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

The Mathematics and Statistics curriculum is designed so that, after completing course requirements, focusing on at least one of the subdisciplines of pure mathematics, applied mathematics, or statistics, and producing their senior thesis, students will gain the following:

a. **Mastery** of mathematical and/or statistical methods and concepts that allow students to solve non-routine and non-algorithmic problems, to apply mathematical or statistical techniques to new contexts, and to achieve ownership of mathematical or statistical ideas. Mastery includes acquiring skills such as processing technical material, understanding and creating logical arguments, formulating models and structures, and being able to deploy appropriate computational techniques.
b. **Communication** of mathematical and statistical ideas in a clear, precise, and structured manner to audiences both expert and general. The core skill is to define terms and assumptions carefully and to build on those definitions using precise arguments and appropriate evidence.
c. **Breadth** of knowledge across the mathematical sciences, including an understanding of links between subfields, connections to other disciplines both in STEM and in the broader liberal arts curriculum, and, in the spirit of Haverford's motto Non doctior, sed meliore doctrina imbutus ("Not more learned, but imbued with better learning"), the social context in which mathematics is developed and used.
d. **Independence, resilience, and persistence** in learning and using mathematics and statistics as a foundation for life-long learning and problem solving, balanced with a capacity to work collaboratively and to create and join communities of mathematical scientists.

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

Curriculum

Majors take a core sequence of courses in calculus and linear algebra designed to provide a foundation for further study in pure math, applied math, or statistics. Apart from these core courses, each student chooses a "focus" (pure math, applied math, or statistics) and takes five courses to fulfill requirements for that focus (see "Major Requirements"). Finally, all majors take a junior seminar and write a senior thesis (supported by a senior seminar).

Majors Offered by the Department

The Department of Mathematics and Statistics offers a major that gives students a choice among three focuses that each address the above learning goals in a distinctive way:

a. Major: Mathematics (focus in pure math)
b. Major: Mathematics (focus in statistics)
c. Major: Mathematics (focus in applied math)

Major Requirements

- Calculus II (MATH H118)
- Multivariable Calculus (MATH H121 or MATH H216)
- Linear Algebra (MATH H215)
- Junior Seminar (MATH H299)
- Senior Seminar (MATH H399)
- Senior Research (MATH H400), including a senior paper and oral presentation
- Five courses in the student's chosen focus (see below)

Focus Requirements in Pure Math

- Two of the following courses: Analysis (MATH H317), Algebra (MATH H333), Topology (MATH H335)
- Three additional math courses 200-level or higher (excluding Junior or Senior Seminar, Senior Research, Teaching Assistant, Independent Study), of which:
  - at least one must be in pure math, and
  - at least one must be outside of pure math, and
  - at least one must be 300-level, and

- at most one can be cross-listed with another department.

Focus Requirements in Statistics

- A course in introductory statistics (STAT H203, ECON H203, ECON H204, PSYC H200, or SOCL H215)
- Applied Multivariate Statistical Analysis (STAT H361)
- Probability (MATH H218)
- Two additional courses from the following list: Mathematical Statistics (STAT H328), Advanced Topics in Statistics (STAT H396), Analysis (MATH H317)

Focus Requirements in Applied Math

- Differential Equations (MATH H204)
- Analysis (MATH H317)
- Two courses, of which at least one is 300-level, from the list below:
  - Linear Optimization (MATH H210)
  - Scientific Computing: Continuous Systems (MATH H222)
  - Modeling and Differential Equations (MATH H382)
  - Partial Differential Equations (MATH H383)
  - Constrained and Combinatorial Optimization (MATH H384)
  - Advanced Topics in Applied Math (MATH H397 and/or MATH B325); can be taken more than once if topics are sufficiently different)
- One additional applied math course, which must be 300-level if a 200-level course was used as part of fulfilling the previous requirement. This additional course could be, but does not have to be, a third course from the list above. We have posted on our webpage a list of courses that are pre-approved as counting towards this requirement.

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 or 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.

Policies Related to Major Requirements

- In reviewing student thesis topic proposals, the department will prioritize proposals where the topic is in the student's focus, to the extent possible given thesis advisor availability in that focus.
- If a student places past a course listed as required, that requirement is waived, but the student must take an additional course that

counts for the major at the 200-level or higher (excluding Junior or Senior Seminar, Senior Research, Teaching Assistant, Independent Study). For example, a student placed past MATH 118 would need to take 1 additional course; a student placed past MATH 121 would need to take 2 additional courses; a student placed past STAT 203 who chooses statistics as their focus would need to take an additional course along with any additional courses implied by their calculus placement.

