The Department of Mathematics, Applied Mathematics, and Statistics at Case Western Reserve University is an active center for mathematical and statistical research. Faculty members conduct research in algebra, analysis, applied mathematics, convexity, dynamical systems, geometry, imaging, inverse problems, life sciences applications, mathematical biology, modeling, numerical analysis, probability, scientific computing, statistics, stochastic systems, and other areas.

The department offers a variety of programs leading to both undergraduate and graduate degrees in traditional and applied mathematics and statistics. Undergraduate degrees are Bachelor of Arts or Bachelor of Science in mathematics, Bachelor of Science in applied mathematics, and Bachelor of Arts or Bachelor of Science in statistics. Graduate degrees are Master of Science and Doctor of Philosophy. Integrated BS/MS programs allow a student to earn a Bachelor of Science in either mathematics or applied mathematics and a Master of Science in this department or another department in five years; there is a similar integrated bachelor’s/master’s degree program in statistics. The department, in cooperation with the college’s Teacher Licensure Program, offers a course of study for individuals interested in pre-college teaching. Together with the Department of Physics, it offers a specialized joint Bachelor of Science in Mathematics and Physics.

Mathematics plays a central role in the physical, biological, economic, and social sciences. Because of this, individuals with degrees in mathematics enjoy excellent employment prospects and career opportunities. A bachelor’s degree in mathematics or applied mathematics provides a strong background for graduate school in many areas (including computer science, medicine, and law, in addition to mathematics and science) or for a position in the private sector. A master’s degree in mathematics or applied mathematics, or an undergraduate degree in applied mathematics combined with a master’s in a different area, is an excellent basis for private-sector employment in a technical field. A PhD degree is usually necessary for college teaching and research.

Statistics links mathematics to other disciplines in order to understand uncertainty and probability, both in the abstract and in the context of actual applications to science, medicine, actuarial science, social science, management science, business, engineering, and contemporary life. As technology brings advances, the statistical theory and methodology required to do them justice becomes more challenging: higher-dimensional, dynamic, or computer-intensive. The field of statistics is rapidly expanding to meet the three facets of these challenges: the underlying mathematical theory, data analysis and modeling methodology, and interdisciplinary collaborations and new fields of application.

Students in the department, both undergraduate and graduate, have opportunities to interact personally with faculty and other students, participate in research, and engage in other activities. In addition, undergraduates can obtain teaching experience through the department’s supplemental instruction program.

**Department Faculty**

Mary Ann Horn, PhD  
(University of Virginia)  
*Professor and Chair*  
Analysis and applied analysis; dynamical systems; life sciences/biomedical research

Alethea Barbaro, PhD  
(University of California, Santa Barbara)  
*Associate Professor*  
Continuum and fluid mechanics; dynamical systems; life sciences and biomedical research

Jenny Brynjarsdóttir, PhD  
(The Ohio State University)  
*Associate Professor*  
Bayesian statistics; spatial statistics; uncertainty quantification

Christopher Butler, MS  
(Case Western Reserve University)  
*Senior Instructor and Theodore M. Focke Professorial Fellow*  
Teaching of mathematics

Daniela Calvetti, PhD  
(University of North Carolina)  
*James Wood Williamson Professor*  
Imaging and inverse problems; numerical analysis and scientific computing; uncertainty quantification

Julia Dobrosotskaya, PhD  
(University of California, Los Angeles)  
*Assistant Professor*  
Analysis and applied analysis; imaging and inverse problems; numerical analysis and scientific computing

Wei Hong Guo, PhD  
(University of Florida)  
*Associate Professor*  
Imaging and inverse problems; numerical analysis and scientific computing

David Gurarie, PhD  
(Hebrew University, Jerusalem, Israel)  
*Professor*  
Continuum and fluid mechanics; dynamical systems; life sciences and biomedical research

Nicholas Gurski, PhD  
(University of Chicago)  
*Assistant Professor*  
Algebra

Michael Hurley, PhD  
(Northwestern University)  
*Professor*  
Dynamical systems
Secondary Faculty

Colin McLarty, PhD
(Case Western Reserve University)
Truman P. Handy Professor of Philosophy, Department of Philosophy
Logic; philosophy of mathematics, history of mathematics

Adjunct Faculty

Carsten Schütt, PhD
(Christian-Albrecht Universität, Kiel)
Adjunct Professor
Convex geometry; Banach space theory; functional analysis

Richard Varga, PhD
(Harvard University)
Adjunct Professor
Rational approximation; Riemann hypothesis; Gershgorin disks

Undergraduate Programs

Majors

A Bachelor of Arts in mathematics, a Bachelor of Science in mathematics, a Bachelor of Science in applied mathematics, a Bachelor of Science in mathematics and physics, a Bachelor of Arts in statistics, and a Bachelor of Science in statistics are available to students at Case Western Reserve University. All undergraduate degrees in the department are based on a four-course sequence in calculus and differential equations and have a computational component. The mathematics degrees all require a further mathematics core in analysis and algebra. The statistics degrees all require a further statistics core. Each of these cores consists of four courses. There are additional technical requirements particular to each degree.

Bachelor of Arts in Mathematics

The BA degree in mathematics requires at least 38 hours of mathematics courses, including:
MATH 121  Calculus for Science and Engineering I  4
MATH 122  Calculus for Science and Engineering II  4
MATH 124  Calculus II  4
MATH 223  Calculus for Science and Engineering III  3
MATH 227  Calculus III  3
MATH 224  Elementary Differential Equations  3
MATH 228  Differential Equations  3
MATH 307  Linear Algebra  3
MATH 308  Introduction to Abstract Algebra  3
MATH 321  Fundamentals of Analysis I  3
MATH 322  Fundamentals of Analysis II  3
MATH 324  Introduction to Complex Analysis  3
MATH 425  Complex Analysis I  3
MATH 330  Introduction of Scientific Computing  3

Four approved technical electives  9

Total Units  41

*  No more than one can be from outside the department.

**  Or other approved computer science course.

Bachelor of Science in Mathematics

The BS degree in mathematics requires at least 50 hours of mathematics courses, including:

MATH 121  Calculus for Science and Engineering I  4
MATH 122  Calculus for Science and Engineering II  4
MATH 124  Calculus II  4
MATH 223  Calculus for Science and Engineering III  3
MATH 227  Calculus III  3
MATH 224  Elementary Differential Equations  3
MATH 228  Differential Equations  3
MATH 307  Linear Algebra  3
MATH 308  Introduction to Abstract Algebra  3
MATH 321  Fundamentals of Analysis I  3
MATH 322  Fundamentals of Analysis II  3
MATH 324  Introduction to Complex Analysis  3
MATH 425  Complex Analysis I  3
MATH 330  Introduction of Scientific Computing  3

Six approved technical electives  18

The following three courses:

PHYS 121  General Physics I - Mechanics  4
PHYS 122  General Physics II - Electricity and Magnetism  4
PHYS 221  Introduction to Modern Physics  3

One of the following sequences:

CHEM 105 & CHEM 106  Principles of Chemistry I and Principles of Chemistry II  6
CHEM 111 & ENGR 145  Principles of Chemistry for Engineers and Chemistry of Materials
EEPS 110 & EEPS 115  Physical Geology and Introduction to Oceanography
EEPS 210  Earth History: Time, Tectonics, Climate, and Life

Total Units  67

*  No more than 9 hours may be from outside the department.

Bachelor of Science in Applied Mathematics

A student in this degree program must design a program of study in consultation with his or her academic advisor. This program of study must explicitly list the mathematics electives and the professional core in the area of application.

