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# Mathematics

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[2009-10 update to the *General Catalog*, changes highlighted]

Revised 12/10/08 (md) Changes in red.

194 Baskin Engineering

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<http://www.math.ucsc.edu>

## *Program Description*

Mathematics is both a fundamental discipline and an essential tool for students of biology, chemistry, computer engineering, computer science, Earth sciences, economics, electrical engineering, information systems management, physics, and psychology. Researchers in all these areas are constantly developing new and cutting-edge ways of applying mathematics to their field. A strong mathematics background is vital to the advanced study of the physical and biological sciences and plays an integral role in studying the social sciences.

The UCSC mathematics program offers a wide variety of undergraduate mathematics courses:

- Courses 2 and 3 do not require thorough preparation in mathematics at the high school level. However, students interested in studying mathematics are strongly encouraged to take algebra, geometry, and trigonometry before entering the university. Prospective freshmen are also encouraged to take the mathematics placement exam during their senior year of high school at a UCSC-scheduled exam. If they place into course 2 or 3, they should take those courses at UCSC during the summer, so they can begin the calculus series when they enter in the fall. Failure to begin the calculus series in the fall could delay progress in some majors.
- Lower-division courses with numbers in the range 11A-B through 30 (calculus, linear algebra, multivariable calculus, differential equations, and problem solving) prepare students for further study in mathematics, the physical and biological sciences, or quantitative areas of the social sciences. Science majors take a combination of these courses as part of their undergraduate studies.
- Upper-division courses, with numbers in the range 100-199, are intended for majors in mathematics and closely related disciplines. Some of these courses provide students with a solid foundation in key areas of mathematics such as algebra, analysis, geometry, and number theory, whereas others introduce students to more specialized areas of mathematics. Calculus, linear algebra, multivariable calculus, and proof and problem solving are prerequisite to most of these advanced courses.

Within the major, there are three concentrations leading to the B.A. degree: pure mathematics, computational mathematics, and mathematics education. These programs are designed to give students a strong background for graduate study, for work in industry or government, or for teaching. Each concentration requires nine courses, one of which must be a senior thesis or senior seminar. Please read the pure mathematics, computational mathematics, and mathematics education program descriptions below for specific information about course requirements. A minor in mathematics is also offered.

The mathematics program also provides an excellent liberal arts background from which to pursue a variety of career opportunities. UCSC graduates with degrees in mathematics hold teaching posts at all levels, as well as positions in law, government, civil service, insurance, software development, business, banking, actuarial science, forensics, and other professions where skills in logic, numerical analysis, and computing are required. In particular, students of mathematics are trained in the art of problem-solving, a skill absolutely essential to all professions.

## **Academic Advising**

Academic advising is available at the Mathematics Department office. The undergraduate adviser provides information about requirements, prerequisites, policies and procedures, learning support, scholarships, and special opportunities for undergraduate research. In addition, the adviser assists with the drafting of study plans, as well as certifying degrees and minors. Students are urged to stay informed and involved with their major, as well as to seek advice should problems arise.

The Mathematics Department's web site (<http://www.math.ucsc.edu>) is a critical resource for students. Here you will find a link to the undergraduate program; the materials at that link constitute the undergraduate handbook. Students should visit this first to seek answers to their questions, because it hosts a wealth of information. Each student in the major is encouraged to regularly review the materials posted to stay current about requirements, course curriculum, and departmental policy.

## *Requirements*

Students who plan to take a mathematics course at UCSC must demonstrate sufficient preparation by their score on either the mathematics placement exam (MPE), the College Entrance Examination Board Advanced Placement (AP) calculus exam, the International Baccalaureate Higher Level Mathematics Exam, or by passing the appropriate prerequisite course.

## UC Santa Cruz Mathematics Placement Exam

Mathematics placement exam scores are valid for one year. Students may take the exam a maximum of three times during the course of their academic career (effective fall 2009). Additionally, if a student receives a D, F, or NP in a course, the placement exam may not be used to place them out of that course. Students whose areas of study require precalculus or calculus courses are strongly advised to take the placement exam and the required courses early in their academic careers. The placement exam is given at the beginning of each quarter and in the sixth and seventh weeks of each quarter ~~weekly through the seventh week of each quarter~~, and at prospective-student orientations. Bring photo identification for entry into the placement exam. Calculators are not permitted.

