

# APPLIED MATHEMATICS

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Mathematical models are widely used throughout natural science, social science, and engineering in fields as diverse as physics, bioinformatics, robotics, image processing, and economics. Despite the broad range of mathematical settings and applications, there exists a core of essential concepts and techniques used in addressing most problems. The Applied Mathematics major provides a foundation in these mathematical techniques and prepares the student to use them in a substantive field of application.

The interdisciplinary major permits a great deal of flexibility in design. It is intended to appeal to students who wish to study the more mathematical aspects of science or engineering, as well as those whose primary interest is in mathematics and statistics and who wish to become acquainted with applications. Core courses are drawn from Computer Science, Mathematics, Statistics and Data Science, and Engineering and Applied Science. Courses applying mathematics may be drawn from participating programs in Applied Physics; Astronomy & Astrophysics; the biological sciences, including Ecology and Evolutionary Biology, Molecular Biophysics and Biochemistry, and Molecular, Cellular, and Developmental Biology; Chemistry; Economics; the various programs in engineering, including Biomedical Engineering, Chemical Engineering, Electrical Engineering, Environmental Engineering, and Mechanical Engineering; Earth and Planetary Sciences; Physics; and even Linguistics and Political Science. The Applied Mathematics degree program requires a three-course concentration in a field in which mathematics is used.

Students in the major are often sought after by graduate programs in either Applied Mathematics or in the disciplines in which they choose their concentration, as well as by industries and startup companies in which their breadth of quantitative skills are essential and often unique.

Students may pursue a major in Applied Mathematics as one of two majors and can thereby equip themselves with mathematical modeling skills while being fully engaged in a field of application. In this case, the concentration requirement of the Applied Mathematics program is flexible in order to recognize the contribution of the other major. A two-course overlap is permitted to satisfy the requirements of the two majors.

**Frequently Asked Questions** Students are encouraged to consult the Applied Mathematics FAQ for more details about courses and policies in the major.

## PREREQUISITE AND INTRODUCTORY COURSES

Multivariable calculus and linear algebra are required and should be taken before or during the sophomore year. This requirement may be satisfied by MATH 120 or ENAS 151, and MATH 222 or 225 or 226. It may also be satisfied by MATH 230, 231 for rising seniors. Computer programming skills are also required and may be acquired by taking ENAS 130 and CPSC 100 or 112. Details of individual programs must be worked

out in consultation with the director of undergraduate studies (DUS), whose signed permission is required.

#### REQUIREMENTS OF THE MAJOR

**Students are held to the requirements that were in place when they declared their major.** However, with approval from the DUS, the following requirements may be fulfilled by students who declared the major in a prior term. Rising seniors may count MATH 230, 231 (linear algebra), MATH 250 (vector analysis), and MATH 300 and 301 (analysis) toward their analysis requirements.

**The B.A. degree program** The program requires eleven term courses beyond the prerequisites, including the senior project, comprising a coherent program:

1. A course in differential equations (ENAS 194 or MATH 246)
2. A course in probability (S&DS 241 or S&DS 238)
3. A course in data analysis (S&DS 361 or S&DS 230)
4. A course in discrete mathematics (AMTH 244 or CPSC 202)
5. Courses in at least three of the following areas\* (with DUS approval) including, but not limited to:
  - (a) optimization: AMTH 232, 431, 437, EENG 433, CPSC 485
  - (b) probability and statistics: S&DS 242, 312, 351, 364, 400, 410, 411, 425, ECON 136, APHY 470
  - (c) partial differential equations and analysis: MATH 247, 250, 255, 256, 260, 300, 301, 302, 305, 310, 447, AMTH 428
  - (d) algorithms and numerical methods: CPSC 365, 366, 424, 440, 465, 467, 468, 469, ENAS 440, 441
  - (e) graph theory: AMTH 362, 420, 562, ENAS 962, MATH 799
  - (f) mathematical economics: ECON 125, 126, 350, 351, 417, 433, 460, 471
  - (g) electrical engineering: EENG 397, 436, 455, AMTH 342, S&DS 364
  - (h) data mining and machine learning: S&DS 262, 365, 669, 671, CPSC 445, 453, 470, 474, 477, 486, 745, AMTH 552
  - (i) biological modeling and computation: CPSC 453, 475, 476, BENG 352, 445, 458, ENAS 559
  - (j) physical sciences: ASTR 320, 420, CHEM 333\*\*, EPS 322, 323, 421, 428, 456, PHYS 342, 343, 344, 401, 402, 410, 420, 430, 440, 442, 460, APHY 439, 448
  - (k) engineering: MENG 280, 285, 361, 365, 383, 463, 469, CENG 301, 315
  - (l) mathematical linguistics: LING 224, 227, 380
  - (m) mathematical philosophy: PHIL 267, 427, MATH 270