Areas of research in applied mathematics well represented in the department include:

- Applied dynamical systems
- Applied probability and stochastic processes
- Imaging
- Life science
- Scientific computing
Study plans with emphasis on areas of application closely related to mathematics but centered in other departments will also be considered. Such areas might include engineering applications, biology, cognitive science, or economics.

The BS degree in applied mathematics requires at least 50 hours of course work in mathematics and related subjects, in addition to a professional core that is specific to the area of application of interest to the student, including:

- **MATH 121** Calculus for Science and Engineering I 4
- **MATH 122** Calculus for Science and Engineering II 4
- or **MATH 124** Calculus II
- **MATH 223** Calculus for Science and Engineering III 3
- or **MATH 227** Calculus III
- **MATH 224** Elementary Differential Equations 3
- or **MATH 228** Differential Equations
- **MATH 307** Linear Algebra 3
- **MATH 321** Fundamentals of Analysis I 3
- **MATH 322** Fundamentals of Analysis II 3
- **MATH 330** Introduction of Scientific Computing 3
- One of the following two courses: 3
  - **MATH 324** Introduction to Complex Analysis
  - **MATH 425** Complex Analysis I

Approved mathematics electives: 21

- Four courses specific to the concentration area of interest to the student (12 units)
- Three MATH courses at the 300 level or higher (9 units)

Professional Core requirement 12

- 12 approved credit hours specific to an area of application. This requirement is intended to promote scientific breadth and encourage application of mathematics to other fields.

Non-mathematics requirements

The following three courses:

- **PHYS 121** General Physics I - Mechanics 4
- **PHYS 122** General Physics II - Electricity and Magnetism 4
- **PHYS 221** Introduction to Modern Physics 3

One of the following sequences: 6-8

- **CHEM 105** Principles of Chemistry I
- **CHEM 106** and Principles of Chemistry II
- **CHEM 111** Principles of Chemistry for Engineers
- **ENGR 145** and Chemistry of Materials
- **EEPS 110** Physical Geology
- **EEPS 115** and Introduction to Oceanography
- or **EEPS 210** Earth History: Time, Tectonics, Climate, and Life

Total Units 79-81

**Bachelor of Science in Mathematics and Physics**

In contrast to the BS in applied mathematics or the BS in physics with a mathematical physics concentration, this degree provides a synergistic, coherent, and parallel education in mathematics and physics. To a close approximation, the challenging course work corresponds to combining the mathematics and physics cores, with the Physics Laboratory cluster replaced by a single, fourth-year laboratory semester. A student in this program may use either of two official advisors, one available from each department, who would also constitute a committee for the administration of the degree and the approval of curriculum petitions.

The BS degree in mathematics and physics requires a total of 126 credits, including:

**A. Mathematics requirements**

- **MATH 121** Calculus for Science and Engineering I 4
- **MATH 122** Calculus for Science and Engineering II 4
- or **MATH 124** Calculus II
- **MATH 223** Calculus for Science and Engineering III 3
- or **MATH 227** Calculus III
- **MATH 224** Elementary Differential Equations 3
- or **MATH 228** Differential Equations
- **MATH 307** Linear Algebra 3
- **MATH 321** Fundamentals of Analysis I 3
- **MATH 322** Fundamentals of Analysis II 3
- **MATH 330** Introduction of Scientific Computing 3
- One of the following two courses: 3
  - **MATH 324** Introduction to Complex Analysis
  - **MATH 425** Complex Analysis I
- Approved Mathematics electives: 6

**B. Physics requirements**

- **PHYS 121** General Physics I - Mechanics 4
- or **PHYS 123** Physics and Frontiers I - Mechanics
- **PHYS 122** General Physics II - Electricity and Magnetism 4
- or **PHYS 124** Physics and Frontiers II - Electricity and Magnetism
- **PHYS 221** Introduction to Modern Physics 3
- **PHYS 310** Classical Mechanics 3
- **PHYS 313** Thermodynamics and Statistical Mechanics 3
- **PHYS 331** Introduction to Quantum Mechanics I 3
- or **PHYS 481** Quantum Mechanics I
- **PHYS 332** Introduction to Quantum Mechanics II 3
- or **PHYS 482** Quantum Mechanics II
- One of the following: 3
  - **PHYS 315** Introduction to Solid State Physics
  - **PHYS 316** Introduction to Nuclear and Particle Physics
  - **PHYS 326** Physical Optics
  - **PHYS 327** Laser Physics

Total Units 126
### PHYS 328
Cosmology and the Structure of the Universe

### PHYS 336
Modern Cosmology

### PHYS 365
General Relativity

### PHYS 423
Classical Electromagnetism

### PHYS 472
Graduate Physics Laboratory

Two of the following:

- PHYS 250: Computational Methods in Physics
- PHYS 349: Methods of Mathematical Physics I
- PHYS 350: Methods of Mathematical Physics II

** C. Senior project and seminar; one of two options: 6-7
  
- C. (i) Mathematics option
    - MATH 351: Senior Project for the Mathematics and Physics Program
    - SAGES departmental seminar in Mathematics
  
- C. (ii) Physics option
    - PHYS 303: Advanced Laboratory Physics Seminar
    - PHYS 351: Senior Physics Project
    - PHYS 352: Senior Physics Project Seminar

### D. Other science requirements

<table>
<thead>
<tr>
<th>Subject</th>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
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<tr>
<td>CHEM</td>
<td>CHEM 105</td>
<td>Principles of Chemistry I</td>
<td>3-4</td>
</tr>
<tr>
<td>or CHEM</td>
<td>CHEM 111</td>
<td>Principles of Chemistry for Engineers</td>
<td>3-4</td>
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<tr>
<td>ENGR</td>
<td>ENGR 145</td>
<td>Chemistry of Materials</td>
<td>3</td>
</tr>
<tr>
<td>ENGR</td>
<td>ENGR 131</td>
<td>Elementary Computer Programming</td>
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</tbody>
</table>

Total Units: 82-85

* If approved by the M&P committee, other science sequence courses may be substituted.

In addition to the major course work listed, there are requirements of 10 hours of SAGES First and University Seminars, 12 hours of CAS distribution requirements, and enough open electives to bring the total number of hours to at least 126.

### First Year

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
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<tr>
<td>Fall</td>
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<tr>
<td>General Physics I - Mechanics (PHYS 121)</td>
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<td>or Physics and Frontiers I - Mechanics (PHYS 123)</td>
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<tr>
<td>Calculus for Science and Engineering I (MATH 121)</td>
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<tr>
<td>Elementary Computer Programming (ENGR 131)</td>
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<tr>
<td>Principles of Chemistry I (CHEM 105)</td>
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<tr>
<td>or Principles of Chemistry for Engineers (CHEM 111)</td>
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<td>SAGES First Seminar</td>
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<td>Principles of Chemistry Laboratory (CHEM 113)</td>
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<td>or Physics and Frontiers II - Electricity and Magnetism (PHYS 124)</td>
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<td>Calculus for Science and Engineering II (MATH 122)</td>
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<td>or Chemistry of Materials (ENGR 145)</td>
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<td>Principles of Chemistry Laboratory (CHEM 113)</td>
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### Second Year

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<tr>
<td>Introduction to Modern Physics (PHYS 221)</td>
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<tr>
<td>Calculus for Science and Engineering III (MATH 223)</td>
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<td>Non-major courses **</td>
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<td>Classical Mechanics (PHYS 310)</td>
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<td>Elementary Differential Equations (MATH 224)</td>
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<td>or Differential Equations (MATH 228)</td>
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<tr>
<td>Introduction to Abstract Algebra (MATH 308)</td>
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<tr>
<td>or Introduction of Scientific Computing (MATH 330)</td>
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<td>Year Total:</td>
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### Third Year