If your MPE score is    May enroll in this course

12-19	2
20-30	3
31-39	11A*
40-45	19A
46 or higher	19A or 20A

\* Students who plan to major in computer engineering, computer science, electrical engineering, information systems management, mathematics, or physics and who receive a score in the range 31-39 on the MPE should take courses 3 and 19A-B rather than courses 11A-B.

### College Board Advanced Placement Calculus Exams

Students who have received 4 credits for the College Entrance Examination Board Advanced Placement (AP) calculus exam should normally enroll in course 19B, and those with 8 credits should normally enroll in course 23A. However, students who received a score of 3 on the calculus AB or BC AP exam, should enroll in course 19A or 19B, respectively, to improve their knowledge of calculus before continuing their studies. Students who wish to challenge themselves, and who received a score of 4 or 5 on the AB or a score of 3, 4, or 5 on the BC exam may choose ~~course 20A, Honors Calculus, courses 20A and 20B, Honors Calculus~~. Non-mathematics majors should consult their major departments before enrolling in a mathematics course.

If your AP AB score is    May enroll in this course

3	Mathematics 11A or 19A	
4 or 5	Mathematics 20A or 11B	or 19B

If your AP BC score is    May enroll in this course

3	Mathematics 11B or 19B	or 20A
4 or 5	Mathematics 20A or 22	or 23A

### International Baccalaureate Higher Level Exam in Mathematics

Students who have received a score of 5, 6, or 7 on the International Baccalaureate (IB) Higher Level Exam in Mathematics may enroll in course 20A, *Honors Calculus*; 22, *Calculus of Several Variables*; or 23A, *Multivariable Calculus*. Non-mathematics majors should consult their major departments before enrolling in a mathematics course.

### Prerequisite Courses

Students who have passed course 2 may enroll in course 3. Students who have passed course 3 may enroll in course 11A or 19A. Students who have passed an articulated precalculus course at a college or university may enroll in course 11A or 19A, but they must verify eligibility of the course and course completion with the Mathematics Department staff.

### Premajor Requirements

Premajor requirements for all concentrations in the major are courses 20A-B, *Honors Calculus*; or 19A-B, *Calculus for Science, Engineering, and Mathematics*; 21, *Linear Algebra*; and 23A-B, *Multivariable Calculus*. The mathematics education concentration has one additional premajor requirement, Applied Mathematics and Statistics (AMS) 5, *Statistics*. For some non-mathematics majors, courses 11A-B can be substituted for 19A-B, but they are not recommended for students planning to major in computer engineering, computer science, electrical engineering, information systems management, or physics. Although not considered a premajor requirement, course 100 is a prerequisite for most upper-division mathematics courses.

It should be emphasized that the nature of mathematics changes dramatically between lower-division and upper-division courses. Students often find that the material becomes far more abstract and theoretical. In addition, the role of computation in assignments diminishes and a greater weight is placed on deductive reasoning and the integral role of mathematical proofs. Therefore, it is strongly recommended that only students who earn grades of B- or better in Mathematics 100 consider applying to the major in mathematics.

In addition, Mathematics 103, 110, or 128A are recommended as possibilities for a student's first upper-division course following Mathematics 100. Students are more successful in making the transition between lower and upper division after taking one of these courses. Mathematics 105A, 111A, 121A, and 124 are particularly demanding and should be taken later in the program. Be aware that top students spend roughly 15 hours per class beyond the lectures and sections, so plan your course load accordingly.

### Major Requirements

#### Pure Mathematics

This concentration is intended for students who desire a comprehensive understanding of mathematics, including those considering graduate studies in the natural sciences. Students are required to complete at least nine courses (with laboratories, if appropriate) from among those numbered 100 or higher.

