APPLIED MATHEMATICS

Applied mathematics graduates have the expertise and mathematical sophistication necessary to make contributions in a wide variety of fields, including scientific computation, actuarial science, financial modeling and most areas of science and engineering that have a mathematical basis.

A professional applied mathematician may work with engineers, scientists, programmers and other specialists. The curriculum at CU Boulder is designed to have the breadth for such an interdisciplinary career.

Course offerings at the undergraduate level focus on providing students with mathematical tools, problem-solving strategies and expertise useful in science and engineering. To fulfill requirements, a concentrated area of engineering courses (or approved natural science courses) must be completed. The college has formulated several recommended options within the discipline.

The objectives of the Department of Applied Mathematics at CU Boulder are summarized below:

- provide undergraduate and graduate students with high-quality education and training in applied mathematics, and prepare them for careers in industry, laboratories and the academic professions;
- offer and monitor degree programs leading to BS, MS and PhD degrees in applied mathematics;
- nourish and maintain a professional environment in which excellence in teaching, learning, scholarship and creativity are of central importance;
- assure teaching and research expertise in a number of key areas of applied mathematics, including the methodology of applied mathematics, computational mathematics and algorithms, industrial applications, mathematical biology, applied probability and statistics.

Courses at the undergraduate level provide training in a broad range of mathematical techniques and problem-solving strategies. These courses teach the concepts and methods central to applications of linear algebra, ordinary and partial differential equations, numerical analysis, probability and statistics, complex variables and nonlinear dynamics. Since applied mathematicians often are involved in interdisciplinary work, the BS degree requires an in-depth knowledge of some area of science or engineering where mathematics is used. This knowledge prepares graduates to successfully communicate with engineers and scientists. The BS degree also requires knowledge of a programming language and skill in using the computer.

Course code for this program is APPM.

Desired Outcomes

The undergraduate degree in applied mathematics emphasizes knowledge and awareness of:

- differential and integral calculus in one and several variables;
- vector spaces and matrix algebra;
- ordinary and partial differential equations;
- at least one programming language;
- at least one application software package in either mathematics or statistics;
- methods of complex variables as used in applications; and
- numerical solutions of linear and nonlinear problems.

In addition, students completing a degree in applied mathematics acquire:

- an in-depth knowledge of an area of application (an engineering discipline or a natural science field or one of the quantitative areas of business and economics);
- knowledge of problem formulation, problem-solving and modeling techniques, and strategies central to applications; and
- the ability to communicate analytic arguments clearly and concisely in oral and written forms.

Bachelor's Degree

- Applied Mathematics - Bachelor of Science (BSAM) (catalog.colorado.edu/undergraduate/colleges-schools/engineering-applied-science/programs-study/applied-mathematics-applied-mathematics-bachelor-science-bs)

Faculty

While many faculty teach both undergraduate and graduate students, some instruct students at the undergraduate level only. For more information, contact the faculty member's home department.

Ablowitz, Mark J (https://experts.colorado.edu/display/fisid_100691) Professor; PhD, Massachusetts Institute of Technology

Appelö, Daniel (https://experts.colorado.edu/display/fisid_159438) Associate Professor; PhD, Royal Institute of Technology, Stockholm, Sweden

Bebernies, Jerrold Professor Emeritus

Becker, Stephen R (https://experts.colorado.edu/display/fisid_154263) Assistant Professor; PhD, California Institute of Technology

Beylkin, Gregory (https://experts.colorado.edu/display/fisid_100437) Professor; PhD, New York University

Bhat, Yermal Sujeet (https://experts.colorado.edu/display/fisid_146506) Instructor; PhD, University of Florida

Bortz, David Matthew (https://experts.colorado.edu/display/fisid_143348) Associate Professor; PhD, North Carolina State University at Raleigh

Corcoran, Jem (https://experts.colorado.edu/display/fisid_118142) Associate Professor; PhD, Colorado State University
Courses