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<tr>
<td>Fall</td>
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<tr>
<td>Thermodynamics and Statistical Mechanics (PHYS 313)</td>
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<tr>
<td>Introduction to Quantum Mechanics I (PHYS 331)</td>
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<td>or Quantum Mechanics I (PHYS 481)</td>
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<td>Fundamentals of Analysis I (MATH 321)</td>
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<tr>
<td>MP Group II</td>
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<td>Non-major courses **</td>
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<tr>
<td>Introduction to Quantum Mechanics II (PHYS 332)</td>
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<tr>
<td>or Quantum Mechanics II (PHYS 482)</td>
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<td>Fundamentals of Analysis II (MATH 322)</td>
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<td>Introduction to Complex Analysis (MATH 324)</td>
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### Fourth Year

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<tr>
<td>PHYS 3XX***</td>
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<tr>
<td>Graduate Physics Laboratory (PHYS 472)</td>
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<tr>
<td>MP Group IV****</td>
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<td>SAGES Departmental Seminar</td>
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<td>Classical Electromagnetism (PHYS 423)</td>
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<td>Senior Project****</td>
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<td>18-19</td>
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</table>

Total Units in Sequence: 129-132
The "M&P group" of four courses corresponds to two physics courses and two mathematics courses. The physics courses would be chosen from PHYS 250, PHYS 349, and PHYS 350. The mathematics courses are subject to approval by the advisory committee and are thereby referred to as 'approved electives.' They may be chosen from the general list of mathematics courses at the 300 level or higher. Also subject to approval, students may choose a course from outside the mathematics and physics departments as a substitute in the M&P group.

The number of open electives will vary depending on whether students choose 3-credit or 4-credit courses to fulfill other requirements (chemistry, senior project)

An advanced physics course to be selected from the following list: PHYS 315 Introduction to Solid State Physics, PHYS 316 Introduction to Nuclear and Particle Physics, PHYS 326 Physical Optics, PHYS 327 Laser Physics, PHYS 328 Cosmology and the Structure of the Universe, PHYS 336 Modern Cosmology, PHYS 365 General Relativity.

The Senior Project and SAGES Departmental Seminar should either be the Mathematics option (MATH 351 Senior Project for the Mathematics and Physics Program and a Mathematics department seminar), or the Physics option (PHYS 351 Senior Physics Project, and PHYS 352 Senior Physics Project Seminar).

### Bachelor's Degrees in Statistics

Students in statistics begin with a foundation in mathematics. Then they add statistical theory, plus intensive modern data analysis and a concentration in a field of their choice. The goal is to develop an appreciation of each facet of the discipline and a mastery of technical skills. This prepares students to enter a growing profession with opportunities in the academic, governmental, actuarial, and industrial spheres.

For the undergraduate student looking toward graduate school, the course of study within these guidelines easily incorporates additional mathematics in preparation for graduate courses. A student interested in Actuarial Science should take STAT 317 and 318 among the 18 hours in statistical methodology, and should discuss with their advisor courses in operations research and numerical analysis which are fundamental to actuarial theory and computation.

### BA in Statistics

The BA degree offers flexibility and the chance to pursue a wider range of interests than the BS degree allows. It also offers students the possibility of expanding the interdisciplinary aspect of the program by completing a second major. For example, students may combine statistics with computer science, biology (molecular, organismal, or ecological), psychology, economics, accounting, or management science.

The BA degree in statistics requires a minimum of 56 hours of approved course work, including 27 hours in statistics and the remainder in related disciplines and a substantive field of application. The specific requirements are as follows:

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH 121</td>
<td>Calculus for Science and Engineering I</td>
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<td>MATH 122</td>
<td>Calculus for Science and Engineering II</td>
<td>4</td>
</tr>
<tr>
<td>or MATH 124</td>
<td>Calculus II</td>
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</tr>
</tbody>
</table>

### BS in Statistics

The BS degree in statistics requires a minimum of 68 hours of approved course work, including 27 hours in statistics and the remainder in related disciplines and a substantive field of application. In addition to the requirements for the BA, the BS degree includes a laboratory science requirement. For students seriously interested in basic science, a natural science is the logical choice as a focus for the application, and the BS degree is the logical choice of program. The specific requirements are as follows:

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH 121</td>
<td>Calculus for Science and Engineering I</td>
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<tr>
<td>MATH 122</td>
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<td>MATH 223</td>
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<td>MATH 224</td>
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<tr>
<td>or MATH 228</td>
<td>Differential Equations</td>
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</tr>
<tr>
<td>MATH 201</td>
<td>Introduction to Linear Algebra for Applications</td>
<td>3</td>
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Two computation classes

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
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<tbody>
<tr>
<td>ENGR 131</td>
<td>Elementary Computer Programming</td>
<td>3</td>
</tr>
<tr>
<td>STAT 325</td>
<td>Data Analysis and Linear Models</td>
<td>3</td>
</tr>
<tr>
<td>STAT 326</td>
<td>Multivariate Analysis and Data Mining</td>
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</tr>
<tr>
<td>STAT 345</td>
<td>Theoretical Statistics I</td>
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</tr>
<tr>
<td>STAT 346</td>
<td>Theoretical Statistics II</td>
<td>3</td>
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</table>

At least 15 hours of courses in statistical methodology, to be chosen from courses numbered 300 and higher offered by the Statistics department, or approved courses in statistical methodology or portability taught in bioscience, electrical engineering, and computer science, economics, mathematics, operations research, systems engineering, etc. At least 9 hours must be in STAT. STAT 243 and STAT 244 may be counted.

Two approved courses (or more) numbered 300 or above in an approved discipline outside statistics.

Total Units

A student in this program has the option of a concentration in Actuarial Science, described below.

### Bachelor's Degrees in Statistics

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH 121</td>
<td>Calculus for Science and Engineering I</td>
<td>4</td>
</tr>
<tr>
<td>MATH 122</td>
<td>Calculus for Science and Engineering II</td>
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<td>or MATH 124</td>
<td>Calculus II</td>
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</tr>
<tr>
<td>MATH 223</td>
<td>Calculus for Science and Engineering III</td>
<td>3</td>
</tr>
<tr>
<td>or MATH 227</td>
<td>Calculus III</td>
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</tr>
<tr>
<td>MATH 224</td>
<td>Elementary Differential Equations</td>
<td>3</td>
</tr>
<tr>
<td>or MATH 228</td>
<td>Differential Equations</td>
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</tr>
<tr>
<td>MATH 201</td>
<td>Introduction to Linear Algebra for Applications</td>
<td>3</td>
</tr>
</tbody>
</table>

Two computation classes

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGR 131</td>
<td>Elementary Computer Programming</td>
<td>3</td>
</tr>
<tr>
<td>STAT 325</td>
<td>Data Analysis and Linear Models</td>
<td>3</td>
</tr>
<tr>
<td>STAT 326</td>
<td>Multivariate Analysis and Data Mining</td>
<td>3</td>
</tr>
<tr>
<td>STAT 345</td>
<td>Theoretical Statistics I</td>
<td>3</td>
</tr>
<tr>
<td>STAT 346</td>
<td>Theoretical Statistics II</td>
<td>3</td>
</tr>
</tbody>
</table>

At least 15 hours of courses in statistical methodology, to be chosen from courses numbered 300 and higher offered by the Statistics department, or approved courses in statistical methodology or portability taught in bioscience, electrical engineering, and computer science, economics, mathematics, operations research, systems engineering, etc. At least 9 hours must be in STAT. STAT 243 and STAT 244 may be counted.

