

APPLIED MATHEMATICS

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Faculty with Research Interests

For information regarding faculty visit the Department of Applied Mathematics website.

Applied mathematics is the mathematics that is created in response to problems in science, engineering, and society. Applied mathematicians work on a wide variety of topics such as how to construct methods for multi-criteria decision making (requiring discrete mathematics and statistics), predicting how the financial markets will behave (requiring probability/statistics, analysis, optimization), analyzing how liquid flows around solids, and how ions move in biological environments (requiring expertise in computational methods and analysis). Students with an applied mathematics background are prepared for careers in the insurance industry, electronics and computer manufacturers, logistics companies, pharmaceutical firms, and more. An applied mathematics background also prepares students for continuing on the academic path, in graduate programs in pure and applied mathematics, statistics, data science, and financial mathematics.

Our graduates work in financial and insurance companies as analysts, computer and IT companies as programmers and hardware developers, and in many different fields as researchers, as well as in academia. They have gone to excellent graduate schools in mathematics (pure, applied, and financial), statistics, physics, design, accounting, and M.B.A. programs. Students have the flexibility to assemble a portfolio of courses that will satisfy both intellectual needs and career preparation. There is a wide variety of courses offered, with strengths in contemporary topics in applied mathematics: stochastic analysis (including mathematical finance), applied analysis, computational mathematics, discrete mathematics, and statistics.

The department offers two degree programs, a B.S. in Applied Mathematics and a B.S. in Statistics. A minor is required, which gives students an area of focus where mathematics or statistics may be applied. With a minor in computer science, business, or one of the engineering areas, for example, the student will be well prepared to enter the job market in business or government.

If desired, students can select a specialization (taking electives appropriate for different career paths) or double major in another subject such as computer science or physics. There is also the option of a co-terminal degree, where a student graduates with a B.S. and a master's degree at the same time, in as little as five years.

Degree Programs

- Bachelor of Science in Applied Mathematics
- Bachelor of Science in Data Science
- Bachelor of Science in Statistics

Co-Terminal Options

The Department of Applied Mathematics also offers the following co-terminal degrees, which enables a student to simultaneously complete both an undergraduate and graduate degree in as few as five years:

- Bachelor of Science in Applied Mathematics/Master of Science in Applied Mathematics
- Bachelor of Science in Applied Mathematics/Master of Computer Science
- Bachelor of Science in Applied Mathematics/Master of Science in Computer Science
- Bachelor of Science in Applied Mathematics/Master of Data Science
- Bachelor of Science in Applied Mathematics/Master of Mathematical Finance

These co-terminal degrees allow students to gain greater knowledge in specialized areas while, in most cases, completing a smaller number of credit hours with increased scheduling flexibility. For more information, please visit the Department of Applied Mathematics website (science.iit.edu/applied-mathematics/programs).

Minors

- Minor in Applied Mathematics
- Minor in Computational Mathematics
- Minor in Data Science
- Minor in Statistics

Course Descriptions

DS 100

Introduction to the Profession

Introduces students to data science as a profession, as currently practiced and continuing to develop. Presents various elements of the data science life cycle at an introductory level, culminating with a start-to-finish data analysis project. Includes guest lectures from data science practitioners and faculty. Explores real-world examples of ethical issues, bias, and privacy in data science. Survey careers in data science and familiarize students with elements of career development.

Lecture: 3 Lab: 0 Credits: 3

DS 151

Introduction to Data Science

This course introduces the critical concepts and skills in statistical inference, machine learning, and computer programming, through hands-on analysis of real-world datasets from various fields.

Lecture: 3 Lab: 0 Credits: 3

DS 251

Mathematical Foundations for Data Science I

This course introduces the critical mathematical foundation knowledge for data science. Specifically, this course covers the basic topics on linear algebra and discrete math that are most relevant to the data science major.

Prerequisite(s): MATH 251

Lecture: 3 Lab: 0 Credits: 3

DS 261

Ethics and Privacy in Data Science

This course introduces the critical concepts and skills of ethics and privacy in data science, as well as hands-on implementation of important algorithms. It will cover important concepts of bias and privacy, and the computational strategies to ensure fairness and privacy in a variety of emerging data science applications. The course provided hands-on experience in collecting, analyzing, and modeling data for tackling ethical issues.