APPM 1235 (4) Pre-Calculus for Engineers
Prepares students for the challenging content and pace of the calculus sequence required for all engineering majors. Covers algebra, trigonometry and selected topics in analytical geometry. Prepares students for the calculus courses offered for engineering students. Requires students to engage in rigorous work sessions as they review topics that they must be comfortable with to pursue engineering course work. Structured to accustom students to the pace and culture of learning encountered in engineering math courses. For more information about the math placement referred to in the "Enrollment Requirements", please contact your academic advisor. Formerly GEEN 1235.
Equivalent - Duplicate Degree Credit Not Granted: MATH 1021 or MATH 1150
Requisites: Requires an ALEKS math exam taken in 2016 or earlier, or placement into pre-calculus based on your admissions data and/or CU Boulder coursework.

APPM 1340 (4) Calculus 1 with Algebra, Part A
Studies selected topics in analytical geometry and calculus: rates of change of functions, limits, derivatives and their applications. This course and APPM 1345 together are equivalent to APPM 1350. The sequence of this course and APPM 1345 is specifically designed for students whose manipulative skills in the techniques of high school algebra and precalculus may be inadequate for APPM 1350. For more information about the math placement referred to in the "Enrollment Requirements", please contact your academic advisor.
Requisites: Requires prerequisite course of APPM 1235 or MATH 1021 or MATH 1150 or MATH 1160 (minimum grade C-) or an ALEKS math exam taken in 2016 or earlier, or placement into pre-calculus based on your admissions data and/or CU Boulder coursework.

APPM 1345 (4) Calculus 1 with Algebra, Part B
Continuation of APPM 1340. Studies selected topics in calculus: derivatives and their applications, integration, differentiation and integration of transcendental functions. Algebraic and trigonometric topics are studied throughout, as needed.
Equivalent - Duplicate Degree Credit Not Granted: APPM 1350 or ECON 1088 or MATH 1081 or MATH 1300 or MATH 1310 or MATH 1330
Requisites: Requires prerequisite course of APPM 1340 (minimum grade C).
APPMM 1350 (4) Calculus 1 for Engineers
Topics in analytical geometry and calculus including limits, rates of change of functions, derivatives and integrals of algebraic and transcendental functions, applications of differentiations and integration. Students who have already earned college credit for calculus 1 are eligible to enroll in this course if they want to solidify their knowledge base in calculus 1. For more information about the math placement referred to in the "Enrollment Requirements", contact your academic advisor.
Equivalent - Duplicate Degree Credit Not Granted: APPM 1345 or ECON 1088 or MATH 1081 or MATH 1300 or MATH 1310 or MATH 1330
Requisites: Requires prerequisite course of APPM 1235 or MATH 1021 or MATH 1150 or MATH 1160 or MATH 1300 (minimum grade C-) or an ALEKS math exam taken in 2016 or earlier, or placement into calculus based on your admissions data and/or CU Boulder coursework.
Additional Information: GT Pathways: GT-MA1 - Mathematics
Arts Sci Core Curr: Quant Reasn Mathmat Skills
Arts Sci Gen Ed: Quantitative Reasoning Math

APPMM 1360 (4) Calculus 2 for Engineers
Continuation of APPM 1350. Focuses on applications of the definite integral, methods of integration, improper integrals, Taylor’s theorem, and infinite series.
Equivalent - Duplicate Degree Credit Not Granted: MATH 2300
Requisites: Requires prerequisite course of APPM 1345 or APPM 1350 or MATH 1300 (minimum grade C-).

APPMM 1390 (1) A Game for Calculus
Coaches students to implement study strategies geared specifically toward APPM Calculus in a structured, supportive, small group environment. Enrollment requires instructor approval.
Repeatable: Repeatable for up to 3.00 total credit hours.

APPMM 2350 (4) Calculus 3 for Engineers
Covers multivariable calculus, vector analysis, and theorems of Gauss, Green, and Stokes.
Equivalent - Duplicate Degree Credit Not Granted: MATH 2400
Requisites: Requires prerequisite course of APPM 1360 or MATH 2300 (minimum grade C-).

