

MATHEMATICS AND STATISTICS

Department Website:

<https://www.haverford.edu/mathematics-and-statistics>

The courses in the Department of Mathematics and Statistics aim to:

- promote rigorous thinking in a systematic, deductive, intellectual discipline.
- help students identify and articulate mathematical and statistical problems that they encounter, both in formal academic work and elsewhere.
- foster technical competence in mathematics and statistics as an aid to the better comprehension of the physical, biological, and social sciences.
- guide and direct majors toward an interest in research in the mathematical and statistical sciences.

Learning Goals

Students taking courses in the Department of Mathematics and Statistics will think rigorously and systematically both within the context of the discipline and in its applications—and, ideally, throughout the liberal arts curriculum. Students will learn to identify and articulate mathematical problems that they encounter, both in mathematics and in other disciplines. Students will develop skills necessary to engage these problems within a mathematical and/or statistical framework. Finally, students will learn how to communicate their mathematical and statistical findings to a variety of audiences.

Haverford's Institutional Learning Goals are available on the President's website, at <http://hav.to/learninggoals>.

Curriculum

Mathematics majors take a three-year core sequence of courses in calculus, linear algebra, abstract algebra, and analysis, designed to provide a foundation for further study in the major areas of modern mathematics. Students with substantial advanced placement may complete this sequence by the end of their sophomore year. Students who have completed the core sequence may take advanced courses in algebra, analysis, topology, statistics, applied math, or other special topics.

Mathematics courses for majors fall into six general categories:

Preliminary Calculus

This category includes MATH H105, MATH H118, or advanced placement. These are not listed among the requirements, but are of course prerequisites for all subsequent courses in mathematics.

Intermediate Calculus/Linear Algebra

This category includes MATH H215, MATH H121 or MATH H216. These courses are taught for the benefit of both majors and non-majors, but are the real "introduction" to math for most majors.

Core Major Courses

This category includes MATH H317-MATH H318 (Analysis) and MATH H333-MATH H334 (Algebra). These courses are the "cornerstone" of the major, introducing many important ideas in which modern mathematics is based, and also sharpening students' skills in mathematical discourse (i.e., careful statements of definitions, theorems, proofs).

Intermediate Electives

These courses are designed for both majors and non-majors, and provide majors an excellent opportunity to explore interests outside the core sequence. Students can expect at least two electives at this level to be offered most semesters. We coordinate with Bryn Mawr so that if a topic is not offered in a given year at Haverford, it may be offered at Bryn Mawr.

Course	Title
MATH H203	Statistical Methods and Their Applications
MATH H204	Differential Equations
MATH H210	Linear Optimization and Game Theory
MATH H218	Probability
MATH H222	Introduction to Scientific Computing
MATH/CMSC H235	Information and Coding Theory
MATH H286	Applied Multivariate Statistical Analysis

Advanced Electives

Courses at this level are very important for students planning to go to graduate school in mathematics or related fields. The department typically offers five to six courses at this level per year.

Course	Title
MATH H328	Mathematical Statistics
MATH H335	Topology
MATH H337	Differential Geometry
MATH/CMSC H340	Analysis of Algorithms
MATH/CMSC H345	Theory of Computation

MATH H390	Advanced Topics in Algebra
MATH H391	Advanced Topics in Geometry and Topology
MATH H392	Advanced Topics in Analysis
MATH H394	Advanced Topics in Discrete Math and Computer Science
MATH H395	Advanced Topics in Combinatorics
MATH H396	Advanced Topics in Probability and Statistics
MATH H397	Advanced Topics in Applied Mathematics

Other Courses

- MATH H399I (Senior Seminar): a required year-long group seminar for seniors that offers advice, support, and practice in preparing the senior paper and oral presentation.
- MATH H400 (Senior Research): a required year-long course for seniors that involves independent work with their senior thesis advisor.
- MATH H460 (Teaching Assistantship in Mathematics): a half-credit course, in which students work closely with a single faculty member in a single course at the 100 or 200 level, offering various kinds of classroom support including problem sessions, review, tutoring, and laboratory assistance. Very good experience for students considering teaching as a career. Open to junior and senior majors by invitation, and may be taken at most twice. Does not count toward the major.