Six of these courses must be

Seven of these courses must be:

- Mathematics 100, *Introduction to Proof and Problem Solving*;
- Mathematics 103, *Complex Analysis*;
- Mathematics 105A, *Real Analysis*;
- Mathematics 111A, *Algebra*;
- Mathematics 117, *Advanced Linear Algebra*;
- one of Mathematics 121A, *Differential Geometry*, Mathematics 124, *Introduction to Topology*, or Mathematics 128A, *Classical Geometry: Euclidean and Non-Euclidean*;
- and either Mathematics 194, *Senior Seminar*, or Mathematics 195, *Senior Thesis*.

The remaining two courses are selected by the student from among Mathematics 24 and any Mathematics course numbered above 100 (excluding Math 188).

~~The remaining three courses are selected by the student from among Mathematics 24 and Mathematics 30 and mathematics courses numbered above 100.~~ A typical program for a pure mathematics major might include the following:

*1st year* Mathematics 20A-B or 19A-B, 21, 23A  
*2nd year* Mathematics 23B, 24, 100, 103, 110 or 128A  
*3rd year* Mathematics 105A-B, 111A-B, 106 ~~or 124~~  
*4th year* Mathematics 107, 117, 121A, 194

The first two years of a typical program for a pure mathematics major who begins mathematics studies with precalculus might include the following:

*1st year* Mathematics 3, 19A-B  
*2nd year* Mathematics 21, 23A-B, 24, 100

### Computational Mathematics

This concentration is intended to prepare students for technical careers in industry or government while providing a solid mathematical background. Students are required to complete a minimum of seven mathematics courses (with laboratories, if appropriate) as follows:

- Mathematics 24, *Ordinary Differential Equations*;
- Mathematics 100, *Introduction to Proof and Problem Solving*;
- Mathematics 103, *Complex Analysis*, or Mathematics 105A, *Real Analysis*;
- Mathematics 110, *Introduction to Number Theory*;
- Mathematics 111A, *Algebra*;
- Mathematics 145, *Introductory Chaos Theory*, or Applied Mathematics and Statistics 146, *Introduction to Dynamical Systems*, or Applied Mathematics and Statistics 147, *Computational Methods and Applications*;
- and either Mathematics 194, *Senior Seminar*, or Mathematics 195, *Senior Thesis*.
- In addition, students must complete two courses selected from the following:
- Applied Mathematics and Statistics 113, 131, 146, 147, 162
- Biomolecular Engineering 110
- Computer Engineering 107, 108, 117, 153, 177
- Computer Science 101, 102, 104A, 109, 112, 122, 130, 132, 142
- Electrical Engineering 103, 130, 135, 151, 154

Mathematics majors who wish to enroll in Computer Science 101 or Computer Science 122 should contact the instructor to request a permission code.

A typical program for a computational mathematics major might include the following:

*1st year* 19A-B, 23A, CMPS 12A and 12B  
*2nd year* 21, 23B, 24, 100, 110, CMPE 16  
*3rd year* 103; 105A; 145 or AMS 146, or AMS 147; CMPS 101  
*4th year* ~~106A~~, 106, 111A, CMPS 109, 194

### Mathematics Education

This concentration is intended to prepare students for teaching kindergarten through high school (K-12) mathematics. In addition to the pre-major requirements (which for this track include Applied Mathematics and Statistics 5, Statistics), students are required to complete the following nine courses:

- Mathematics 100, *Introduction to Proof and Problem Solving*;
- either Mathematics 103, *Complex Analysis*, or 105A, *Real Analysis*;
- Mathematics 110, *Introduction to Number Theory*;
- Mathematics 111A, *Algebra*;
- Mathematics 128A, *Classical Geometry: Euclidean and Non-Euclidean*;
- Applied Mathematics and Statistics 131, *Introduction to Probability Theory*;
- Mathematics 181, *History of Math*;
- Mathematics 188, *Supervised Teaching Experience*;
- and either Mathematics 194, *Senior Seminar*, or Mathematics 195, *Senior Thesis*.

UCSC students can pursue a degree in mathematics while preparing to teach at the secondary level. In California, students seeking a single-subject credential (for secondary teaching) in mathematics are required to take the CSET, a series of exams that must be passed in order to enter a teaching-credential program (formerly The National Teachers Examination). Students who complete the mathematics education track, plus three additional specified courses, qualify for the California Single Subject Program,

exempting themselves from the CSET. Both the Mathematics Department undergraduate adviser and the Education Department advising office have more information about the additional required courses.