Lecture: 3 Lab: 0 Credits: 3

DS 351

Mathematical Foundations for Data Science II

This course introduces mathematical tools from optimization, differential equations, and numerical analysis etc. that are relevant to the data science major.

Prerequisite(s): DS 251

Lecture: 3 Lab: 0 Credits: 3

DS 451

Data Science Life Cycle

This course is designed to educate the data science students in the typical project life-cycle stages required in the data science professions. Stages of a data science project from start to finish such as obtaining data, exploring data, determining what questions the data can answer, exploratory analysis, ethical impacts analysis and mitigation, hypothesis (re-)formulation, in-depth analysis, validation, and reporting, are presented.

Prerequisite(s): DS 251 or MATH 484 or CS 484 or CS 422

Lecture: 3 Lab: 0 Credits: 3

DS 472

Data Science Practicum

In this project-oriented course, students will work in small groups to solve real-world data analysis problems and communicate their results. Innovation and clarity of the presentation will be key elements of evaluation. Students will have an option to do this as an independent data analytics internship with an industry partner.

Prerequisite(s): DS 451 or CSP 571

Credit: Variable

DS 480

Data Science Projects

In this capstone course, students will work in teams to explore a data-rich real-world issue from business, industry, government, or scientific research. Teams will identify a problem, then model, solve, and communicate their solution using data science techniques such as data mining, regression, machine learning, hypothesis testing, and data visualization. Emphasis will be placed on team building, planning, reflection and course correction, and reporting in written and presentation form. Ethics and privacy implications will be identified and explored, so that each team conducts the modeling and reporting process appropriately.

Prerequisite(s): CS 422 or CS 484 or DS 451 or MATH 476 or MATH 484

Lecture: 3 Lab: 0 Credits: 3

MATH 100

Introduction to the Profession

Introduces the student to the scope of mathematics as a profession, develops a sense of mathematical curiosity and problem solving skills, identifies and reinforces the student's career choices, and provides a mechanism for regular academic advising. Provides integration with other first-year courses. Introduces applications of mathematics to areas such as engineering, physics, computer science, and finance. Emphasis is placed on the development of teamwork skills.

Lecture: 3 Lab: 0 Credits: 3

Satisfies: Communications (C)

MATH 119**Geometry for Architects**

Basic Euclidean and analytic geometry in two and three dimensions; trigonometry. Equations of lines, circles and conic sections; resolution of triangles; polar coordinates. Equations of planes, lines, quadratic surfaces. Applications. This course does not count toward business, computer science, engineering, mathematics, or natural science degree programs.

Lecture: 3 Lab: 1 Credits: 3

MATH 122**Introduction to Calculus**

Basic concepts of calculus of a single variable; limits, continuity, derivatives, and integrals. Applications. This course does not count toward any business, computer science, engineering, mathematics, or natural science degree programs.

Prerequisite(s): MATH 119 or MATH 148

Lecture: 3 Lab: 1 Credits: 3

MATH 130**Thinking Mathematically**

This course allows students to discover, explore, and apply modern mathematical ideas. Emphasis is placed on using sound reasoning skills, visualizing mathematical concepts, and communicating mathematical ideas effectively. Classroom discussion and group work on challenging problems are central to the course. Topics from probability, statistics, logic, number theory, graph theory, combinatorics, chaos theory, the concept of infinity, and geometry may be included. This course does not count toward any computer science, engineering, mathematics, or natural science degree programs.

Lecture: 3 Lab: 0 Credits: 3

MATH 131**Mathematics for Sustainability**

The course provides students with the mathematical background and quantitative reasoning skills necessary to engage as informed citizens in discussions of sustainability related to climate change, resources, pollution, recycling, economic change, and similar matters of public interest. Introduces mathematical modeling techniques with examples related to environmental and economic sustainability. Emphasis is placed on quantitative reasoning, visualization of mathematical concepts and effective communication, both verbally and textually, through writing projects that require quantitative evidence to support an argument, classroom activities, and group work. Topics range from probability, statistics, decision theory, graph theory, physics, modeling, and algebra.

Lecture: 3 Lab: 0 Credits: 3

MATH 147**College Algebra**

This course is an in-depth study of the properties of the set of real numbers; operations with exponents (integer and rational), radicals, and logarithms; simplifying polynomials and rational expressions; and solving equations, inequalities, and systems of equations.