Major Requirements

- MATH H215, and either MATH H121 or MATH H216.
- MATH H317 and MATH H333, and one of MATH H318 or MATH H334.
- Four additional electives in mathematics or approved related courses at the 200 level or higher. At least one of these must be at the 300 level. (Note: MATH H399F, MATH H399I, MATH H400, MATH H460, and MATH H480 do not count toward this requirement.)
- The senior seminar, fall and spring.
- A senior paper and oral presentation.

We strongly advise students planning graduate study in mathematics or related fields to take additional courses at the 300 level. Majors may substitute equivalent courses in mathematics at Bryn Mawr College for any requirement, subject to advisor approval.

Majors must take either MATH H317 or MATH H333 at Haverford College; exceptions to this rule are granted only under unusual circumstances, with

advance permission of the department chair. Majors may substitute equivalent courses at Bryn Mawr College for any other course requirement for the major, subject to advisor approval. Courses taken at other institutions may be used to satisfy major requirements, provided that the department chair approves these courses in advance.

Senior Project

A senior paper is written by each major in close coordination with a faculty member. The senior paper is a year-long research project that includes both a written thesis and an oral presentation. All seniors take a year-long senior seminar to support the senior paper. In the seminar, students learn how to use library resources, produce a mathematical document, and take turns presenting portions of their senior papers to each other to develop their skills in constructing and giving oral presentations.

In the fall of the senior year, the student begins to focus on a topic (sometimes an interesting theorem, other times building a mathematical model or analyzing a data set) and works through the material with the faculty advisor. The student completes a detailed thesis proposal, an annotated bibliography, a "mini-paper," and a core fragment of the thesis. In the spring, the student develops the first draft, the second draft, and the final draft of the thesis, and concludes by presenting the thesis to faculty and fellow students.

Senior Project Learning Goals

Our students will engage with advanced content and techniques in pure mathematics, applied mathematics and statistics. They will gain ownership of the process and material through understanding the content and the details of the problem they are investigating, constructing illustrative examples, carrying out novel computations or carefully analyzing a data set. Our students will write clear, careful and correct mathematics/statistics, from precise definition or description of a model to rigorous proofs or well-supported analyses. They will develop an oral presentation that highlights the central ideas of their thesis work at a level appropriate for an audience in the mathematical/statistical sciences.

Senior Project Assessment

The grade for the senior thesis is determined by the following:

- Level of engagement with advanced mathematics or statistics.
- Level of ownership of the material and of the writing process.

- Adherence to professional standards of written mathematics and statistics.

The grade for the senior seminar is determined by the following:

- Completing all the assignments in accordance with the assignment description.
- Meeting deadlines for each assignment.
- Quality of intermediate drafts, including whether easily discernible progress has been made from one assignment to another.
- Engaged participation in seminar meetings.
- Quality of the thesis presentation.

Minor Requirements

Mathematics minors take the same core sequence as do the majors, though not necessarily to the same depth, followed by a selection of electives tailored to the student's interest. Statistics minors take a separate core sequence in probability and statistics, with later flexibility in pursuing either a more applied or a more theoretical track.

Mathematics Minor Requirements

- MATH H215 (Linear Algebra) and either MATH H121 (Multivariable calculus) or MATH H216 (Advanced Calculus).
- MATH H317 (Analysis I) and MATH H333 (Algebra I).
- Two additional electives in mathematics at the 200 level or higher.

Courses taken at other institutions may be used to satisfy minor requirements, provided that the department chair approves these courses in advance.

Statistics Minor Requirements

- One of the following courses (Introduction to Statistics): STAT H203, ECON H204, PSYC H200, SOCL H215
- STAT H286 (Applied Multivariate Statistical Analysis)
- MATH H218 (Probability)
- MATH H215 (Linear Algebra)
- MATH H121 or MATH H216 (Multivariable Calculus)
- One of the following:
 - STAT H328 (Mathematical Statistics)
 - STAT H396 (Advanced Topics in Probability and Statistics)
 - ECON H324 (Advanced Econometrics)

Courses taken at other institutions may be used to satisfy minor requirements, provided that the department chair approves these courses in

advance. For classes of 2020-2022, ECON H304 or SOCL H320 can be used as the 300-level course.