A typical program for a mathematics education major might include the following:

*1st year* Mathematics 19A-B, 23A  
*2nd year* Mathematics 21, 23B, 100; Applied Mathematics and Statistics 5  
*3rd year* Mathematics 30, 103, 110, 181; Applied Mathematics and Statistics 131  
*4th year* Mathematics 111A, 128A, 188, 194

### *Disciplinary Communication (DC) Requirement*

Students of every major must satisfy that major's upper-division Disciplinary Communication (DC) requirement. The DC requirement will normally be met within one to three courses already required for the major. For detailed information on this major's DC requirement, consult your major adviser or see the 2010-11 general catalog.

### *Honors*

Honors in the Mathematics major are awarded to graduating seniors whose academic performance in coursework for the major is judged to be consistently excellent to outstanding. Students must also excel on their senior exit requirement. Each graduating senior within a particular quarter will be considered for honors by review of their academic record by both the chair and undergraduate vice chair. "Highest honors in the major" is determined by review of all the departmental narrative evaluations for all students considered for honors. Highest honors in the major is awarded for overall superlative performance in the major as reflected in the narrative evaluations.

### *Minor Requirements*

The minor is intended for students who are interested in mathematics and want a strong mathematical foundation for studying in areas that rely heavily on analytical skills. Students are required to complete at least ~~seven~~ eight courses as follows:

- Mathematics 21, *Linear Algebra*;
- Mathematics 23A and 23 B, *Multivariable Calculus*;
- and any five courses numbered 100 and above.

No senior seminar or thesis is required.

A typical mathematics minor program for a physics major might be:

*1st year* Mathematics 19A-B, 23A  
*2nd year* Mathematics 21, 23B, 24, 100  
*3rd year* Mathematics 103, 105A, 106A, 121A or 124  
*4th year* Mathematics 107, 145 or Applied Mathematics and Statistics 146

### *Disqualification from the Major or Minor*

The Mathematics Department disqualification policy regarding performance in the major or minor is effective fall 2008. Students who receive a W, D, F, or NP grade in any single mathematics course twice or three or more upper-division mathematics courses combined, will be considered not making normal progress and will be disqualified from the major or minor. Students at risk of disqualification should meet with an undergraduate adviser to discuss their options for continuing in the major.

Students who have reason to believe that there are valid, extenuating circumstances surrounding their failure of a course for the second time, or their failure in three courses, may appeal their disqualification from the major or minor. The appeal must be in writing and explain the reasons why the student should not be disqualified. Supporting evidence should be included. An appeal must be submitted to the department's advising office no later than 15 days from the date the disqualification notice was mailed. The department's lead undergraduate adviser and undergraduate chair will review appeals. Decisions will be made within 30 days upon receipt of an appeal.

### *Combined Majors*

The combined major, requiring fewer courses than a double major, is administered through the Economics Department.

#### **Economics and Mathematics**

The major in Economics and Mathematics is designed to meet the needs of undergraduate students who plan to pursue doctoral study in economics or business, or who wish to pursue a career as an actuary or other professional requiring a sophisticated understanding of economics and mathematics. The major combines the main undergraduate content of both Economics and Mathematics within a programmatic structure that joins the two disciplines. It provides a coursework combination required to prepare for a modern Economics Ph.D. program, or for a group of technically demanding professional careers.