Lecture: 4 Lab: 0 Credits: 4

MATH 148**Preparation for Calculus**

Review of algebra and analytic geometry. Functions, limits, derivatives. Trigonometry, trigonometric functions and their derivatives. Inverse functions, inverse trigonometric functions and their derivatives. Exponential and logarithmic functions. This course does not count toward any mathematics requirements in business, computer science, engineering, mathematics, or natural science degree programs.

Prerequisite(s): MATH 147 with min. grade of C

Lecture: 4 Lab: 0 Credits: 4

MATH 151**Calculus I**

Analytic geometry. Functions and their graphs. Limits and continuity. Derivatives of algebraic and trigonometric functions. Applications of the derivative. Introduction to integrals and their applications.

Prerequisite(s): IIT Mathematics Placement score of 151 or MATH 145 with min. grade of C or MATH 148 with min. grade of C

Lecture: 4 Lab: 1 Credits: 5

Satisfies: Communications (C)

MATH 152**Calculus II**

Transcendental functions and their calculus. Integration techniques. Applications of the integral. Indeterminate forms and improper integrals. Polar coordinates. Numerical series and power series expansions.

Prerequisite(s): MATH 149 with min. grade of C or MATH 151 with min. grade of C

Lecture: 4 Lab: 1 Credits: 5

Satisfies: Communications (C)

MATH 180**Fundamentals of Discrete Mathematics**

Basic counting techniques, discrete probability, graph theory, algorithm complexity, logic and proofs, and other fundamental discrete topics. Required for students in the Bachelor of Information Technology and Management degree. This course does not count toward any computer science, engineering, mathematics, or natural science degree program. Credit will only be granted for one of MATH 180, MATH 230, and CS 330.

Lecture: 3 Lab: 0 Credits: 3

MATH 191**Business Calculus**

This is an introduction to basic calculus with an emphasis on applications to business economics, management, information science, and related fields. Topics include relations and functions, limits, continuity, derivatives, techniques of differentiation, chain rule, applications of differentiation, antiderivatives, the definite integral, the fundamental theorem of calculus, and applications of integration.

Prerequisite(s): MATH 148

Lecture: 4 Lab: 0 Credits: 4

MATH 192**Finite Mathematics**

Finite Mathematics contains a carefully selected set of topics in probability and linear algebra, topics that provide the foundation for understanding any future statistics course and many phenomena you may well encounter in your life. The probability portion in the first half of the course provides the basis of understanding chance. It culminates in a discussion of Bayes' formula which is useful for understanding medical testing, drug testing, and lie detector testing and for understanding public policy for the use of these tests. The second half covers basic linear algebra culminating in linear optimization techniques which are useful in applications from baking to business. The two topics are tied together at the end of the course through a brief introduction to Markov chains, a common elementary mathematical model in social science, business, and science.

Lecture: 3 Lab: 0 Credits: 3

MATH 225**Introductory Statistics**

An introduction to statistics; data collection, description, visualization and analysis; basic probability; statistical reasoning and inference including hypothesis tests and confidence intervals: t-tests, chi-squared tests, ANOVA, correlation and regression.

Lecture: 3 Lab: 0 Credits: 3

Satisfies: Communications (C)

MATH 230**Introduction to Discrete Math**

Sets, statements, and elementary symbolic logic; relations and digraphs; functions and sequences; mathematical induction; basic counting techniques and recurrence. Credit will not be granted for both CS 330 and MATH 230.

Lecture: 3 Lab: 0 Credits: 3

Satisfies: Communications (C)

MATH 251**Multivariate and Vector Calculus**

Analytic geometry in three-dimensional space. Partial derivatives. Multiple integrals. Vector analysis. Applications.

Prerequisite(s): MATH 152

Lecture: 4 Lab: 1 Credits: 4

MATH 252**Introduction to Differential Equations**

Linear differential equations of order one. Linear differential equations of higher order. Series solutions of linear DE. Laplace transforms and their use in solving linear DE. Introduction to matrices. Systems of linear differential equations.

Prerequisite(s): MATH 152

Lecture: 4 Lab: 0 Credits: 4

MATH 332**Elementary Linear Algebra**

Systems of linear equations; matrix algebra, inverses, determinants, eigenvalues, and eigenvectors, diagonalization; vector spaces, basis, dimension, rank and nullity; inner product spaces, orthonormal bases; quadratic forms.