Two approved courses (or more) numbered 300 or above in an approved discipline outside statistics.

Total Units

A student in this program has the option of a concentration in Actuarial Science, described below.
An additional higher-numbered course in computation. Recommended courses include MATH 330, various EECS offerings, and PQHS 414. Consult your advisor for other suggestions.

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>STAT 325</td>
<td>Data Analysis and Linear Models</td>
<td>3</td>
</tr>
<tr>
<td>STAT 326</td>
<td>Multivariate Analysis and Data Mining</td>
<td>3</td>
</tr>
<tr>
<td>STAT 345</td>
<td>Theoretical Statistics I</td>
<td>3</td>
</tr>
<tr>
<td>STAT 346</td>
<td>Theoretical Statistics II</td>
<td>3</td>
</tr>
</tbody>
</table>

At least 15 hours of courses in statistical methodology, to be chosen from courses numbered 300 and higher offered by the Statistics department, or approved courses in statistical methodology or probability taught in biostatistics, electrical engineering and computer science, economics, mathematics, operations research, systems engineering, etc. At least 9 house must be in STAT, STAT 243 and STAT 244 may be counted.

Total Units 68

A student in this program has the option of a concentration in Actuarial Science, described below.

**Actuarial Science**

A student in either the BA or the BS program in statistics may opt for a concentration in Actuarial Science, the requirements of which exceed the basic major requirements. The basic major requirement of 15 hours in statistical methodology is increased to 18 hours, and these must include STAT 317, 318, and at least six additional hours of approved STAT courses. A student finishing this concentration will have completed at least 30 hours in statistics. Students in this concentration should consult with their advisors before choosing these courses, and for information about additional non-required courses that might be useful for actuarial science.

**Integrated BS/MS Program in Mathematics and/or Applied Mathematics**

The integrated BS/MS program is intended for highly motivated candidates for the BS in mathematics and applied mathematics who wish to pursue an advanced degree. Application to the BS/MS program must be made after completion of 75 semester hours of course work and prior to attaining senior status (completion of 90 semester hours). Generally, this means that a student will submit the application during his/her sixth semester of undergraduate course enrollment and will have no fewer than two semesters of remaining BS requirements to complete. Applicants should consult the dean of undergraduate studies.

A student admitted to the program may, in the senior year, take up to nine hours of graduate courses (400 level and above) that will count towards both BS and MS requirements. The courses to be doubled-counted must be specified at the time of application. Any undergraduate course work that is to be applied to the MS must be beyond that used to satisfy BS degree requirements and must conform to university, graduate school, and department rules. Students may petition to transfer graduate course work taken prior to application to the BS/MS program subject to the rules of the graduate school.

Students for whom the master’s project or thesis is a continuation and development of the senior project should register for (or the appropriate project course) during the senior year and are expected to complete all other courses for the BS before enrolling in further MS course work and thesis (continuing the senior project). Students for whom the master's thesis or project is distinct from the senior project will be expected to complete the BS degree before taking further graduate courses for the master’s degree.

**Integrated BS/MS in Applied Mathematics and Another Discipline**

There is the possibility of an integrated five-year study plan leading to a BS in applied mathematics and an MS in the area of application. In order to complete the requirements for the BS/MS in five years, students must choose an area outside mathematics that integrates well with mathematics, such as computing/information science, operations research, systems engineering, control theory, biology, or cognitive science. The general academic requirements for Integrated BS/MS programs must be followed. (Since the graduate courses required for the MS degree are determined by the respective department, each student in the dual-degree program should have a secondary advisor in that department, starting no later than the junior year, and should consult with this advisor concerning requirements for the MS degree.)

**Integrated Bachelors/MS in Statistics**

The combined bachelor-master degrees in statistics require a minimum of 21 hours beyond the bachelor's degree requirements. In total, 42 hours must be in statistics, including an MS thesis or MS research project, with the remainder (either 41 or 26 hours for BS or BA, respectively) in approved coursework in related disciplines and a field of application. In addition to the BS or BA requirements, a combined degree program must include:

1. STAT 455 and three semesters of STAT 491;
2. STAT 495;
3. MS research project (STAT 621) or MS Thesis (STAT 651);
4. At least 6 additional hours of courses in statistical theory and methodology (making a total of 21 credit hours including at least 4 STAT courses numbered 400 or higher) to be chosen from STAT offerings numbered 300 and higher, or approved courses in statistical methodology or probability taught in biostatistics, computer science, economics, mathematics, operations research, systems
Minor in Mathematics

A minor in mathematics is available to all undergraduates. No more than two courses can be used to satisfy both minor requirements and the requirements of the student’s major field (meaning departmental degree requirements, including departmental technical electives and common course requirements of the student's school).

The minor in mathematics requires 17 hours of mathematics courses, including:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH 121</td>
<td>Calculus for Science and Engineering I</td>
</tr>
<tr>
<td>or MATH 125</td>
<td>Math and Calculus Applications for Life, Managerial, and Social Sci I</td>
</tr>
<tr>
<td>MATH 122</td>
<td>Calculus for Science and Engineering II</td>
</tr>
<tr>
<td>or MATH 124</td>
<td>Calculus II</td>
</tr>
<tr>
<td>or MATH 126</td>
<td>Math and Calculus Applications for Life, Managerial, and Social Sci II</td>
</tr>
<tr>
<td>MATH 223</td>
<td>Calculus for Science and Engineering III</td>
</tr>
<tr>
<td>or MATH 227</td>
<td>Calculus III</td>
</tr>
<tr>
<td>MATH 224</td>
<td>Elementary Differential Equations</td>
</tr>
<tr>
<td>or MATH 228</td>
<td>Differential Equations</td>
</tr>
<tr>
<td>MATH 150</td>
<td>Mathematics from a Mathematician's Perspective</td>
</tr>
<tr>
<td>MATH 201</td>
<td>Introduction to Linear Algebra for Applications</td>
</tr>
<tr>
<td>or MATH 307</td>
<td>Linear Algebra</td>
</tr>
<tr>
<td>MATH 301</td>
<td>Undergraduate Reading Course</td>
</tr>
<tr>
<td>MATH 302</td>
<td>Departmental Seminar</td>
</tr>
<tr>
<td>MATH 303</td>
<td>Elementary Number Theory</td>
</tr>
<tr>
<td>MATH 304</td>
<td>Discrete Mathematics</td>
</tr>
<tr>
<td>MATH 308</td>
<td>Introduction to Abstract Algebra</td>
</tr>
<tr>
<td>MATH 321</td>
<td>Fundamentals of Analysis I</td>
</tr>
<tr>
<td>MATH 322</td>
<td>Fundamentals of Analysis II</td>
</tr>
<tr>
<td>MATH 324</td>
<td>Introduction to Complex Analysis</td>
</tr>
<tr>
<td>MATH 327</td>
<td>Convexity and Optimization</td>
</tr>
<tr>
<td>MATH 330</td>
<td>Introduction of Scientific Computing</td>
</tr>
<tr>
<td>MATH 333</td>
<td>Mathematics and Brain</td>
</tr>
<tr>
<td>MATH 338</td>
<td>Introduction to Dynamical Systems</td>
</tr>
<tr>
<td>MATH 343</td>
<td>Theoretical Computer Science</td>
</tr>
<tr>
<td>MATH 363</td>
<td>Knot Theory</td>
</tr>
<tr>
<td>MATH 380</td>
<td>Introduction to Probability</td>
</tr>
<tr>
<td></td>
<td>Or any 400-level MATH course</td>
</tr>
</tbody>
</table>

* To count toward a minor in mathematics, MATH 150 Mathematics from a Mathematician's Perspective must be taken in the first or second year.