APPMM 2360 (4) Introduction to Differential Equations with Linear Algebra
Equivalent - Duplicate Degree Credit Not Granted: both MATH 2130 and MATH 3430
Requisites: Requires prerequisite course of APPM 1360 or MATH 2300 (minimum grade C-).

APPMM 2450 (1) Calculus 3 Computer Lab
Selected topics in analytic geometry and calculus with a focus on symbolic computation using Mathematica.
Requisites: Requires a corequisite course of APPM 2350.
Grading Basis: Pass/Fail

APPMM 2460 (1) Differential Equations Computer Lab
Selected topics in differential equations and linear algebra with a focus on symbolic computation using MATLAB.
Requisites: Requires enrollment in a corequisite course of APPM 2360.
Grading Basis: Pass/Fail

APPMM 2720 (1-3) Open Topics in Lower Division Applied Mathematics
Provides a vehicle for the development and presentation of new topics that are accessible to lower division Applied Mathematics students. These topics have the potential to be incorporated into the core APPM curriculum.
Repeatable: Repeatable for up to 6.00 total credit hours. Allows multiple enrollment in term.
Requisites: Requires prerequisite course of APPM 1350 or MATH 1300 (minimum grade C-).
Grading Basis: Letter Grade

APPMM 2750 (4) Java: Training, Mathematical Algorithms, and Mobile Apps
Preparatory course for Java programming. Provides necessary background for Java language: basic object-oriented concepts, analysis, and design. Learn to create Java applets, applications and mobile apps, create graphic context, and identify the key features of Java foundation classes as well as other Java-related technology. Material is taught in the context of mathematical algorithms from calculus. Department enforced requisite, knowledge of a programming language.
Requisites: Requires prerequisite course of APPM 1350 or MATH 1300 (minimum grade C-).

APPMM 3010 (3) Chaos in Dynamical Systems
Introduces undergraduate students to chaotic dynamical systems. Topics include smooth and discrete dynamical systems, bifurcation theory, chaotic attractors, fractals, Lyapunov exponents, synchronization and networks of dynamical systems. Applications to engineering, biology and physics will be discussed.
Requisites: Requires prerequisite course of APPM 2360 or MATH 3430 (minimum grade C-).
Additional Information: Arts Sci Gen Ed: Distribution-Natural Sciences

APPMM 3050 (3) Scientific Computing in Matlab
Topics covered include: approximations in computing, computer arithmetic, interpolation, matrix computations, nonlinear equations, optimization, and initial-value problems with emphasis on the computational cost, efficiency, and accuracy of algorithms. The problem sets are application-oriented with examples taken from orbital mechanics, physics, genetics, and fluid dynamics.
Requisites: Requires prerequisite course of APPM 2360 or MATH 3430 (minimum grade C-).

APPMM 3170 (3) Discrete Applied Mathematics
Introduces students to ideas and techniques from discrete mathematics that are widely used in science and engineering. Mathematical definitions and proofs are emphasized. Topics include formal logic notation, proof methods; set theory, relations; induction, well-ordering; algorithms, growth of functions and complexity; integer congruences; basic and advanced counting techniques, recurrences and elementary graph theory. Other selected topics may also be covered.
Requisites: Requires a prerequisite of APPM 1360 or MATH 2300 (all minimum grade C-).

APPMM 3310 (3) Matrix Methods and Applications
Introduces linear algebra and matrices with an emphasis on applications, including methods to solve systems of linear algebraic and linear ordinary differential equations. Discusses vector space concepts, decomposition theorems, and eigenvalue problems.
Equivalent - Duplicate Degree Credit Not Granted: MATH 2130 and MATH 2135
Requisites: Requires prerequisite course of APPM 2350 or APPM 2360 or MATH 2400 (minimum grade C-).
Additional Information: Arts Sci Gen Ed: Distribution-Natural Sciences
**APPM 3350 (3) Advanced Engineering Calculus**
Extends the treatment of engineering mathematics beyond the topics covered in Calculus 3 and differential equations. Topics include non-dimensionalization, elementary asymptotics and perturbation theory, Reynold’s transport theorem and extensions of Leibnitz’s rule, as applied to continuum conservation equations, Hamiltonian formulations, Legendre and Laplace transforms, special functions and their orthogonality properties.