Prerequisite(s): MATH 251*. An asterisk (*) designates a course which may be taken concurrently.

Lecture: 3 Lab: 0 Credits: 3

MATH 333**Matrix Algebra and Complex Variables**

Vectors and matrices; matrix operations, transpose, rank, inverse; determinants; solution of linear systems; eigenvalues and eigenvectors. The complex plane; analytic functions; contour integrals; Laurent series expansions; singularities and residues.

Prerequisite(s): MATH 251

Lecture: 3 Lab: 0 Credits: 3

MATH 350**Introduction to Computational Mathematics**

Study and design of mathematical models for the numerical solution of scientific problems. This includes numerical methods for the solution on linear and nonlinear systems, basic data fitting problems, and ordinary differential equations. Robustness, accuracy, and speed of convergence of algorithms will be investigated including the basics of computer arithmetic and round-off errors. Same as MMAE 350.

Prerequisite(s): (CS 104 or CS 105 or CS 115) and MATH 251 and MATH 252*. An asterisk (*) designates a course which may be taken concurrently.

Lecture: 3 Lab: 0 Credits: 3

Satisfies: Communications (C)

MATH 374**Probability and Statistics for Electrical and Computer Engineers**

This course focuses on the introductory treatment of probability theory including: axioms of probability, discrete and continuous random variables, random vectors, marginal, joint, conditional and cumulative probability distributions, moment generating functions, expectations, and correlations. Also covered are sums of random variables, central limit theorem, sample means, and parameter estimation. Furthermore, random processes and random signals are covered. Examples and applications are drawn from problems of importance to electrical and computer engineers. Credit only granted for one of MATH 374, MATH 474, and MATH 475.

Prerequisite(s): MATH 251

Lecture: 3 Lab: 0 Credits: 3

MATH 380**Introduction to Mathematical Modeling**

This course provides an introduction to problem-driven (as opposed to method-driven) applications of mathematics with a focus on design and analysis of models using tools from all parts of mathematics.

Prerequisite(s): (CS 104 or CS 105 or CS 115) and MATH 251 and MATH 252* and MATH 332*. An asterisk (*) designates a course which may be taken concurrently.

Lecture: 3 Lab: 0 Credits: 3

Satisfies: Communications (C)

MATH 400**Real Analysis**

Real numbers, continuous functions; differentiation and Riemann integration. Functions defined by series.

Prerequisite(s): MATH 251 or Graduate standing

Lecture: 3 Lab: 0 Credits: 3

MATH 402**Complex Analysis**

Analytic functions, conformal mapping, contour integration, series expansions, singularities and residues, and applications. Intended as a first course in the subject for students in the physical sciences and engineering.

Prerequisite(s): MATH 251 or Graduate standing

Lecture: 3 Lab: 0 Credits: 3

MATH 405**Introduction to Iteration and Chaos**

Functional iteration and orbits, periodic points and Sharkovsky's cycle theorem, chaos and dynamical systems of dimensions one and two. Julia sets and fractals, physical implications.

Prerequisite(s): (MATH 251 and MATH 252 and MATH 332) or (MATH 252 and MATH 333 and MATH 251) or Graduate standing

Lecture: 3 Lab: 0 Credits: 3

MATH 410**Number Theory**

Divisibility, congruencies, distribution of prime numbers, functions of number theory, diophantine equations, applications to encryption methods.

Prerequisite(s): MATH 230 or Graduate standing

Lecture: 3 Lab: 0 Credits: 3

MATH 420**Geometry**

The course is focused on selected topics related to fundamental ideas and methods of Euclidean geometry, non-Euclidean geometry, and differential geometry in two and three dimensions and their applications with emphasis on various problem-solving strategies, geometric proof, visualization, and interrelation of different areas of mathematics. Permission of the instructor is required.

Lecture: 3 Lab: 0 Credits: 3

MATH 425**Statistical Methods**

Concepts and methods of gathering, describing and analyzing data including basic statistical reasoning, basic probability, sampling, hypothesis testing, confidence intervals, correlation, regression, forecasting, and nonparametric statistics. No knowledge of calculus is assumed. This course is useful for students in education or the social sciences. This course does not count for graduation in any mathematics programs. Credit not given for both MATH 425 and MATH 476.