- In order to develop a connection between a student and the pool of potential thesis advisors, a major must take at least one course in their chosen focus at Haverford; exceptions to this rule are granted if, at the time of major declaration, the student gets approval from the department chair of a course plan that develops that connection in a different way.
- A student's transcript can only show one focus, but can minor in a second focus area in certain combinations (see below).
- In the atypical circumstance that a student elects to graduate in seven semesters, they must inform the department of this choice when they declare their major in the spring of their sophomore year and complete the senior seminar and senior paper during the fall and spring of their junior year, i.e., during their fifth and sixth semesters. (This means that students have to complete Math 299 (Junior Seminar) before the 5th semester.)
- Students who graduate nine or more semesters after matriculating should make every effort to complete the Senior Seminar and senior paper during a single academic year (fall then spring), but students in this circumstance can complete these requirements "off-cycle" (spring then fall) with permission of the department chair. This permission should be sought as soon as the student knows of their interest in an off-cycle thesis, and no later than the spring pre-registration immediately preceding their proposed spring-fall thesis year. Off-cycle thesis students may have limited options for thesis advisors, since their spring-fall thesis year will overlap with two different fall-spring faculty sabbatical periods.
- If a student elects to spend the whole junior year abroad, they must complete Math 299 (Junior Seminar) before the 5th semester and inform the department of this choice when they declare their major in the spring of their sophomore year.

Minors Offered by the Department

- Minor: Pure Math
- Minor: Statistics
- Minor: Applied Math

Pure Math Minor Requirements

- Calculus II (MATH H118)
- Multivariable Calculus (MATH H121 or MATH H216)
- Linear Algebra (MATH H215)
- Two of the following courses: Analysis (MATH H317), Algebra (MATH H333), Topology (MATH H335)
- One additional course in pure math (a third course from the previous requirement, or another 200- or 300-level course in pure math)

Statistics Minor Requirements

- Multivariable Calculus (MATH H121 or MATH H216)
- Linear Algebra (MATH H215)
- A course in introductory statistics (STAT H203, ECON H203, ECON H204, PSYC H200, or SOCL H215)
- Probability (MATH H218)
- Advanced Multivariate Statistical Analysis (STAT H361)
- One additional course in statistics from the following list: Mathematical Statistics (STAT H328), Advanced Topics in Statistics (STAT H396), or Advanced Econometrics (ECON H324)

Applied Math Minor Requirements

- Calculus II (MATH H118)
- Multivariable Calculus (MATH H121 or MATH H216)
- Linear Algebra (MATH H215)
- Differential Equations (MATH H204)
- Two additional courses in applied math, of which at least one must be at the 300-level; these two courses should come from the following list (or be approved as a substitution):
  - Modeling and Differential Equations (MATH H382)
  - Partial Differential Equations (MATH H383)
  - Scientific Computing: Continuous Systems (MATH H222)
  - Linear Optimization (MATH H210)
  - Constrained and Combinatorial Optimization (MATH H384)
  - Advanced Topics in Applied Math (MATH H397 and/or (MATH B325); can be taken more than once if topics are sufficiently different)

Policies Related to Minor Requirements

- If a student places past a course listed as required, that requirement is waived, but the student must take an additional course that counts for the minor at the 200-level or higher (excluding Junior or Senior Seminar, Senior Research, Teaching Assistant, Independent Study). For example, a student placed past MATH

118 would need to take 1 additional course; a student placed past MATH 121 would need to take 2 additional courses; a statistics minor placed past STAT 203 would need to take an additional course along with any additional courses implied by their calculus placement.

- A pure math minor **cannot** be combined with a math major (focus in pure math) or with a math major (focus in applied math).
- An applied math minor **cannot** be combined with a math major (focus in pure math) or with a math major (focus in applied math).
- A statistics minor **cannot** be combined with a math major (focus in statistics).
- Other than the case discussed in the previous bullet point, a minor in our department can be combined with a major, minor, or concentration (inside or outside of our department) as long as three or fewer courses are “double-counted”. For example:
  - A student could complete a “Minor in statistics” and a “Concentration in Mathematical Economics” (as an economics major) if they use MATH 215, 216, and 218 to fulfill minor and concentration requirements, and then have no overlap in the courses they use to satisfy the remaining requirements.
  - A student who places past MATH 118 would replace the MATH 118 major requirement by an additional 200-level course of their choosing (as per a major requirement policy above). Such a student could complete a "Major in Math (with focus in applied math)" and a "Minor in statistics" if they use MATH 121 and 215 to satisfy requirements for both the major and the minor, and MATH 218 to satisfy a minor requirement and as their “additional course” (replacing 118) for the major, and then have no overlap in the courses they use to satisfy the remaining requirements.