**Requisites:** Requires prerequisite course of APPM 2350 or MATH 2400 and APPM 2360 (all minimum grade C-).

**APPM 3570 (3) Applied Probability**
Studies axioms, counting formulas, conditional probability, independence, random variables, continuous and discrete distribution, expectation, joint distributions, moment generating functions, law of large numbers and the central limit theorem.

**Equivalent - Duplicate Degree Credit Not Granted:** ECEN 3810 or MATH 4510 STAT 3100

**Requisites:** Requires a prerequisite or corequisite course of APPM 2350 or MATH 2400 (prereq minimum grade C-).

**Additional Information:** Arts Sci Gen Ed: Distribution-Natural Sciences

**APPM 4120 (3) Introduction to Operations Research**
Studies linear and nonlinear programming, the simplex method, duality, sensitivity, transportation and network flow problems, some constrained and unconstrained optimization theory, and the Kuhn-Tucker conditions, as time permits.

**Equivalent - Duplicate Degree Credit Not Granted:** APPM 5120 and MATH 4120 and MATH 5120

**Requisites:** Requires a prerequisite course of APPM 3310 or MATH 3130 or MATH 3135 (minimum grade C-).

**Additional Information:** Arts Sci Gen Ed: Distribution-Natural Sciences

**APPM 4350 (3) Methods in Applied Mathematics: Fourier Series and Boundary Value Problems**
Reviews ordinary differential equations, including solutions by Fourier series. Physical derivation of the classical linear partial differential equations (heat, wave, and Laplace equations). Solution of these equations via separation of variables, with Fourier series, Fourier integrals, and more general eigenfunction expansions.

**Equivalent - Duplicate Degree Credit Not Granted:** APPM 5350

**Requisites:** Requires prerequisite courses of APPM 2350 or MATH 2400 and APPM 2360 (all minimum grade C-) and a prerequisite or corequisite course of APPM 3310 or MATH 3130 or MATH 3135 (prereq minimum grade C-).

**Additional Information:** Arts Sci Gen Ed: Distribution-Natural Sciences

**APPM 4360 (3) Methods in Applied Mathematics: Complex Variables and Applications**
Introduces methods of complex variables, contour integration and theory of residues. Applications include solving partial differential equations by transform methods, Fourier and Laplace transforms and Reimann-Hilbert boundary-value problems, conformal mapping to ideal fluid flow and/or electrostatics.

**Equivalent - Duplicate Degree Credit Not Granted:** APPM 5360

**Requisites:** Requires prerequisite courses of APPM 2350 or MATH 2400 and APPM 2360 (all minimum grade C-) and a prerequisite or corequisite course of APPM 3310 or MATH 3130 or MATH 3135 (prereq minimum grade C-).

**Additional Information:** Arts Sci Gen Ed: Distribution-Natural Sciences

**APPM 4380 (3) Modeling in Applied Mathematics**
An exposition of a variety of mathematical models arising in the physical and biological sciences. Students’ modeling projects are presented in class. Topics may include: GPS navigation, medical imaging, ocean waves, and computerized facial recognition.

**Equivalent - Duplicate Degree Credit Not Granted:** APPM 5380

**Requisites:** Requires prerequisite courses of APPM 2350 or MATH 2400 and APPM 2360 (all minimum grade C-).

**Recommended:** Prerequisites APPM 3310 and APPM 4350 and APPM 4650.

**Additional Information:** Arts Sci Gen Ed: Distribution-Natural Sciences

**APPM 4390 (3) Modeling in Mathematical Biology**
Investigates how complex systems in biology can be studied using applied mathematics. Examines several case studies which include topics from microbiology, enzyme reaction kinetics, neuroscience, ecology, epidemiology, physiology and bioengineering.

**Equivalent - Duplicate Degree Credit Not Granted:** APPM 5390

**Requisites:** Requires prerequisite courses of APPM 2360 and APPM 3310 or MATH 3130 or MATH 3135 (all minimum grade C-).