\* Because departmental curricula from which the program draws regularly change, the DUS maintains a more exhaustive list of courses and areas satisfying this particular

requirement. Additionally, due to rapid advances in many areas, these categories are often fluid, and their union can evolve. In order to accommodate this fluidity, students are strongly encouraged to revisit their program of study each term and share their checklist with the DUS. Students can independently and systematically plan multiple routes toward completion of the major by using the checklist and the master list of courses.

\*\* Chemistry courses numbered 410 and above may count as a breadth requirement (either 1 full-term 1 credit course or 2 half-credit courses) with permission of the DUS.

6. At least *three advanced courses* in a field of concentration involving the application of mathematics to that field. Programs in science, engineering, computer science, statistics, and economics are natural sources of concentration. Alternatively, when two majors are undertaken, if the second major is in a participating program, then, recognizing that there can be an overlap of two courses, the student may take for the remaining course an additional choice relevant to the Applied Mathematics major such as those listed in point 5 above or for the B.S. below. Details of a student's program to satisfy the concentration requirement must be worked out in consultation with, and approved by, the DUS.

**The B.S. degree program** In addition to the courses indicated for the B.A. degree, the B.S. degree, which totals fourteen term courses beyond the prerequisites and includes the senior requirement, must also include the three items listed below.

1. A vector analysis course, (MATH 302 or MATH 305). MATH 310, 320, 325, and 447 and those courses listed under "(c) partial differential equations and analysis" can act as replacements for MATH 250, 300, 301 and/or act as concentration or breadth courses.

The course selected may not be counted toward the requirements for the major under item 5 above. (MATH 350 and MATH 440 can in specific cases be considered in consultation with the DUS.)

2. An additional course selected from item 5 above.

3. Another course numbered 300 or higher selected from item 5 above, or a course numbered 300 or higher in mathematics, applied mathematics, statistics, or quantitative computer science or engineering, subject to the approval of the DUS.

Alternatively, students may petition to receive a B.S. in Applied Mathematics by fulfilling the B.A. requirements in Applied Mathematics and the B.S. requirements in another program.

**Credit/D/Fail** A maximum of one course credit taken Credit/D/Fail may be counted toward the requirements of the major.

#### SENIOR REQUIREMENT

Both the B.A. and B.S. degree programs require a senior thesis research project (AMTH 491).

#### SUMMARY OF MAJOR REQUIREMENTS

**Prerequisites** MATH 120 or ENAS 151, and MATH 222 or 225 or 226, or equivalents; ENAS 130, CPSC 100, or 112

**Number of courses** *B.A.* – 11 term courses beyond prereqs (incl senior req); *B.S.* – 14 term courses beyond prereqs (incl senior req)

**Specific courses required** *B.A.* – ENAS 194 or MATH 246; S&DS 241 or S&DS 238; S&DS 361 or S&DS 230; AMTH 244 or CPSC 202; *B.S.* – same as *B.A. degree*

**Distribution of courses** *B.A.* – at least 3 advanced courses in a concentration concerning the application of math to that field; 3 addtl courses, as specified; *B.S.* – same as *B.A. degree*, plus MATH 302 or 305 (or MATH 350 and 440 with DUS approval), with 2 addtl courses, as specified

**Senior requirement** Senior thesis research project (AMTH 491)

### Prerequisites

- Computer programming, ENAS 130 and CPSC 100 or CPSC 112
- Multivariable calculus and linear algebra, MATH 120 or ENAS 151 and [MATH 222 or MATH 225 or MATH 226] or [MATH 230 and MATH 231 for rising seniors]

### **B.A. Degree requirements: 11 courses (11 credits), beyond prerequisites, including senior requirement**

- 1 differential equations course, ENAS 194 or MATH 246
- 1 probability course, S&DS 241 or S&DS 238
- 1 data analysis\* course, S&DS 361 or S&DS 230
- 1 discrete mathematics course, AMTH 244 or CPSC 202
- 3 courses as listed on the Overview page under the item 5 options
- 3 advanced courses in a concentration involving applied mathematics
- AMTH 491, senior requirement

\*Rising seniors may count MATH 230, MATH 231 (linear algebra), MATH 250 (vector analysis) or MATH 300 and MATH 301 (analysis) toward their analysis requirements.