Minor in Statistics

A minor in statistics requires a minimum of 15 credit hours of approved course work. The minor must satisfy the requirements below and must include a minimum of 12 credit hours in STAT courses.

One of the following sequences: 6

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>STAT 243 &amp; STAT 244</td>
<td>Statistical Theory with Application I</td>
</tr>
<tr>
<td>STAT 345 &amp; STAT 346</td>
<td>Theoretical Statistics I</td>
</tr>
</tbody>
</table>

Or other approved sequence

One of the following: 3

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>STAT 312</td>
<td>Basic Statistics for Engineering and Science</td>
</tr>
<tr>
<td>STAT 313</td>
<td>Statistics for Experimenters</td>
</tr>
<tr>
<td>STAT 332</td>
<td>Statistics for Signal Processing</td>
</tr>
<tr>
<td>STAT 333</td>
<td>Uncertainty in Engineering and Science</td>
</tr>
<tr>
<td>STAT 325</td>
<td>Data Analysis and Linear Models</td>
</tr>
</tbody>
</table>

Two approved elective courses numbered 300 or above. 6

Total Units 15

Graduate Programs

The department offers programs leading to the Master of Science and the Doctor of Philosophy degrees. At the master’s level, students may pursue degrees in mathematics, applied mathematics, or statistics. At the doctoral level, students may pursue degrees in mathematics or applied mathematics.

A student must satisfy all of the general requirements of the graduate school as well as the more specific requirements of the department to earn either a master’s or doctoral degree. Each graduate student is assigned a faculty advisory committee during the first year of study. The committee’s primary responsibility is to help the student plan an appropriate and sufficiently broad program of course work and study that will satisfy both the degree requirements and the special interests of the student. With the aid of the advisory committee, each student must present a study plan indicating how he or she intends to satisfy the requirements for a graduate degree.

The main requirements are as follows.

Master of Science in Mathematics

A minimum of 30 credit hours of approved course work, at least 18 of which must be at the 400 level or higher, is required for the MS degree in mathematics. The 30 credit hours required for graduation must include 6 credits each from two of the following three basic areas:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH 401</td>
<td>Abstract Algebra I</td>
</tr>
<tr>
<td>MATH 402</td>
<td>Abstract Algebra II</td>
</tr>
</tbody>
</table>

Analysis 6

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH 423</td>
<td>Introduction to Real Analysis I</td>
</tr>
<tr>
<td>MATH 424</td>
<td>Introduction to Real Analysis II</td>
</tr>
<tr>
<td>MATH 425</td>
<td>Complex Analysis I</td>
</tr>
</tbody>
</table>

Geometry and Topology 6

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH 461</td>
<td>Introduction to Topology</td>
</tr>
</tbody>
</table>
The student must pass a comprehensive oral examination on three areas, two of which must be selected from the basic ones listed above (although no particular courses are specified). The third area for the examination may be any approved subject.

A student in the MS program in mathematics may substitute the comprehensive exam examination requirement with an expository or original thesis, which will count as 6 credit hours of course work. The thesis will be defended in the course of an oral examination, during which the student will be questioned about the thesis and related topics. These two variants correspond to the graduate school's Plan A and Plan B.

**Master of Science in Applied Mathematics**

The department offers specialized programs in applied mathematics. For each of the programs, there is a minimum requirement of 30 credit hours of course work, at least 18 of which must be at the 400 level or higher. Students in the program must complete course work requirements in each of the following groups:

- At least 15 hours of courses designated MATH
- At least 6 hours of courses not designated MATH
- 6 hours of thesis work (see below) or successful completion of a comprehensive exam

Given the great diversity of topics used in applications, there cannot be a large common core of requirements for the MS in applied mathematics. Still, all students pursuing this degree are strongly advised to take MATH 431 Introduction to Numerical Analysis I and MATH 441 Mathematical Modeling. In addition, to add breadth to the student's education, the set of courses taken within the department must include three credit hours of approved course work in at least three of the following seven breadth areas. (The list includes suitable courses for each area. Please note that a course may be used to satisfy only one breadth area requirement.)

**Applied Mathematics Breadth Areas**

Analysis and Linear Analysis:

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH 471</td>
<td>Advanced Engineering Mathematics</td>
</tr>
<tr>
<td>MATH 423</td>
<td>Introduction to Real Analysis I</td>
</tr>
<tr>
<td>MATH 405</td>
<td>Advanced Matrix Analysis</td>
</tr>
</tbody>
</table>

Probability and its Applications:

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH 439</td>
<td>Bayesian Scientific Computing</td>
</tr>
<tr>
<td>MATH 491</td>
<td>Probability I</td>
</tr>
</tbody>
</table>

Numerical Analysis and Scientific Computing:

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH 431</td>
<td>Introduction to Numerical Analysis I</td>
</tr>
<tr>
<td>MATH 432</td>
<td>Numerical Differential Equations</td>
</tr>
<tr>
<td>MATH 433</td>
<td>Numerical Solutions of Nonlinear Systems and Optimization</td>
</tr>
</tbody>
</table>

Differential Equations:

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH 435</td>
<td>Ordinary Differential Equations</td>
</tr>
<tr>
<td>MATH 445</td>
<td>Introduction to Partial Differential Equations</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH 449</td>
<td>Dynamical Models for Biology and Medicine</td>
</tr>
</tbody>
</table>

Inverse Problems and Imaging:

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH 439</td>
<td>Bayesian Scientific Computing</td>
</tr>
<tr>
<td>MATH 440</td>
<td>Computational Inverse Computing</td>
</tr>
<tr>
<td>MATH 475</td>
<td>Mathematics of Imaging in Industry and Medicine</td>
</tr>
</tbody>
</table>

Logic and Discrete Mathematics:

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH 406</td>
<td>Mathematical Logic and Model Theory</td>
</tr>
<tr>
<td>MATH 408</td>
<td>Introduction to Cryptology</td>
</tr>
</tbody>
</table>

Life Science:

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH 441</td>
<td>Mathematical Modeling</td>
</tr>
<tr>
<td>MATH 449</td>
<td>Dynamical Models for Biology and Medicine</td>
</tr>
<tr>
<td>MATH 478</td>
<td>Computational Neuroscience</td>
</tr>
</tbody>
</table>

* Not suitable for credit towards the PhD requirements.

Other suitable courses for students in applied mathematics include:

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH 424</td>
<td>Introduction to Real Analysis II</td>
<td>3</td>
</tr>
<tr>
<td>MATH 425</td>
<td>Complex Analysis I</td>
<td>3</td>
</tr>
<tr>
<td>MATH 427</td>
<td>Convexity and Optimization</td>
<td>3</td>
</tr>
<tr>
<td>MATH 444</td>
<td>Mathematics of Data Mining and Pattern Recognition</td>
<td>3</td>
</tr>
<tr>
<td>MATH 475</td>
<td>Mathematics of Imaging in Industry and Medicine</td>
<td>3</td>
</tr>
<tr>
<td>MATH 492</td>
<td>Probability II</td>
<td>3</td>
</tr>
</tbody>
</table>

The student must pass a comprehensive oral examination on three areas, two of which must be on the list of breadth areas (although no particular courses are specified). The third area for the examination may be any approved subject.

A student in the MS program in applied mathematics may substitute the comprehensive examination requirement with an expository or original thesis, which will count as 6 credit hours of course work. The thesis will be defended in the course of an oral examination, during which the student will be questioned about the thesis and related topics. These two variants correspond to the graduate school's Plan A and Plan B.