**Additional Information:** Arts Sci Gen Ed: Distribution-Natural Sciences

**APPM 4440 (3) Undergraduate Applied Analysis 1**
Provides a rigorous treatment of topics covered in Calculus 1 and 2. Topics include convergent sequences; continuous functions; differentiable functions; Darboux sums, Riemann sums, and integration; Taylor and power series and sequences of functions.

**Requisites:** Requires prerequisite courses of APPM 2350 or MATH 2400 and APPM 2360 (all minimum grade C-) and a prerequisite or corequisite course of APPM 3310 or MATH 3130 or MATH 3135 (prereq minimum grade C-).

**Additional Information:** Arts Sci Gen Ed: Distribution-Natural Sciences

**APPM 4450 (3) Undergraduate Applied Analysis 2**
Continuation of APPM 4440. Study of multidimensional analysis including n-dimensional Euclidean space, continuity and uniform continuity of functions of several variables, differentiation, linear and nonlinear approximation, inverse function and implicit function theorems, and a short introduction to metric spaces.

**Requisites:** Requires prerequisite course of APPM 4440 or MATH 3001 (minimum grade C-).

**APPM 4500 (3) Statistical Collaboration**
Educates and trains students to become effective interdisciplinary collaborators by developing the communication and collaboration skills necessary to apply technical statistics and data science skills to help domain experts answer research questions. Topics include structuring effective meetings and projects; communicating statistics to non-statisticians; using peer feedback, self-reflection and video analysis to improve collaboration skills; creating reproducible statistical workflows; working ethically.

**Equivalent - Duplicate Degree Credit Not Granted:** APPM 5500

**Requisites:** Requires a prerequisite course of APPM 4520 (minimum grade C-).

**Grading Basis:** Letter Grade

**Additional Information:** Arts Sci Gen Ed: Distribution-Natural Sciences
APPM 4505 (2) Advanced Statistical Collaboration
Educates and trains students to become advanced interdisciplinary collaborators by developing and refining the communication, collaboration and technical statistics and data science skills necessary to collaborate with domain experts to answer research questions. Students work on multiple projects. Discussions center on technical skills necessary to solve research problems and video analysis to improve communication and collaboration skills.
Equivalent - Duplicate Degree Credit Not Granted: APPM 5505
Requisites: Requires prerequisite course of APPM 4500 or APPM 5500 (minimum grade C-).
Grading Basis: Letter Grade
Additional Information: Arts Sci Gen Ed: Distribution-Natural Sciences

APPM 4510 (3) Data Assimilation in High Dimensional Dynamical Systems
Develops and analyzes approximate methods of solving the Bayesian inverse problem for high-dimensional dynamical systems. After briefly reviewing mathematical foundations in probability and statistics, the course covers the Kalman filter, particle filters, variational methods and ensemble Kalman filters. The emphasis is on mathematical formulation and analysis of methods.
Equivalent - Duplicate Degree Credit Not Granted: APPM 5510, STAT 4250 and STAT 5250
Requisites: Requires prerequisite courses of APPM 3310 and APPM 3570 or STAT 3100 or MATH 4510 (all minimum grade C-).
Additional Information: Arts Sci Gen Ed: Distribution-Natural Sciences

APPM 4530 (3) Stochastic Analysis for Finance
Studies mathematical theories and techniques for modeling financial markets. Specific topics include the binomial model, risk neutral pricing, stochastic calculus, connection to partial differential equations and stochastic control theory.
Equivalent - Duplicate Degree Credit Not Granted: APPM 5530, STAT 4230 and STAT 5230
Requisites: Requires prerequisite courses of APPM 3310 and APPM 3570, or STAT 3100, or MATH 4510 (all minimum grade C-).