Notes for the Statistics Minor

- A *math minor* can also be a statistics minor. If a student wants to be a math minor and a statistics minor, the following courses: STAT H203, ECON H204, MATH H218, STAT H286, STAT H328 and STAT H396, cannot be counted to satisfy both the math minor and statistics minor.
- A *math major* can also be a statistics minor. If a student wants to be a math major and a statistics minor, the following apply:
 - STAT H203, ECON H204 and STAT H286 cannot be counted to satisfy both the math major and statistics minor requirement.
 - At most one of the following courses can be counted to satisfy both the math major and statistics minor: MATH H218, STAT H328 and STAT H396.
- *Math majors with economics concentration*: If a math major wants to be an econ concentrator and a statistics minor, MATH H218, STAT H286, STAT H328 and STAT H396 cannot be counted toward both the economics concentration and the statistics minor.
- *Economics majors with math concentration*: If an economics major wants to be a math concentrator and also a stat minor, MATH H218, STAT H286, STAT H328 and STAT H396 cannot be counted to satisfy both the stat minor and the math concentration requirement.

For further information about the statistics minor, please see the PDF supplement on the mathematics website, or contact the minor coordinator.

Concentrations and Interdisciplinary Minors

Mathematics majors can pursue four areas of concentration:

Computer Science (more theoretical)

It may come as a surprise to some that many of the fundamental questions in computer science (including the famous P versus NP problem) are in essence mathematical questions. Conversely, some of the deepest foundational questions about the nature of mathematics (such as: what constitutes a proof?) are inherently computational in nature. Computers have also become a powerful tool in mathematical research and its applications, both theoretical and experimental. A full understanding of their capability and potential can only be realized

by formal coursework in computer science. The concentration is open to math or physics majors.

Scientific Computing (more applied)

Many disciplines in the natural and social sciences include a significant sub-discipline that is explicitly computational. Examples include astronomy, biology, chemistry, economics, and physics. In some fields, such as biology, the use of computation has become so widespread that basic literacy in computation is increasingly important and may soon become required. The Concentration in Scientific Computing gives students an opportunity to develop a basic facility with the tools and concepts involved in applying computation to a scientific problem, and to explore the specific computational aspects of their own major disciplines.

Mathematical Economics (for majors interested in applying their skills to economic problems)

Mathematics and economics are complementary disciplines. Most branches of modern economics use mathematics and statistics extensively, and some important areas of mathematical research have been motivated by economic problems. Economists and mathematicians have made important contributions to each other's disciplines. Economist Kenneth Arrow, for example, did path-breaking work in the field of mathematical optimization; and in 1994 mathematician John Nash was awarded the Nobel Prize in economics for introducing a theory of equilibrium in non-cooperative games that has become central to contemporary economic theory. Haverford's Area of Concentration in Mathematical Economics enables students in each of the disciplines not only to gain proficiency in the other, but also to understand the ways in which they are related and complementary.

Mathematics Education (for majors interested in teaching mathematics)

The Bryn Mawr-Haverford Education Program invites students to study the discipline of education; explore the interdisciplinary field of educational studies; begin the path of teacher preparation for traditional classrooms; and participate in teaching experiences in a range of classroom and extra-classroom settings. Focused on teaching and learning as social, political, and cultural activities, the Education Program challenges students to explore the relationships among schooling, human development, and society as they gain knowledge and skills of educational theory and practice. Students who complete one of the Education Program options are prepared to become lifelong learners, educators, researchers, leaders and agents of change.

For the requirements for these concentrations, see those headings in this catalog or visit the departmental website.

Affiliated Programs

Many of our graduates have pursued successful and interesting careers in various engineering disciplines. Our 4+1 program with the University of Pennsylvania, 3/2 engineering program with CalTech, and the Master's degree course exchange agreements with Swarthmore and the University of Pennsylvania offer robust—and unique—opportunities. For more information on these options, visit the Engineering website: <https://www.haverford.edu/engineering/>

Faculty

Timur Akhunov

Visiting Assistant Professor of Mathematics and Statistics

Tarik Aougab

Assistant Professor of Mathematics and Statistics

Lynne Butler

Professor of Mathematics and Statistics

Rebecca Everett

Assistant Professor of Mathematics and Statistics

David Lippel

Visiting Assistant Professor of Mathematics and Statistics

Robert Manning

Professor of Mathematics and Statistics; William H. and Johanna A. Harris Chair of Computational Science