Lecture: 3 Lab: 0 Credits: 3

MATH 426**Statistical Tools for Engineers**

Descriptive statistics and graphs, probability distributions, random sampling, independence, significance tests, design of experiments, regression, time-series analysis, statistical process control, introduction to multivariate analysis. Same as CHE 426. Credit not given for both Math 426 and CHE 426.

Lecture: 3 Lab: 0 Credits: 3

MATH 430**Applied Algebra**

Introduction to groups, homomorphisms, group actions, rings, field theory. Applications, including constructions with ruler and compass, solvability by radicals, error correcting codes.

Prerequisite(s): MATH 230 or MATH 332* or Graduate standing, An asterisk (*) designates a course which may be taken concurrently.

Lecture: 3 Lab: 0 Credits: 3

Satisfies: Communications (C)

MATH 431**Computational Algebraic Geometry**

Systems of polynomial equations and ideals in polynomial rings; solution sets of systems of equations and algebraic varieties in affine n-space; effective manipulation of ideals and varieties, algorithms for basic algebraic computations; Groebner bases; applications. Credit may not be granted for both MATH 431 and MATH 530.

Prerequisite(s): MATH 332 and MATH 230

Lecture: 3 Lab: 0 Credits: 3

Satisfies: Communications (C)

MATH 435**Linear Optimization**

Introduction to both theoretical and algorithmic aspects of linear optimization: geometry of linear programs, simplex method, anticycling, duality theory and dual simplex method, sensitivity analysis, large scale optimization via Dantzig-Wolfe decomposition and Benders decomposition, interior point methods, network flow problems, integer programming. Credit may not be granted for both MATH 435 and MATH 535.

Prerequisite(s): MATH 332

Lecture: 3 Lab: 0 Credits: 3

MATH 446**Introduction to Time Series**

This course introduces the basic time series analysis and forecasting methods. Topics include stationary processes, ARMA models, spectral analysis, model and forecasting using ARMA models, nonstationary and seasonal time series models, multivariate time series, state-space models, and forecasting techniques.

Prerequisite(s): MATH 475 with min. grade of C or ECE 511 with min. grade of C

Lecture: 3 Lab: 0 Credits: 3

MATH 453**Combinatorics**

Permutations and combinations; pigeonhole principle; inclusion-exclusion principle; recurrence relations and generating functions; enumeration under group action.

Prerequisite(s): MATH 230 or Graduate standing

Lecture: 3 Lab: 0 Credits: 3

MATH 454**Graph Theory and Applications**

Graph Theory is the study of mathematical structures underlying the ubiquitous network models occurring in computer science, machine learning and optimization, electrical and computer engineering, physics, chemistry, and social networks. This course lays a rigorous foundation in graph theory through existential and algorithmic problems, structural and extremal results, and applications to science and engineering. Topics include trees, matchings, connectivity, planarity, and coloring. Credit will not be granted for both MATH 553 and MATH 454.

Prerequisite(s): (MATH 230 and MATH 251) or MATH 252

Lecture: 3 **Lab:** 0 **Credits:** 3

Satisfies: Communications (C)

MATH 461**Fourier Series and Boundary-Value Problems**

Fourier series and integrals. The Laplace, heat, and wave equations: Solutions by separation of variables. D'Alembert's solution of the wave equation. Boundary-value problems.

Prerequisite(s): (MATH 251 and MATH 252) or Graduate standing

Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 474**Probability and Statistics**

Elementary probability theory including discrete and continuous distributions, sampling, estimation, confidence intervals, hypothesis testing, and linear regression. Credit not granted for both MATH 474 and MATH 475.

Prerequisite(s): MATH 251 or Graduate standing

Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 475**Probability**

Elementary probability theory; combinatorics; random variables; discrete and continuous distributions; joint distributions and moments; transformations and convolution; basic theorems; simulation. Credit not granted for both MATH 474 and MATH 475.

Prerequisite(s): MATH 251 or Graduate standing

Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 476**Statistics**

Estimation theory; hypothesis tests; confidence intervals; goodness-of-fit tests; correlation and linear regression; analysis of variance; nonparametric methods.

Prerequisite(s): MATH 475 or Graduate standing

Lecture: 3 **Lab:** 0 **Credits:** 3

Satisfies: Communications (C)

MATH 477**Numerical Linear Algebra**

Fundamentals of matrix theory; least squares problems; computer arithmetic, conditioning and stability; direct and iterative methods for linear systems; nonlinear systems. Credit may not be granted for both MATH 477 and MATH 577.