APPM 4560 (3) Markov Processes, Queues, and Monte Carlo Simulations
Brief review of conditional probability and expectation followed by a study of Markov chains, both discrete and continuous time, including Poisson point processes. Queuing theory, terminology and single queue systems are studied with some introduction to networks of queues. Uses Monte Carlo simulation of random variables throughout the semester to gain insight into the processes under study.
Equivalent - Duplicate Degree Credit Not Granted: APPM 5560 and STAT 4100
Requisites: Requires prerequisite courses of APPM 3570 or STAT 3100 or MATH 4510 (all minimum grade C-).
Additional Information: Arts Sci Gen Ed: Distribution-Natural Sciences

APPM 4565 (3) Random Graphs
Introduces mathematical techniques, including generating functions, the first- and second-moment method and Chernoff bounds to study the most fundamental properties of the Erdos-Renyi model and other celebrated random graph models such as preferential attachment, fixed degree distribution, and stochastic block models.
Equivalent - Duplicate Degree Credit Not Granted: APPM 5565
Requisites: Requires prerequisite APPM 3570 or MATH 4510 (both minimum grade C).
Grading Basis: Letter Grade

APPM 4570 (3) Statistical Methods
Covers basic statistical concepts with accompanying introduction to the R programming language. Topics include discrete and continuous probability laws, random variables, expectation and variance, central limit theorem, testing hypothesis and confidence intervals, linear regression analysis, simulations for validation of statistical methods and applications of methods in R.
Equivalent - Duplicate Degree Credit Not Granted: APPM 5570
Requisites: Requires prerequisite course of APPM 1360 or MATH 2300 (minimum grade C-).
Additional Information: Arts Sci Gen Ed: Distribution-Natural Sciences

APPM 4590 (3) Statistical Modeling
Introduces methods, theory and applications of statistical models, from linear models (simple and multiple linear regression), to hierarchical linear models. Topics such as estimation, residual diagnostics, goodness of fit, transformations, and various strategies for variable selection and model comparison will be discussed in depth. Examples and exercises will be demonstrated using statistical software.
Equivalent - Duplicate Degree Credit Not Granted: APPM 5590
Requisites: Requires prerequisite course of APPM 4520 or APPM 4570 or MATH 4520 (minimum grade C-).
Additional Information: Arts Sci Gen Ed: Distribution-Natural Sciences

APPM 4650 (3) Intermediate Numerical Analysis 1
Focuses on numerical solution of nonlinear equations, interpolation, methods in numerical integration, numerical solution of linear systems, and matrix eigenvalue problems. Stresses significant computer applications and software. Department enforced prerequisite: knowledge of a programming language.
Equivalent - Duplicate Degree Credit Not Granted: MATH 4650
Requisites: Requires a prerequisite course of MATH 3430 or APPM 2360 and APPM 3310 (minimum grade C-).

APPM 4660 (3) Intermediate Numerical Analysis 2
Continuation of APPM 4650. Examines numerical solution of initial-value problems and two-point boundary-value problems for ordinary differential equations. Also looks at numerical methods for solving partial differential equations. Department enforced prerequisite: knowledge of a programming language.
Equivalent - Duplicate Degree Credit Not Granted: MATH 4660
Requisites: Requires prerequisite course of APPM 4650 or MATH 4650 (minimum grade C-).

APPM 4720 (1-3) Open Topics in Applied Mathematics
Provides a vehicle for the development and presentation of new topics that may be incorporated into the core courses in applied mathematics. Department enforced prerequisite: variable, depending on the topic, see instructor.
Equivalent - Duplicate Degree Credit Not Granted: APPM 5720
Repeatability: Repeatable for up to 15.00 total credit hours. Allows multiple enrollment in term.

APPM 4840 (1-3) Reading and Research in Applied Mathematics
Introduces undergraduate students to the research foci of the Department of Applied Mathematics. Department enforced prerequisite: variable depending on the topic.
Repeatability: Repeatable for up to 9.00 total credit hours.
**APPM 4950 (1-3) Seminar in Applied Mathematics**
Introduces undergraduate students to the research foci of the program in applied mathematics. It is also designed to be a capstone experience for the program’s majors. Department enforced prerequisite: variable depending on the topic.

**Repeatable:** Repeatable for up to 6.00 total credit hours. Allows multiple enrollment in term.