**PhD Programs in Mathematics and Applied Mathematics**

The doctorate is conferred not merely upon completion of a stipulated course of study, but rather upon clear demonstration of scholarly attainment and capability of original research work in mathematics. A doctoral student may plan either a traditional program of studies in mathematics (mathematics track) or a program of studies oriented toward applied mathematics (applied mathematics track). In either case, each student must take 36 credit hours of approved courses with a grade average of B or better. For students entering with a master's degree in a mathematical subject compatible with our program, as determined by the graduate committee, this requirement is reduced to 18 credit hours of approved courses.

In addition to the course work, all PhD students in both tracks must complete the following specific requirements:
Qualifying Exams

Each student will be required to take two written qualifying exams. The exams will be in analysis and algebra for the mathematics track, and in numerical analysis and modeling for the applied mathematics track. Syllabi for the exams are available to students. Exams will be offered twice a year, usually in January and May. Students may attempt each exam up to two times. Under normal circumstances, students are expected to have passed both exams by the end of their fifth semester.

Area Exam

Each student will be required to pass an oral examination showing knowledge of the background and literature in the chosen area of specialization. The exam will be administered by the student’s advising committee, chaired by the principal advisor. The exam should normally take place within one year after final passage of the qualifying examinations and at least one year before the defense takes place. A student may retake the required exam once.

A written syllabus, with a list of the papers for which the student will be responsible, should be prepared and agreed upon by the student and advising committee at least two months before the exam takes place, at which time a specific date and time for the exam should be decided. Both the syllabus and the scheduled date of the exam should then be reported to the graduate committee. Once the syllabus and exam date have been reported to the graduate committee, the student will advance to PhD candidacy.

Yearly Progress Reports

After passing the area exam, students will present yearly progress reports to their advising committees, usually in April. These reports will consist of both a written summary of progress and an oral presentation delivered to the advising committee.

Dissertation, Expository Talk, and Defense

Students are required to produce a written dissertation and present an oral defense. The dissertation is expected to constitute an original contribution to mathematical knowledge. It must be provided to the defense committee (the composition of which is discussed below) at least 10 days prior to the defense. Students are required to give a colloquium-level presentation of their thesis work, open to all students and faculty, followed by an oral defense of the thesis work to the defense committee. The committee consists of at least four faculty members, including the student’s principal advisor and at least one outside faculty member.

Deadlines for the thesis defense and approval of the dissertation are determined by the School of Graduate Studies. It is the student’s responsibility to be aware of deadlines and make sure they are met.

Requirements specific to the different tracks

Mathematics Track

A student in the traditional mathematics program must demonstrate knowledge of the basic concepts and techniques of algebra, analysis (real and complex), and topology. This includes taking all courses in the three basic areas, and successfully completing qualifying examinations in algebra and analysis.

Qualifying Examination

A doctoral student in the mathematics track must take written examinations on abstract algebra and real analysis, as well as an oral examination in his or her chosen area of specialization. Subjects include complex analysis, control and calculus of variations, differential equations, dynamical systems, functional analysis, geometry, probability, and topology.

The course requirements are:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH 401</td>
<td>Abstract Algebra I</td>
<td>3</td>
</tr>
<tr>
<td>MATH 402</td>
<td>Abstract Algebra II</td>
<td>3</td>
</tr>
<tr>
<td>MATH 423</td>
<td>Introduction to Real Analysis I</td>
<td>3</td>
</tr>
<tr>
<td>MATH 424</td>
<td>Introduction to Real Analysis II</td>
<td>3</td>
</tr>
<tr>
<td>MATH 425</td>
<td>Complex Analysis I</td>
<td>3</td>
</tr>
<tr>
<td>MATH 461</td>
<td>Introduction to Topology</td>
<td>3</td>
</tr>
<tr>
<td>MATH 462</td>
<td>Algebraic Topology</td>
<td>3</td>
</tr>
<tr>
<td>MATH 465</td>
<td>Differential Geometry</td>
<td>3</td>
</tr>
<tr>
<td>MATH 467</td>
<td>Differentiable Manifolds</td>
<td>3</td>
</tr>
<tr>
<td>18 credit hours of approved course work</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>Total Units</td>
<td></td>
<td>36</td>
</tr>
</tbody>
</table>

A student with a master’s degree in a mathematical subject compatible with our program, as determined by the graduate committee, must take 18 credit hours of approved courses. The graduate committee will determine which of the specific course requirements stated above have been satisfied by the master’s course work.

Applied Mathematics Track

A student in the applied mathematics track must demonstrate knowledge of scientific computing, mathematical modeling, and differential equations. This includes taking qualifying examinations in the areas of computational mathematics and mathematical modeling, and taking certain courses in these three areas, as specified below.

Qualifying Examination

A doctoral student in the applied mathematics track must take written examinations in numerical analysis and in mathematical modeling, as well as an oral examination in his or her chosen area of specialization. Subjects include but are not restricted to fluid mechanics, statistical mechanics, epidemiology, neuroscience, and more traditional fields of mathematics.

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH 431</td>
<td>Introduction to Numerical Analysis I</td>
<td>3</td>
</tr>
<tr>
<td>One of the following:</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>MATH 432</td>
<td>Numerical Differential Equations</td>
<td>3</td>
</tr>
<tr>
<td>MATH 433</td>
<td>Numerical Solutions of Nonlinear Systems and Optimization</td>
<td>3</td>
</tr>
<tr>
<td>MATH 441</td>
<td>Mathematical Modeling</td>
<td>3</td>
</tr>
<tr>
<td>One of the following:</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>MATH 435</td>
<td>Ordinary Differential Equations</td>
<td>3</td>
</tr>
<tr>
<td>MATH 445</td>
<td>Introduction to Partial Differential Equations</td>
<td>3</td>
</tr>
<tr>
<td>24 hours of approved courses</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>Total Units</td>
<td></td>
<td>33</td>
</tr>
</tbody>
</table>
A student with a master's degree in a mathematical subject compatible with our program, as determined by the graduate committee, must take 18 credit hours of approved courses, which must include at least 6 credit hours of courses offered outside the Department of Mathematics, Applied Mathematics, and Statistics and at least 9 credit hours offered by the Department of Mathematics, Applied Mathematics, and Statistics. The graduate committee will determine which of the specific course requirements stated above have been satisfied by the master’s course work.

Sample study plans for students with concentrations in scientific computing, imaging, mathematical biology, and stochastics follow. The graduate committee will entertain ideas for other serious study plans or qualifying exam subjects in addition to the most common variants.

**Scientific Computing Concentration**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credit Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH 431</td>
<td>Introduction to Numerical Analysis I</td>
<td>3</td>
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<tr>
<td>MATH 432</td>
<td>Numerical Differential Equations</td>
<td>3</td>
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<tr>
<td>MATH 433</td>
<td>Numerical Solutions of Nonlinear Systems and Optimization</td>
<td>3</td>
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<tr>
<td>MATH 439</td>
<td>Bayesian Scientific Computing</td>
<td>3</td>
</tr>
<tr>
<td>or MATH 440</td>
<td>Computational Inverse Problems</td>
<td>3</td>
</tr>
<tr>
<td>MATH 441</td>
<td>Mathematical Modeling</td>
<td>3</td>
</tr>
<tr>
<td>MATH 445</td>
<td>Introduction to Partial Differential Equations</td>
<td>3</td>
</tr>
<tr>
<td>MATH 449</td>
<td>Dynamical Models for Biology and Medicine</td>
<td>3</td>
</tr>
<tr>
<td>or MATH 478</td>
<td>Computational Neuroscience</td>
<td>3</td>
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**Imaging Concentration**