### **B.S. Degree requirements: 14 courses (14 credits), beyond prerequisites, including senior requirement**

- 11 of the required courses follow the requirements for the B. A. Degree, including the senior requirement
- 1 additional vector analysis course, different from the one taken to fulfill the B.A. degree requirements; options listed as partial differential equations and analysis courses (see Overview)
- 1 additional course as listed in item 5 (see Overview)
- 1 additional course, 300-level or higher selected from item 5 (see Overview) or as approved by DUS

Mathematical models are used to study a multitude of problems in fields as diverse as bioinformatics, systems engineering, and business management. Despite the wide

range of the applications, relatively few essential mathematical techniques and concepts are used in addressing most problems. The Applied Mathematics major is designed to provide a foundation in these common mathematical techniques and to train students to use them to solve problems in one or two fields of application.

The major is intended for students interested in theoretical and quantitative aspects of the natural and social sciences. Students currently combine applied mathematics with astronomy, chemistry, computer science, economics, engineering, geophysics, physics, and statistics and data science, but any other discipline with enough quantitative courses may serve as the area of specialization.

Prerequisites for the major include courses in computer programming, multivariable calculus, and linear algebra. Students who want to keep their options open should take, in addition to the prerequisites, an introductory sequence in physics or chemistry (for those interested in the natural sciences) or a year of introductory economics (for those who wish to concentrate in the social or management sciences), for these serve as prerequisites for the advanced courses in those areas of concentration for the Applied Mathematics major.

Prospective majors are encouraged to consult the Applied Mathematics FAQ website for a more detailed description of the Applied Mathematics program, including a sample curriculum and a list of appropriate upper-level courses. The director of undergraduate studies (DUS) may be contacted with any further questions.

#### FACULTY ASSOCIATED WITH THE PROGRAM OF APPLIED MATHEMATICS

**Professors** Andrew Barron (*Statistics & Data Science*), David Bercovici (*Earth & Planetary Sciences*), Donald Brown (*Emeritus*) (*Economics, Mathematics*), Joseph Chang (*Statistics & Data Science*), Ronald Coifman (*Mathematics*), Michael Fischer (*Computer Science*), Igor Frenkel (*Mathematics*), Anna Gilbert (*Mathematics, Statistics & Data Science*), Roger Howe (*Emeritus*) (*Mathematics*), Peter Jones (*Mathematics*), John Lafferty (*Statistics & Data Science*), A. Stephen Morse (*Electrical Engineering*), Corey O'Hern (*Mechanical Engineering & Materials Science*), David Pollard (*Statistics & Data Science*), Nicholas Read (*Physics, Applied Physics*), Vladimir Rokhlin (*Computer Science, Mathematics*), John Schotland (*Mathematics*), Peter Schultheiss (*Emeritus*) (*Electrical Engineering*), Martin Schultz (*Emeritus*) (*Computer Science*), Mitchell Smooke (*Mechanical Engineering & Materials Science, Applied Physics*), Daniel Spielman (*Computer Science, Statistics & Data Science*), Mary-Louise Timmermans (*Earth & Planetary Sciences*), Van Vu (*Mathematics*), Günter Wagner (*Ecology & Evolutionary Biology*), John Wettlaufer (*Earth & Planetary Sciences, Mathematics, Physics*), Huibin Zhou (*Statistics & Data Science*), Steven Zucker (*Computer Science, Biomedical Engineering*)

**Associate Professors** John Emerson (*Statistics & Data Science*), Thierry Emonet (*Molecular, Cellular, & Developmental Biology, Physics*), Josephine Hoh (*Epidemiology & Public Health*), Yuval Kluger (*Pathology*), Michael Krauthammer (*Pathology*), Smita Krishnaswamy (*Genetics, Computer Science*), Sekhar Tatikonda (*Electrical Engineering, Statistics & Data Science*), Madhusudhan Venkadesan (*Mechanical Engineering & Materials Science*)

**J. W. Gibbs Assistant Professors** Yariv Aizenbud, Abinand Gopal, Erik Hiltunen, Boris Landa, Kevin O'Neill

See visual roadmap of the requirements.

[View Courses](#)