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 Accelerated Masters 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

Tarik Aougab
Associate Professor of Mathematics and Statistics

Lynne Butler
Professor of Mathematics and Statistics

Rebecca Everett
Associate Professor of Mathematics and Statistics

Curtis Greene
Professor Emeritus of Mathematics and Statistics

Dale Husemoller
Professor Emeritus of Mathematics

Anthony Kling
Visiting Assistant Professor of Mathematics and Statistics

David Lippel
Lab Instructor and Visiting Assistant Professor of Mathematics and Statistics

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

RB McGee
Associate Professor of Mathematics and Statistics

Weiwen Miao
Professor of Mathematics and Statistics

Elizabeth Milićević
Associate Professor of Mathematics and Statistics

Samuel Pérez-Ayala
Visiting Assistant Professor of Mathematics and Statistics

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

Lawrence Seminario-Romero
Visiting Assistant Professor of Mathematics and Statistics

Yung-Sheng Tai
Professor Emeritus of Mathematics

Jeffrey Tecosky-Feldman
Senior Lecturer of Mathematics and Statistics

Affiliated Faculty

Sorelle Friedler
The Shibulal Family Computer Science Professor; Professor of Computer Science

Steven Lindell
Professor of Computer Science

Giri Parameswaran
Associate Professor and Chair of 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

MATH H105 APPLIED MODELING WITH CALCULUS (1.0 Credit)
Samuel Pérez-Ayala
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 2024)

MATH H118 CALCULUS: DYNAMICS AND INTEGRATION (1.0 Credit)
Rebecca Everett
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 2024, Spring 2025)

MATH H121 MULTIVARIABLE CALCULUS (1.0 Credit)
Anthony Kling, Lawrence Seminario-Romero
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 2024)

MATH H146 ETHICS AND THE USE OF MATHEMATICS, WITH A FOCUS ON ANTI-RACISM (0.5 Credit)
Tarik Aougab
This half-credit 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:** Spring 2025)

MATH H203 STATISTICAL METHODS AND THEIR APPLICATIONS (1.0 Credit)
Lynne Butler
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 2024)

MATH H204 DIFFERENTIAL EQUATIONS (1.0 Credit)
Robert Manning
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. Lottery Preferences: juniors, then sophomores, then seniors, and then first-year students

MATH H206 INTRODUCTION TO MATHEMATICAL CRYPTOGRAPHY (1.0 Credit)
Anthony Kling
Division: Natural Science
Domain(s): C: Physical and Natural Processes
This course introduces modern cryptography from a mathematical perspective, focusing on public key cryptosystems. We will emphasize the theory, analysis, and practical application of various cryptosystems. Topics will include Diffie-Hellman, RSA, and elliptic curve cryptography. We will also develop any necessary mathematical background, including modular arithmetic. Pre-requisite(s): MATH 121 or 215, or permission of the instructor Lottery Preference: Random

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:** Fall 2024)

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. Prerequisite(s): MATH 121 or equivalent placement, or 118 with instructor consent, or CMSC 231
(**Offered:** Fall 2024)

MATH H216 MULTIVARIABLE CALC USING LINEAR ALGEBRA (1.0 Credit)
Joshua Sabloff
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. Requites a strong background in single-variable calculus and a course in linear algebra, or instructor consent
(**Offered:** Spring 2025)

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 2024)

MATH H222 SCIENTIFIC COMPUTING: CONTINUOUS SYSTEMS (1.0 Credit)
Rebecca Everett
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. Regular computer work in class 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 121

MATH H235 INFORMATION AND CODING THEORY (1.0 Credit)
Steven Lindell
Domain(s): C: Physical and Natural Processes
This course covers the mathematical theory of the transmission (sending or storing) of information. Included will be encoding and decoding techniques, both for the purposes of data compression and for the detection and correction of errors. Prerequisite(s): CMSC 231 or equivalent background in mathematics