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<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credit Hours</th>
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<tbody>
<tr>
<td>MATH 431</td>
<td>Introduction to Numerical Analysis I</td>
<td>3</td>
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<tr>
<td>MATH 432</td>
<td>Numerical Differential Equations</td>
<td>3</td>
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<tr>
<td>MATH 433</td>
<td>Numerical Solutions of Nonlinear Systems and Optimization</td>
<td>3</td>
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<tr>
<td>MATH 439</td>
<td>Bayesian Scientific Computing</td>
<td>3</td>
</tr>
<tr>
<td>or MATH 440</td>
<td>Computational Inverse Problems</td>
<td>3</td>
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<tr>
<td>MATH 441</td>
<td>Mathematical Modeling</td>
<td>3</td>
</tr>
<tr>
<td>MATH 444</td>
<td>Mathematics of Data Mining and Pattern Recognition</td>
<td>3</td>
</tr>
<tr>
<td>MATH 445</td>
<td>Introduction to Partial Differential Equations</td>
<td>3</td>
</tr>
<tr>
<td>MATH 475</td>
<td>Mathematics of Imaging in Industry and Medicine</td>
<td>3</td>
</tr>
<tr>
<td>EBME 410</td>
<td>Medical Imaging Fundamentals</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 431</td>
<td>Physics of Imaging</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 460</td>
<td>Advanced Topics in NMR Imaging</td>
<td>3</td>
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**Life Science Concentration**

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<tr>
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<th>Credit Hours</th>
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<tr>
<td>MATH 431</td>
<td>Introduction to Numerical Analysis I</td>
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<tr>
<td>MATH 432</td>
<td>Numerical Differential Equations</td>
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<td>Computational Inverse Problems</td>
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**Stochastics Concentration**

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<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credit Hours</th>
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<tbody>
<tr>
<td>MATH 423</td>
<td>Introduction to Real Analysis I</td>
<td>3</td>
</tr>
<tr>
<td>MATH 424</td>
<td>Introduction to Real Analysis II</td>
<td>3</td>
</tr>
<tr>
<td>MATH 431</td>
<td>Introduction to Numerical Analysis I</td>
<td>3</td>
</tr>
<tr>
<td>MATH 441</td>
<td>Mathematical Modeling</td>
<td>3</td>
</tr>
<tr>
<td>MATH 491</td>
<td>Probability I</td>
<td>3</td>
</tr>
<tr>
<td>MATH 492</td>
<td>Probability II</td>
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</tbody>
</table>

**PhD students entering with a bachelor's degree are subject to the same breadth requirements as students pursuing the MS degree in applied mathematics.**

**Petitions**

Any exceptions to departmental regulations or requirements must have the formal approval of the department’s graduate committee. Such exceptions are to be sought by a written petition, approved by the student’s advisory committee or thesis advisor, to the graduate committee.

Any exception to university rules and regulations must be approved by the dean of graduate studies. Such exceptions are to be sought by presenting a written petition to the graduate committee for departmental endorsement and approval prior to forwarding the petition to the dean.

**Master of Science in Statistics**

The dual core of the MS program is mathematical statistics and modern data analysis, with the option of a special Entrepreneurial Track. Expanding from this core, students develop technical facility in a variety of statistical methodologies. This breadth of competence is designed to equip graduates to go beyond the appropriate choice of method for implementation and to be able to adapt these techniques and to construct new methods to meet the specific objectives and constraints of new situations.

The MS degree in statistics requires a minimum of 30 hours of approved course work in statistics and related disciplines and an MS research project (plan B) or a thesis (plan A). Each student’s program is developed in consultation with the director of graduate studies or a senior faculty mentor and must satisfy the following requirements:

**Plan A**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credit Hours</th>
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<tbody>
<tr>
<td>STAT 425</td>
<td>Data Analysis and Linear Models</td>
<td>6</td>
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<tr>
<td>&amp; STAT 426</td>
<td>and Multivariate Analysis and Data Mining</td>
<td></td>
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<tr>
<td>STAT 445</td>
<td>Theoretical Statistics I</td>
<td>6</td>
</tr>
<tr>
<td>&amp; STAT 446</td>
<td>and Theoretical Statistics II</td>
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<tr>
<td>STAT 455</td>
<td>Linear Models</td>
<td>3</td>
</tr>
<tr>
<td>STAT 495A</td>
<td>Consulting Forum</td>
<td>3</td>
</tr>
</tbody>
</table>

or Approved Elective
The Master of Science in Statistics–Entrepreneurial Track (MSS–ET) is a professional degree designed to provide training in statistics focused on developing data analysis and decision-making skills in industrial, government, and consulting environments where uncertainties and related risks are present. It expands our master's program in statistics for new and growing ventures. The MSS–ET program requires a minimum of 30 hours.

The required New Venture Creation and Technology Entrepreneurship courses will be offered by the Weatherhead School of Management. Students on internships will sign up for the consulting forum sequence. In addition, students are required to participate in an intensive (up to 30 hours) one-week annual workshop on the industrial use of statistics from the management perspective. This non-credit workshop will take place during the fall or spring undergraduate breaks.

### Doctor of Philosophy in Statistics

Please note: Currently, admission to the doctoral program in Statistics is frozen due to reorganization of the program (students are being accepted into the master's program in Statistics). Please check with the department for the latest update.

The doctoral program focuses on research, with a plan of study devoted to the development of statistical methodology or theory with innovative applications. Graduates will be able to extend the theoretical basis for statistics and to bring statistical thought to scientific research in other fields. The objective of preparing students to collaborate in interdisciplinary work demands breadth as well, so advanced knowledge of a substantive field and participation in the collaborative experience are also integral to the program.

Students planning to enter the doctoral program in statistics should obtain information from the departmental office. Plans of study are prepared individually by the graduate student and a faculty advisor to develop the talents and interests of each student.

### MATH Courses

**MATH 120. Elementary Functions and Analytic Geometry.** 3 Units. Polynomial, rational, exponential, logarithmic, and trigonometric functions (emphasis on computation, graphing, and location of roots) straight lines and conic sections. Primarily a precalculus course for the student without a good background in trigonometric functions and graphing and/or analytic geometry. Not open to students with credit for MATH 121 or MATH 125. Prereq: Three years of high school mathematics.

**MATH 121. Calculus for Science and Engineering I.** 4 Units. Functions, analytic geometry of lines and polynomials, limits, derivatives of algebraic and trigonometric functions. Definite integral, antiderivatives, fundamental theorem of calculus, change of variables. Recommended preparation: Three and one half years of high school mathematics. Credit for at most one of MATH 121, MATH 123 and MATH 125 can be applied to hours required for graduation. Counts for CAS Quantitative Reasoning Requirement. Prereq: MATH 120 or a score of 30 on the mathematics diagnostic test or exempt from the mathematics diagnostic test.

**MATH 122. Calculus for Science and Engineering II.** 4 Units. Continuation of MATH 121. Exponential and logarithmic, growth and decay, inverse trigonometric functions, related rates, basic techniques of integration, area and volume, polar coordinates, parametric equations. Taylor polynomials and Taylor’s theorem. Credit for at most one of MATH 122, MATH 124, and MATH 126 can be applied to hours required for graduation. Prereq: MATH 121, MATH 123 or MATH 126.
MATH 123. Calculus I. 4 Units.
Limits, continuity, derivatives of algebraic and transcendental functions, including applications, basic properties of integration. Techniques of integration and applications. Students must have 31/2 years of high school mathematics. Credit for at most one of MATH 121, MATH 123, and MATH 125 can be applied to hours required for graduation. Counts for CAS Quantitative Reasoning Requirement.

