominant balance; asymptotic approximations; complex variable theory and the asymptotic evaluation of integrals via Laplace's method, stationary phase, and steepest descents; the method of matched asymptotic expansions (boundary-layer theory), coordinate straining, multiple scales, averaging, homogenization theory, and WKBJ analysis for singularly perturbed ODEs and PDEs. Prereq: MATH 527, MATH 528, MATH 644 or equivalent. Pre- or Coreq: PHYS 931.

IAM 950 - Spatiotemporal and Turbulent Dynamics**Credits:** 3

Advanced graduate course on the dynamics of spatiotemporal patterns in nonlinear time-dependent PDEs. Topics include nonlinear pattern formation, bifurcations and symmetry, nonlinear WKB analysis, phase diffusion/amplitude modulation theory, unstable coherent structures in turbulence, and periodic orbit theory. Example systems include 1d and 2d Swift-Hohenberg equation, the 1d Kuramoto-Sivashinsky equation, Rayleigh-Benard convection, and Navier-Stokes in plane Couette and pipe flows. Prereq: MATH 847 and IAM 932, or equivalent; or permission.

IAM 961 - Numerical Analysis I: Numerical Linear Algebra

Credits: 3

Introduction to numerical analysis and computational methods for linear systems. Topics include: IEEE floating point arithmetic; vector norms and induced norms; conditioning; projectors; LU decompositions; pivoting; Cholesky factorization; QR decompositions; Gram-Schmidt orthogonalization; Householder triangularization; Singular Value decompositions; least squares problems; stability; eigenvalue problems; power iterations; QR algorithm; Krylov methods; Arnoldi iteration; GMRES; Lanczos iteration; Conjugate gradient algorithms; and Preconditioning. Prereq: scientific programming and linear algebra.

IAM 962 - Numerical Partial Differential Equations

Credits: 3

Numerical analysis applied to partial differential equations. Initial topics include the implementation of finite difference and spectral methods applied to the heat equation, wave equation, Burger's equation, and other model equations. The remainder of the course treats numerical analysis, starting with a brief review of function spaces. The primary topics include approximation theory for Sobolov spaces, projection operators, completeness, convergence, and error estimates. Prereq: IAM 961 or permission.

Faculty

See <http://ceps.unh.edu/faculty/mathematics-statistics> for faculty.