MATH H295 TOPICS IN MATHEMATICS: COMPUTATIONAL NUMBER THEORY (1.0 Credit)
Anthony Kling
Division: Natural Science
Domain(s): C: Physical and Natural Processes
A 200-level course in a topic in mathematics. Fall 2024: An introduction to number theory with a heavy focus on computation and algorithms. We will explore properties of integers and their relationships through primarily computational techniques. Throughout, we will emphasize both theoretical understanding and practical application. Topics will include primality testing, arithmetic functions, complexity, Diophantine equations, and investigating conjectures. We will be using Python in this course, but prior programming experience is not needed. Prerequisite: MATH 121 or permission from instructor Lottery Preference: Math majors, then math/stat minors
(**Offered:** Fall 2024)

MATH H299 JUNIOR SEMINAR IN MATHEMATICS AND STATISTICS (1.0 Credit)
Robert Manning
Division: Natural Science
Domain(s): C: Physical and Natural Processes
A course to introduce all math majors to research and communication methods used by mathematicians and statisticians, and to discuss the structures and workings of mathematical

communities, including the ethical implications of bringing mathematical skills to a workplace or community. Students produce a “junior paper” anchored in an application of linear algebra, helping prepare them to write a thesis as a senior, and plan a colloquium or panel discussion open to the entire Haverford community. Pre-requisite(s): Linear Algebra (MATH H215) or instructor consent Lottery Preference: Math Majors, by seniority within that group
(**Offered:** Fall 2024, Spring 2025)

MATH H317 ANALYSIS I (1.0 Credit)
Samuel Pérez-Ayala
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 2024, Spring 2025)

MATH H318 ANALYSIS II: COMPLEX ANALYSIS (1.0 Credit)
Joshua Sabloff
Division: Natural Science
Domain(s): C: Physical and Natural Processes
A continuation of Math 317. The topic for Spring 2023 is complex analysis, including the algebra and geometry of complex numbers, analytic functions, complex integration (including the Cauchy integral formula and the calculus of residues), and conformal mappings (including, hopefully, the Riemann Mapping Theorem). Prerequisite: Math 317 or permission of instructor

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

MATH H333 ALGEBRA I (1.0 Credit)
Tarik Aougab
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 2024)

MATH H334 ALGEBRA II: ALGEBRAIC GEOMETRY (1.0 Credit)
Anthony Kling
Division: Natural Science
Domain(s): C: Physical and Natural Processes
We will build upon our algebraic tools to study geometric objects. In particular, we will study affine varieties, plane curves, projective varieties, and morphisms between these objects. We will also cover significant results, including Hilbert's Nullstellensatz and Bezout's Theorem. Prerequisite(s): MATH 333 or instructor consent

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:** Spring 2025)

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 2024)

MATH H345 THEORY OF COMPUTATION (1.0 Credit)
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, 107, 151, or 206) and CMSC 231, and junior or senior standing, or instructor consent
(**Offered:** Spring 2025)

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

MATH H361 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 2024)

MATH H382 MATHEMATICAL MODELING AND DIFFERENTIAL EQUATIONS (1.0 Credit)
Rebecca Everett
Division: Natural Science
Domain(s): C: Physical and Natural Processes
An introduction to modeling in applied mathematics using differential equations, with examples from biology, chemistry, engineering, physics, and/or the social sciences. Through these examples, we build mathematical models that reflect real world scenarios and analyze them to gain an understanding of the problem. Techniques of analysis may include phase plane methods, stability analysis, bifurcation theory, and computer simulation. Pre-requisite(s): MATH H204 or equivalent, or permission of the instructor Lottery Preference: Math majors, then math minors, then by seniority

MATH H383 PARTIAL DIFFERENTIAL EQUATIONS (1.0 Credit)
Robert Manning
Division: Natural Science
Domain(s): C: Physical and Natural Processes
This course is an introduction to partial differential equations, involving a mix of (1) analysis (the use of various tools to ask questions of existence and uniqueness of solutions and, in special cases, find solutions), (2) computation (the development of numerical techniques to find approximate solutions on the computer), and (3) modeling (the connection of mathematics to real problems). The balance of these features will vary from instructor to instructor. Pre-requisite(s): MATH H204 or equivalent, or instructor permission Lottery Preference: Math majors, then math minors, then by seniority
(**Offered:** Fall 2024)

MATH H390 ADVANCED TOPICS IN ALGEBRA: ALGEBRAIC COMBINATORICS (1.0 Credit)
Division: Natural Science
Domain(s): C: Physical and Natural Processes
A 300-level course in algebra, building on the introductory abstract algebra course MATH 333, with the particular topic(s) varying each time it is offered. Fall 2023: An introduction to applications of algebra to combinatorics and vice versa. Topics include Polya's theory of counting, generating functions, the matrix-tree theorem, the Robinson-Schensted-Knuth correspondence, symmetric functions, and the basic theory of Coxeter groups. Prerequisite(s): MATH 333