Weiwen Miao

Professor of Mathematics and Statistics

Elizabeth Milićević

Associate Professor of Mathematics and Statistics

Liem Nguyen

Visiting Assistant Professor of Mathematics and Statistics

Joshua Sabloff

J. McLain King 1928 Professor in Mathematics; Professor of Mathematics and Statistics

Jeffrey Tecosky-Feldman

Senior Lecturer of Mathematics and Statistics

Affiliated Faculty

Sorelle Friedler

Associate Professor of Computer Science

Steven Lindell

Professor of Computer Science

Giri Parameswaran

Associate Professor of Economics; Coordinator of Mathematical Economics

Courses

MATH H103 INTRODUCTION TO PROBABILITY AND STATISTICS (1.0 Credit)

Division: Natural Science; Quantitative
Domain(s): C: Physical and Natural Processes
 Basic concepts and methods of elementary probability and quantitative reasoning, with practical applications. Topics include: sample average and standard deviation, normal curves, regression, expected value and standard error, confidence intervals and hypothesis tests. Crosslisted: Mathematics, Statistics Prerequisite(s): Not open to students who have (a) placed into 121 or higher, (b) taken 118 or higher, (c) taken any other introductory statistics class at Haverford or Bryn Mawr, (d) received a score of 4 or 5 on the AP Statistics exam
(Typically offered: Every Year)

MATH H105 APPLIED MODELING WITH CALCULUS (1.0 Credit)

Division: Natural Science; Quantitative
Domain(s): C: Physical and Natural Processes
 An introduction to aspects of calculus useful in applied work in the natural and social sciences, with a strong emphasis on developing mathematical modeling skills. Topics include differential and integral calculus of functions of one variable, multivariable optimization, and modeling with differential equations. Applications to biology, economics, and physics. This course is taught at the level of a beginning calculus course, and no prior calculus experience is assumed. Prerequisite(s): Not open to students placing into MATH 118 or higher or Math 105 cannot be taken by students who have AP credit for calculus or with previous calculus credit, except with instructor consent
(Offered: Fall 2021; **typically offered:** Every Spring)

MATH H118 CALCULUS: DYNAMICS AND INTEGRATION (1.0 Credit)

Staff

Division: Natural Science; Quantitative
Domain(s): C: Physical and Natural Processes
 A study of the evolution of systems defined by difference and differential equations. Methods of analysis come from calculus: the limit, the derivative, and the integral from numerical, graphical, and symbolic perspectives. Not open to students placing into Math 121 or higher, except with instructor permission. Prerequisite(s): MATH 105 or placement. Not open to students with credit for MATH B102

(Calculus II) or equivalent, except with instructor consent

(Offered: Fall 2021, Spring 2022; **typically offered:** Every Fall)

MATH H121 MULTIVARIABLE CALCULUS (1.0 Credit)

David Lippel, Timur Akhunov, Staff

Division: Natural Science; Quantitative
Domain(s): C: Physical and Natural Processes
 An introduction to functions of several variables, vector geometry, partial derivatives, optimization, Taylor's Theorem, multiple integrals, line integrals, and Green's and Stokes' Theorems. Prerequisite(s): MATH 118 or equivalent placement, or instructor consent. Not open to students who have previously taken multivariable calculus at the college level, either at Haverford or elsewhere, except with instructor consent
(Offered: Fall 2021; **typically offered:** Every Semester)

MATH H146 ETHICS AND THE USE OF MATHEMATICS, WITH A FOCUS ON ANTI-RACISM (0.5 Credit)

Elizabeth Milićević, Tarik Aougab

This seminar will explore what it means to "do math ethically", to emphasize the ways in which mathematics is inherently political, and to think about anti-racism in mathematical disciplines. This course is graded P/F. Crosslisted: Independent College Programs, Mathematics
(Offered: Fall 2021; **typically offered:** Occasionally)

MATH H203 STATISTICAL METHODS AND THEIR APPLICATIONS (1.0 Credit)

Weiwen Miao

Division: Natural Science; Quantitative
Domain(s): C: Physical and Natural Processes
 An introduction to statistical methods used to analyze data in the natural and social sciences. It covers descriptive statistics, the binomial and normal distributions, expected value and variance, confidence intervals and hypothesis testing, comparison of two samples, regression, and analysis of variance. A required computer lab, using R, is taught alongside this course. Crosslisted: Mathematics, Statistics Prerequisite(s): MATH 118 or higher, placement into MATH 121 or higher, or instructor consent. Students who have taken another introductory statistics course at Haverford or Bryn Mawr may only enroll in STAT 203 with instructor consent
(Offered: Fall 2021; **typically offered:** Every Semester)