Prerequisite(s): MATH 350 or MMAE 350

Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 478**Numerical Methods for Differential Equations**

Polynomial interpolation; numerical integration; numerical solution of initial value problems for ordinary differential equations by single and multi-step methods, Runge-Kutta, Predictor-Corrector; numerical solution of boundary value problems, and eigenvalue problems. Credit may not be granted for both MATH 478 and MATH 578.

Prerequisite(s): MATH 350 or MMAE 350

Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 481**Introduction to Stochastic Processes**

This is an introductory, undergraduate course in stochastic processes. Its purpose is to introduce students to a range of stochastic processes which are used as modeling tools in diverse fields of applications, especially in risk management applications for finance and insurance. The course covers basic classes of stochastic processes: Markov chains and martingales in discrete time; Brownian motion; and Poisson process. It also presents some aspects of stochastic calculus.

Prerequisite(s): (MATH 332 and MATH 475) or (MATH 475 and MATH 333)

Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 483**Design and Analysis of Experiments**

Basic concepts for experimental design; introductory regression analysis; experiments with a single factor; experiments with more than one factor; full factorial experiments at two levels; fractional factorial design at two levels; full and fractional factorial design at three levels and at mixed levels; response surface methodology; introduction to computer experiments and space-filling design.

Prerequisite(s): MATH 476 or MATH 474

Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 484**Regression**

This course introduces the basic statistical regression model and design of experiments concepts. Topics include simple linear regression, multiple linear regression, least square estimates of parameters; hypothesis testing and confidence intervals in linear regression, testing of models, data analysis and appropriateness of models, generalized linear models, design and analysis of single-factor experiments.

Prerequisite(s): MATH 474 with min. grade of C or (MATH 476 with min. grade of C and MATH 475 with min. grade of C)

Lecture: 3 **Lab:** 0 **Credits:** 3

Satisfies: Communications (C)

MATH 485**Introduction to Mathematical Finance**

This is an introductory course in mathematical finance. Technical difficulty of the subject is kept at a minimum while the major ideas and concepts underlying modern mathematical finance and financial engineering are explained and illustrated. The course covers the binomial model for stock prices and touches on continuous time models and the Black-Scholes formula.

Prerequisite(s): MATH 475

Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 486**Mathematical Modeling I**

The course provides a systematic approach to modeling applications from areas such as physics and chemistry, engineering, biology, and business (operations research). The mathematical models lead to discrete or continuous processes that may be deterministic or stochastic. Dimensional analysis and scaling are introduced to prepare a model for study. Analytic and computational tools from a broad range of applied mathematics will be used to obtain information about the models. The mathematical results will be compared to physical data to assess the usefulness of the models. Credit may not be granted for both MATH 486 and MATH 522.

Prerequisite(s): MATH 251 and MATH 332 and MATH 252

Lecture: 3 **Lab:** 0 **Credits:** 3

Satisfies: Communications (C)

MATH 487**Mathematical Modeling II**

The formulation of mathematical models, solution of mathematical equations, interpretation of results. Selected topics from queuing theory and financial derivatives.

Prerequisite(s): MATH 252 or Graduate standing

Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 488**Ordinary Differential Equations and Dynamical Systems**

Boundary-value problems and Sturm-Liouville theory; linear system theory via eigenvalues and eigenvectors; Floquet theory; nonlinear systems: critical points, linearization, stability concepts, index theory, phase portrait analysis, limit cycles, and stable and unstable manifolds; bifurcation; and chaotic dynamics.

Prerequisite(s): (MATH 252 and MATH 251) or Graduate standing

Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 489**Partial Differential Equations**

First-order equations, characteristics. Classification of second-order equations. Laplace's equation; potential theory. Green's function, maximum principles. The wave equation: characteristics, general solution. The heat equation: use of integral transforms.

Prerequisite(s): MATH 252

Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 491**Reading and Research**

Independent reading and research. **Instructor permission required.**

Credit: Variable

Satisfies: Communications (C)

MATH 493**Summer Research and Independent Study**

Students will conduct research work with advisers.

Lecture: 0 **Lab:** 0 **Credits:** 0

MATH 497**Special Problems**

Special problems.

Credit: Variable

Satisfies: Communications (C)