#### **Requirements for the Major**

In addition to completing the university's general education requirements, students must complete 17 courses: 12 required (60 units) and 5 electives (25 units). The 17 courses include:

#### **Economics Required Courses**

1, *Introduction to Microeconomics*  
2, *Introduction to Macroeconomic*  
100A or 100M, *Intermediate Microeconomic*  
100B or 100N, *Intermediate Macroeconomics*  
113, *Introduction to Econometrics*  
and AMS 5, *Statistics*

#### **Economics Elective Courses**

(choose 3 from the following list)

- 101, *Managerial Economics*
- 102, *Forecasting*
- 104, *Is There Truth in Numbers: The Role of Statistics in Economics*
- 106, *Evolutionary Thought in the Social Sciences*
- 107, *Economic Justice*
- 114, *Advanced Quantitative Methods*
- 115, *Introduction to Management Science*
- 120, *Economic Development*
- 125, *Economic History of the U.S.*
- 126, *Why Economies Succeed or Fail*
- 128, *Poverty and Public Policy*
- 130, *Money and Banking*
- 131, *International Financial Markets*
- 133, *Security Markets and Financial Institutions*
- 135, *Corporate Finance*
- 136, *Business Strategy*
- 137, *Performing Arts in the Public and Private Economy*
- 138, *Economics and Management of Technology and Innovation*
- 139A, *Economics of Electronic Commerce*
- 139B, *E-Commerce Strategy*
- 140, *International Trade*
- 141, *International Finance*
- 142, *Advanced Topics in International Finance*
- 148, *Latin American Economies*
- 149, *The Economies of East and Southeast Asia*
- 150, *Public Finance*
- 152, *Setting Domestic Priorities*
- 153, *Cost-Benefit Analysis*
- 156, *Health Care and Medical Economics*
- 160A, *Industrial Organization*
- 161A, *Marketing*
- 162, *Legal Environment of Business*
- 164, *Economics and the Telecommunications Industry*
- 165, *Economics as an Experimental Science*
- 169, *Economic Analysis of the Law*
- 170, *Environmental Economics*
- 171, *Natural Resource Economics*
- 175, *Energy Economics*
- 180, *Labor Economics*
- 181, *Economics of Real Estate*
- 183, *Women in the Economy*
- 184, *Labor Wars in Theory and Film*
- 188, *Management in the Global Economy*
- 189, *Political Economy of Capitalism*

#### **Mathematics Required Courses**

- 19A, *Calculus for Science, Engineering, and Mathematics*
- 19B, *Calculus for Science, Engineering, and Mathematics*
- 21, *Linear Algebra*
- 22, *Calculus of Several Variables*, or 23A-B, *Multivariable Calculus*
- 100, *Mathematical Proof*
- 105A, *Real Analysis*

#### **Mathematics Electives**

(choose 2 from the following list)

- Math 106, *Systems of Ordinary Differential Equations*
- Math 107, *Partial Differential Equations*
- Math 114, *Introduction to Financial Mathematics*
- Math 117, *Advanced Linear Algebra*
- Math 145/L, *Chaos Theory*
- Math 194, *Senior Seminar*
- AMS 114, *Introduction to Dynamical Systems*
- AMS 131, *Introduction to Probability Theory*
- AMS 132, *Statistical Inference*
- AMS 147, *Computational Methods and Applications*
- AMS 162, *Design and Analysis of Computer Simulation Experiments*

In addition to successfully completing program requirements, students need to satisfy the comprehensive requirement for this major; this can be satisfied by one of the following options:  
Math 194 or 195;

Passing a comprehensive examination administered by the Economics Department;

Completion of a senior thesis.

#### **Major Admission requirements:**

Although there are no specific requirements, high school students are encouraged to take four years of high school mathematics and an economics class. Transfer students are encouraged to complete as many lower-division (mathematics and economics) courses as they can at their community college.

The admission requirements for the proposed mathematical economics major are the same as for the other economics major programs.

### **Major Disqualification Policy**

Students are expected to maintain good academic standing. Only courses with a grade of P or a letter grade of C or better will satisfy the major requirements; students who receive a lower grade in upper-division core courses (Economics 100A (or 100M), 100B (or 100N), and 113; and Math 100 and 105A) twice will be disqualified from the major. Students who are disqualified will be notified by the first day of instruction in the subsequent quarter, as well as the student's college and the Office of the Registrar.

Students may appeal their disqualification by submitting a letter to the Economics Department. This appeal must be filed no later than 15 days after the disqualification notification was mailed, or the 10th day of classes in the quarter of their disqualification, whichever is later.