MATH H204 DIFFERENTIAL EQUATIONS (1.0 Credit)*Staff***Division:** Natural Science; Quantitative**Domain(s):** C: Physical and Natural Processes

An introduction to the theory of ordinary differential equations (ODEs) including algebraic techniques for solving a single ODE or a linear system of ODEs, numerical techniques for generating approximate solutions, geometric techniques for displaying solutions to understand their behavior, analyzing nonlinear systems, and some key theorems (such as existence and uniqueness of solutions). The focus of this course will be on applications of the methods and solving real systems. Prerequisite(s): MATH 121 or MATH 215 (or 216) or consent of instructor.

(Offered: Fall 2021; **typically offered:** Every other Year)

MATH H210 LINEAR OPTIMIZATION (1.0 Credit)*Robert Manning***Division:** Natural Science**Domain(s):** C: Physical and Natural Processes

An introduction to the optimization of a linear function subject to linear constraints, with applications that include game theory, transportation problems, and network flows. The course includes some theoretical material on the properties of these linear optimization problems, and also a strong emphasis on algorithms, especially the simplex method and some enhancements to it (which are especially relevant since many applications involve many variables and many constraints). Crosslisted: Mathematics, Computer Science, Economics Prerequisite(s): Co-requisite of Math 121 or 215, or equivalent placement, or instructor consent

(Offered: Spring 2022; **typically offered:** Every other Year)

MATH H215 LINEAR ALGEBRA (1.0 Credit)*Jeffrey Tecosky-Feldman***Division:** Natural Science; Quantitative**Domain(s):** C: Physical and Natural Processes

An abstract introduction to linear algebra, focusing on proof techniques. Topics covered include: vector spaces, linear transformations and matrices, determinants, eigenvalue problems, quadratic forms, and the spectral theorem. One extra hour of weekly discussions. Prerequisite(s): MATH 121 or equivalent placement, or 118 with instructor consent, or CMSC 231

(Offered: Fall 2021; **typically offered:** Every Semester)

MATH H216 MULTIVARIABLE CALC USING LINEAR ALGEBRA (1.0 Credit)*Lynne Butler***Division:** Natural Science; Quantitative**Domain(s):** C: Physical and Natural Processes

Calculus in n-dimensional Euclidean space: continuous and differentiable functions, extreme value problems, multiple integration, line and surface integrals, parametrized surfaces, Green's, Gauss' and Stokes' Theorems. Tools from linear algebra are used to formulate general statements of definitions, theorems and proofs. Prerequisite(s): Not open to students who have previously taken multivariable calculus at the college level, either at Haverford or elsewhere, except with instructor permission. Requires a strong background in single-variable calculus and a course in linear algebra, or instructor consent

(Offered: Spring 2022; **typically offered:** Every Spring)

MATH H218 PROBABILITY (1.0 Credit)*Lynne Butler***Division:** Natural Science; Quantitative**Domain(s):** C: Physical and Natural Processes

An introduction to probability theory. Topics include: sample spaces, combinatorics, conditional probability, independence, discrete and continuous random variables, functions of random variables, expected value and variance, the moment generating function, and some basic limit theorems. Prerequisite(s): MATH 216 or 121 or consent

(Offered: Fall 2021; **typically offered:** Every Fall)

MATH H222 SCIENTIFIC COMPUTING: CONTINUOUS SYSTEMS (1.0 Credit)*Robert Manning***Division:** Natural Science; Quantitative**Domain(s):** C: Physical and Natural Processes

A survey of major algorithms in modern scientific computing, with a focus on continuous problems. Topics include numerical differentiation and integration, numerical linear algebra, root-finding, optimization, Monte Carlo methods, and discretization of differential equations. Basic ideas of error analysis are presented. A regular computer lab introduces students to the software package Matlab, in which the algorithms are implemented and applied to various problems in the natural and social sciences. Crosslisted: Mathematics, Computer Science Prerequisite(s): Math 215

(Offered: Spring 2022; **typically offered:** Every other Year)

MATH H286 APPLIED MULTIVARIATE STATISTICAL ANALYSIS (1.0 Credit)*Weiwen Miao***Division:** Natural Science; Quantitative**Domain(s):** C: Physical and Natural Processes