MATH H391 ADVANCED TOPICS IN GEOMETRY AND TOPOLOGY (1.0 Credit)
Tarik Aougab
Division: Natural Science
Domain(s): C: Physical and Natural Processes
A 300-level course in geometry and/or topology, sometimes building on the introductory topology course MATH 335, with the particular topic(s) varying each time it is offered. Spring 2024: The goal of this course is to introduce you to a suite of topological invariants, which are properties of topological spaces that must be preserved under homeomorphism. When one is aware of many topological invariants, it becomes easier to tell spaces apart (for example, if space A disagrees with space B with respect to some given invariant, they can not possibly be homeomorphic!) It turns out that the most fruitful place for developing invariants comes from abstract algebra. We will learn about how one can start with a topological space, and produce various groups and rings, such that if two spaces are homeomorphic, the corresponding algebraic structures must be

isomorphic. Prerequisite(s): MATH 335 and co-req of MATH 333

MATH H392 ADVANCED TOPICS IN ANALYSIS: FUNCTION SPACES AND DIFFERENTIAL EQUATIONS (1.0 Credit)
Joshua Sabloff
Division: Natural Science; Quantitative
Domain(s): C: Physical and Natural Processes
A 300-level course in analysis. Fall 2024: Introduction to analysis in spaces of functions with a focus on generalizing ideas from the reals. Foundational topics include uniform convergence, power series, Weierstrass approximation, and compactness. We will then build on those foundations by studying functionals and the calculus of variations, operators and ordinary differential equations, and Hilbert spaces and Laplace's equation. Prerequisite: MATH 317.
(**Offered:** Fall 2024)

MATH H394 ADVANCED TOPICS IN THEORETICAL COMPUTER SCIENCE: MATH FOUNDATIONS OF MACHINE LEARNING (1.0 Credit)
Division: Natural Science
Domain(s): C: Physical and Natural Processes
A 300-level course on the mathematical foundations of computer science, with the particular topic(s) varying each time it is offered. Fall 2023: An introduction to the mathematical principles behind modern machine learning algorithms. Covers advanced topics in linear algebra, vector calculus, probability theory, and optimization, with a particular focus on their relevance to machine learning tasks. We will also discuss various practical applications. Crosslisted: Mathematics, Computer Science. Prerequisite(s): MATH 121 and 215, or instructor permission

MATH H396 ADVANCED TOPICS: PROBABILITY AND STATISTICS (1.0 Credit)
Weiwen Miao
Division: Natural Science; Quantitative
Domain(s): C: Physical and Natural Processes
A 300-level course in probability and/or statistics, with the particular topic(s) varying each time it is offered. Spring 2025: The main topics for this course are nonparametric methods and categorical data analysis. Students will learn nonparametric statistical tests in one-sample, two-sample and k-sample situations as well as basic categorical data analysis. Crosslisted: Mathematics, Statistics. Prerequisite(s): MATH 218 and one of the following: MATH 203, ECON 203/204, PSYC 200, SOCL 215 or instructor permission
(**Offered:** Spring 2025)

MATH H397 ADVANCED TOPICS IN APPLIED MATHEMATICS: MODELS FOR DYNAMIC PROCESSES (1.0 Credit)
Division: Natural Science
Domain(s): C: Physical and Natural Processes
will cover dynamical systems' models construction and analysis. First, we will see how physical, biological and sociological principles drive the models' construction. We will perform qualitative analysis of these models. Later, we will discuss data driven dynamical processes' modeling with R software and its practical applications (e.g., econometrics and finance). If time permits, we will investigate an idea of combining physical principles with a data driven approach. Prerequisites: Math 215 or instructor permission
(**Offered:** Spring 2025)

MATH H399F SENIOR SEMINAR (0.5 Credit)
David Lippel
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 2024)

MATH H399I SENIOR SEMINAR (0.5 Credit)
Joshua Sabloff, Staff
Division: Natural Science
Seminar for students writing senior papers, dealing with the oral and written exposition of advanced material.
(**Offered:** Spring 2025)

MATH H400 SENIOR RESEARCH (0.5 Credit)
Joshua Sabloff, 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 2024)

MATH H460 TEACHING ASSISTANT (1.0 Credit)
Staff
(**Offered:** Spring 2025)

MATH H480 INDEPENDENT STUDY (1.0 Credit)
David Lippel
Independent Study
(**Offered:** Fall 2024)