### **Additional Preparation for the major:**

Students interested in the combined major must meet a minimum GPA requirement in ECON 1 and 2. Transfer students will be able to meet the same articulation agreements with community colleges as mathematics, economics, biomolecular engineering, and global economics majors. Students who have met all articulations before transferring will need at least six economics and four to five mathematics classes at UCSC to complete the major.

## *Graduate Program*

The Mathematics Department offers programs leading to the M.A. and Ph.D. degrees. Contact the Division of Graduate Studies for further information on the M.A. and Ph.D. programs, as well as on university application procedures.

### **M.A. Degree Requirements**

Students are required to complete two of Mathematics 200, 201, 202, 203; two of Mathematics 204, 205, 206; one of Mathematics 208, 209, 210; and complete five additional courses in mathematics or a related subject by approval. In addition, students must do one of the following:

pass an M.A.-level preliminary examination;

write a master's thesis.

### **Ph.D. Degree Requirements**

All of the following are required:

obtain a Ph.D.-level pass on two of the three written preliminary examinations, or a Ph.D.-level pass on one and a master's-level pass on the remaining two. Students who opt for the Ph.D.-level pass on two of the three preliminary examinations must complete the full sequence in the track associated with the preliminary examination they did not pass;

satisfy the foreign language requirement;

pass the qualifying examination;

complete three quarters as a teaching assistant;

complete six graduate courses in mathematics other than Mathematics 200, 201, 202, 203, 204, 205, and 206. No more than three courses may be independent study or thesis research courses;

write a Ph.D. thesis and present the thesis defense.

Students admitted to the Ph.D. program may receive an M.A. degree en route to the Ph.D.; students admitted to the M.A. program may transfer to the Ph.D. program upon passing the required preliminary examinations at the Ph.D. level.

## *Course Information*

Mathematics 2, *College Algebra for Calculus*, is designed for students who do not meet the requirements for admission to Mathematics 3, Precalculus, and who need comprehensive and careful preparation for calculus. Mathematics 2 emphasizes algebra, graphs, and functions. The prerequisite for course 2 is a minimum placement examination score of 12.

Mathematics 3, *Precalculus*, is recommended for students who need some preparation in algebra and trigonometry prior to taking calculus. This course covers functions and their inverse, exponentials, logarithms, and trigonometry.

Mathematics 11A-B, *Calculus with Applications*, are intended for biology and Earth sciences majors. However, students in these majors who score 40 or more points on the Mathematics Placement Exam are strongly encouraged to take the 19A-B sequence, which is required for most upper-division mathematics courses. Laboratory sections are mandatory.

Mathematics 19A-B, *Calculus for Science, Engineering, and Mathematics*, are intended for chemistry, computer engineering, computer science, electrical engineering, information systems management, mathematics, and physics majors. Laboratory sections are mandatory.

Mathematics 20A-B, *Honors Calculus*, are intended for students who would enjoy delving particularly deeply into the foundational and theoretical issues of calculus. Laboratory sections are mandatory.

Mathematics 21, *Linear Algebra*, covers vector spaces, matrices, determinants, systems of linear equations, and eigenvalues. It is intended for students in the physical and biological and social sciences and is prerequisite to Mathematics 111A.

Mathematics 22, *Introduction to Calculus of Several Variables*, is intended for science students whose schedules do not permit a full and comprehensive two quarters of multivariable calculus. Students who intend to pursue further studies in mathematics must take Mathematics 23A-B and not 22. Laboratory sections are mandatory.

Mathematics 23A-B, *Multivariable Calculus*, are intended for mathematics majors and minors and students in computer engineering, computer science, electrical engineering, information systems

management, and physics majors which require more rigorous mathematical training. Laboratory sections are mandatory.

Mathematics 100, *Introduction to Proof and Problem Solving*, is an introduction to the methodology of advanced mathematics, emphasizing proof techniques. Basic areas such as set theory and logic are introduced, together with extensive applications within mathematics. This course serves as a prerequisite for nearly all upper-division courses.

*Graduate-level courses.* All graduate courses are open to undergraduates who have taken the recommended prerequisites; students should consult with the course instructor. Advanced undergraduates are strongly advised to take or audit graduate courses that interest them.