An introduction to multivariate statistical analysis. The course includes methods for choosing, fitting,

and evaluating multiple regression models and analysis of variance models. A required computer lab, using R, is taught alongside this course. Crosslisted: Mathematics, Statistics Prerequisite(s): MATH 215 and one of the following: ECON 204, MATH 203, PSYC 200, SOCL 215
(Offered: Fall 2021; typically offered: Every other Year)

MATH H317 ANALYSIS I (1.0 Credit)

Robert Manning

Division: Natural Science; Quantitative
Domain(s): C: Physical and Natural Processes
A rigorous development of topics in calculus, including the axioms of the real number line, cardinality, convergence of sequences, point-set topology (open/closed sets, compactness, connectedness), continuity, differentiability, and the Riemann integral. The course also has a major focus on the writing of clear and correct mathematical proofs. Prerequisite(s): MATH 215 and either 121 or 216, or instructor consent
(Offered: Fall 2021; typically offered: Every Fall)

MATH H318 ANALYSIS II (1.0 Credit)

Robert Manning

Division: Natural Science
Domain(s): C: Physical and Natural Processes
A continuation of MATH 317, focusing on measure theory, the Lebesgue integral, function spaces, and sequences and series of functions with applications (e.g., Fourier series, existence and uniqueness of solutions to differential equations). Prerequisite(s): MATH 317
(Offered: Spring 2022; typically offered: Every Spring)

MATH H328 MATHEMATICAL STATISTICS (1.0 Credit)

Weiwen Miao

Division: Natural Science
Domain(s): C: Physical and Natural Processes
An introduction to mathematical theory of statistics. Topics include: Estimation, Hypothesis Testing, one-sample inference, two-sample inference, and regression. Additional topics may include: goodness-of-fit tests and analysis of variance. Crosslisted: Mathematics, Statistics Prerequisite(s): MATH 218
(Offered: Spring 2022; typically offered: Every other Year)

MATH H333 ALGEBRA I (1.0 Credit)

Elizabeth Milićević

Division: Natural Science; Quantitative
Domain(s): C: Physical and Natural Processes
A rigorous treatment of fundamental algebraic structures. Topics include: introduction to groups, modular arithmetic, polynomials, rings, fields, Galois

theory, vector spaces, and modules. Prerequisite(s): MATH 215 and either 121 or 216, or instructor consent
(Offered: Fall 2021; typically offered: Every Fall)

MATH H334 ALGEBRA II (1.0 Credit)

Elizabeth Milićević

Division: Natural Science
Domain(s): C: Physical and Natural Processes
A continuation of Math 333. Topics include: group actions, Sylow's theorems, representation theory of finite groups, finite abelian groups, Galois theory, advanced linear algebra, and modules. Prerequisite(s): MATH 333 or instructor consent
(Offered: Spring 2022; typically offered: Every Spring)

MATH H335 TOPOLOGY (1.0 Credit)

Tarik Aougab

Division: Natural Science
Domain(s): C: Physical and Natural Processes
Generalizes topological concepts from Euclidean spaces to arbitrary topological spaces, and introduces elements of algebraic topology. Concepts covered include continuity, connectedness, and compactness. The course culminates in an exploration of the fundamental group and covering spaces. Prerequisite(s): MATH 317 with MATH 333 as a co-requisite, or instructor consent
(Offered: Fall 2021; typically offered: Every other Year)

MATH H337 DIFFERENTIAL GEOMETRY (1.0 Credit)

Tarik Aougab

Division: Natural Science
Domain(s): C: Physical and Natural Processes
A study of the differential geometry of curves and surfaces. Concepts covered include both the local theory (including metrics, curvature, and geodesics) and the global theory, including the Gauss-Bonnet theorem. Prerequisite(s): MATH 317 or MATH 216 with special permission, or instructor consent
(Typically offered: Every other Year)

MATH H340 ANALYSIS OF ALGORITHMS (1.0 Credit)

Steven Lindell

Division: Natural Science; Quantitative
Domain(s): C: Physical and Natural Processes
Qualitative and quantitative analysis of algorithms and their corresponding data structures from a precise mathematical point of view. Performance bounds, asymptotic and probabilistic analysis, worst case and average case behavior. Correctness and complexity. Particular classes of algorithms such as sorting searching will be studied in detail. Crosslisted: Computer Science, Mathematics

Prerequisite(s): CMSC 106 or 107 or B206, and 231, or instructor consent

(Offered: Fall 2021; **typically offered:** Every Fall)

MATH H345 THEORY OF COMPUTATION (1.0 Credit)

Steven Lindell

Division: Natural Science

Domain(s): C: Physical and Natural Processes
Introduction to the mathematical foundations of computer science: finite state automata, formal languages and grammars, Turing machines, computability, unsolvability, and computational complexity. Attendance at the weekly discussion section is required. Crosslisted: Computer Science, Mathematics Prerequisite(s): (CMSC 106 or CMSC 107) and CMSC 231, and junior or senior standing, or instructor consent

(Offered: Spring 2022; **typically offered:** Every Spring)

MATH H360 MATHEMATICAL ECONOMICS (1.0 Credit)

Giri Parameswaran

Division: Quantitative; Social Science

Domain(s): C: Physical and Natural Processes
A study of advanced mathematical tools used in economic analysis. Topics include eigenvalues and quadratic forms, differential equations, convex programming and dynamic programming. Applications to consumer theory, generalized linear regression, stability of equilibrium, and models of growth and search. Fulfills Mathematic Economics (MTEC) concentration. Crosslisted: Economics, Mathematics Prerequisite(s): MATH 215; either MATH 121 or 216; ECON 203 or 204 or MATH 203 or SOCL 215 or PSYCH 200 or Bryn Mawr's ECON B253 recommended

(Typically offered: Every Fall)

MATH H394 ADVANCED TOPICS IN THEORETICAL COMPUTER SCIENCE & DISCRETE MATHEMATICS: LOGIC (1.0 Credit)

David Lippel

Division: Natural Science

Domain(s): C: Physical and Natural Processes
An introduction to mathematical logic. Topics include: propositional logic, first-order logic, natural deduction, semantics, the Completeness and Compactness Theorems. Crosslisted: Mathematics, Computer Science Prerequisite(s): Either MATH 333 or MATH 317, or instructor consent

(Typically offered: Occasionally)

MATH H395 ADVANCED TOPICS IN COMBINATORICS (1.0 Credit)

Division: Natural Science

Domain(s): C: Physical and Natural Processes

"Enumerative combinatorics, bijective combinatorial proof methods, ordinary and exponential generating functions."

(Typically offered: Every other Year)

MATH H397 ADVANCED TOPICS IN APPLIED MATHEMATICS: MATHEMATICAL MODELING (1.0 Credit)

Rebecca Everett

Division: Natural Science

Domain(s): C: Physical and Natural Processes
This course will provide a general introduction to modeling in applied mathematics using differential equations, with an emphasis on models in mathematical biology. Other applications that may be discussed include topics from chemistry, engineering, physics, and the social sciences. A goal of this course is to give insights into the connections between mathematics and real-world problems. This involves building and understanding mathematical models that reflect real world scenarios, and analyzing models to gain an understanding of the problem. Techniques for analyzing mathematical models may include phase plane methods, stability analysis, bifurcation theory, and computer simulations using MATLAB. Prerequisite(s): Math 204 or equivalent, or permission from instructor.

(Offered: Spring 2022; **typically offered:** Every other Year)

MATH H399F SENIOR SEMINAR (0.5 Credit)

Rebecca Everett

Division: Natural Science

Domain(s): C: Physical and Natural Processes
Seminar for students writing senior papers, dealing with the oral and written exposition of advanced material.

(Offered: Fall 2021; **typically offered:** Every Fall)

MATH H399I SENIOR SEMINAR (0.5 Credit)

Rebecca Everett

Division: Natural Science

Seminar for students writing senior papers, dealing with the oral and written exposition of advanced material.

(Offered: Spring 2022; **typically offered:** Every Spring)

MATH H400 SENIOR RESEARCH (0.5 Credit)

Elizabeth Milićević, Lynne Butler, Rebecca Everett, Robert Manning, Tarik Aougab, Weiwen Miao, Staff

Division: Natural Science; Quantitative

Domain(s): C: Physical and Natural Processes
Work on Senior Thesis with Advisor.

(Offered: Fall 2021; **typically offered:** Every Year)

MATH H460 TEACHING ASSISTANT (1.0 Credit)

Jeffrey Tecosky-Feldman

(**Offered:** Spring 2022)

MATH H480 INDEPENDENT STUDY (1.0 Credit)

Joshua Sabloff

Independent Study

(**Offered:** Fall 2021; **typically offered:**

Occasionally)