MATH 124. Calculus II. 4 Units.
Review of differentiation. Techniques of integration, and applications of the definite integral. Parametric equations and polar coordinates. Taylor’s theorem. Sequences, series, power series. Complex arithmetic. Introduction to multivariable calculus. Credit for at most one of MATH 122, MATH 124, and MATH 126 can be applied to hours required for graduation. Prereq: MATH 121 and placement by department.

MATH 125. Math and Calculus Applications for Life, Managerial, and Social Sci I. 4 Units.
Discrete and continuous probability; differential and integral calculus of one variable; graphing, related rates, maxima and minima. Integration techniques, numerical methods, volumes, areas. Applications to the physical, life, and social sciences. Students planning to take more than two semesters of introductory mathematics should take MATH 121. Recommended preparation: Three and one half years of high school mathematics. Credit for at most one of MATH 121, MATH 123, and MATH 125 can be applied to hours required for graduation. Counts for CAS Quantitative Reasoning Requirement. Prereq: MATH 120 or a score of 30 on the mathematics diagnostic test or exempt from the mathematics diagnostic test.

MATH 126. Math and Calculus Applications for Life, Managerial, and Social Sci II. 4 Units.
Continuation of MATH 125 covering differential equations, multivariable calculus, discrete methods. Partial derivatives, maxima and minima for functions of two variables, linear regression. Differential equations; first and second order equations, systems, Taylor series methods; Newton’s method; difference equations. Credit for at most one of MATH 122, MATH 124, and MATH 126 can be applied to hours required for graduation. Prereq: MATH 121, MATH 123 or MATH 125.

MATH 150. Mathematics from a Mathematician’s Perspective. 3 Units.
An interesting and accessible mathematical topic not covered in the standard curriculum is developed. Students are exposed to methods of mathematical reasoning and historical progression of mathematical concepts. Introduction to the way mathematicians work and their attitude toward their profession. Should be taken in freshman year to count toward a major in mathematics. Prereq: Three and one half years of high school mathematics. Counts for CAS Quantitative Reasoning Requirement.

MATH 201. Introduction to Linear Algebra for Applications. 3 Units.
Matrix operations, systems of linear equations, vector spaces, subspaces, bases and linear independence, eigenvalues and eigenvectors, diagonalization of matrices, linear transformations, determinants. Less theoretical than MATH 307. Appropriate for majors in science, engineering, economics. Prereq: MATH 122, MATH 124 or MATH 126.

MATH 223. Calculus for Science and Engineering III. 3 Units.
Introduction to vector algebra; lines and planes. Functions of several variables: partial derivatives, gradients, chain rule, directional derivative, maxima/minima. Multiple integrals, cylindrical and spherical coordinates. Derivatives of vector valued functions, velocity and acceleration. Vector fields, line integrals, Green’s theorem. Credit for at most one of MATH 223 and MATH 227 can be applied to hours required for graduation. Prereq: MATH 122 or MATH 124.

MATH 224. Elementary Differential Equations. 3 Units.
A first course in ordinary differential equations. First order equations and applications, linear equations with constant coefficients, linear systems, Laplace transforms, numerical methods of solution. Credit for at most one of MATH 224 and MATH 228 can be applied to hours required for graduation. Prereq: MATH 223 or MATH 227.

MATH 227. Calculus III. 3 Units.
Vector algebra and geometry. Linear maps and matrices. Calculus of vector valued functions. Derivatives of functions of several variables. Multiple integrals. Vector fields and line integrals. Credit for at most one of MATH 223 and MATH 227 can be applied to hours required for graduation. Prereq: MATH 124 and placement by the department.

MATH 228. Differential Equations. 3 Units.
Elementary ordinary differential equations: first order equations; linear systems; applications; numerical methods of solution. Credit for at most one of MATH 224 and MATH 228 can be applied to hours required for graduation. Prereq: MATH 227 or placement by the department.

MATH 301. Undergraduate Reading Course. 1 - 3 Units.
Students must obtain the approval of a supervising professor before registration. More than one credit hour must be approved by the undergraduate committee of the department.

MATH 302. Departmental Seminar. 3 Units.
A seminar devoted to understanding the formulation and solution of mathematical problems. SAGES Department Seminar. Students will investigate, from different possible viewpoints, via case studies, how mathematics advances as a discipline—what mathematicians do. The course will largely be in a seminar format. There will be two assignments involving writing in the style of the discipline. Enrollment by permission (limited to majors depending on demand). Counts as SAGES Departmental Seminar.

MATH 303. Elementary Number Theory. 3 Units.
Primes and divisibility, theory of congruencies, and number theoretic functions. Diophantine equations, quadratic residue theory, and other topics determined by student interest. Emphasis on problem solving (formulating conjectures and justifying them). Prereq: MATH 122 or MATH 124.

MATH 304. Discrete Mathematics. 3 Units.
A general introduction to basic mathematical terminology and the techniques of abstract mathematics in the context of discrete mathematics. Topics introduced are mathematical reasoning, Boolean connectives, deduction, mathematical induction, sets, functions and relations, algorithms, graphs, combinatorial reasoning. Offered as EECS 302 and MATH 304. Prereq: MATH 122, MATH 124 or MATH 126.

MATH 305. Introduction to Advanced Mathematics. 3 Units.
A course on the theory and practice of writing, and reading mathematics. Main topics are logic and the language of mathematics, proof techniques, set theory, and functions. Additional topics may include introductions to number theory, group theory, topology, or other areas of advanced mathematics. Prereq: MATH 122, MATH 124 or MATH 126.
MATH 307. Linear Algebra. 3 Units.
A course in linear algebra that studies the fundamentals of vector spaces, inner product spaces, and linear transformations on an axiomatic basis. Topics include: solutions of linear systems, matrix algebra over the real and complex numbers, linear independence, bases and dimension, eigenvalues and eigenvectors, singular value decomposition, and determinants. Other topics may include least squares, general inner product and normed spaces, orthogonal projections, finite dimensional spectral theorem. This course is required of all students majoring in mathematics and applied mathematics. More theoretical than MATH 201. Prereq: MATH 122 or MATH 124.

MATH 308. Introduction to Abstract Algebra. 3 Units.
A first course in abstract algebra, studied on an axiomatic basis. The major algebraic structures studied are groups, rings and fields. Topics include homomorphisms and quotient structures. This course is required of all students majoring in mathematics. It is helpful, but not necessary, for a student to have taken MATH 307 before MATH 308. Prereq: MATH 122 or MATH 124.

MATH 319. Applied Probability and Stochastic Processes for Biology. 3 Units.
Applications of probability and stochastic processes to biological systems. Mathematical topics will include: introduction to discrete and continuous probability spaces (including numerical generation of pseudo random samples from specified probability distributions), Markov processes in discrete and continuous time with discrete and continuous sample spaces, point processes including homogeneous and inhomogeneous Poisson processes and Markov chains on graphs, and diffusion processes including Brownian motion and the Ornstein-Uhlenbeck process. Biological topics will be determined by the interests of the students and the instructor. Likely topics include: stochastic ion channels, molecular motors and stochastic ratchets, actin and tubulin polymerization, random walk models for neural spike trains, bacterial chemotaxis, signaling and genetic regulatory networks, and stochastic predator-prey dynamics. The emphasis will be on practical simulation and analysis of stochastic phenomena in biological systems. Numerical methods will be developed using a combination of MATLAB, the R statistical package, MCell, and/or URDME, at the discretion of the instructor. Student projects will comprise a major part of the course. Offered as BIOL 319, EECIS 319, MATH 319, SYBB 319, BIOL 419, EBME 419, MATH 419, PHOL 419, and SYBB 419. Prereq: MATH 224 or MATH 223 and BIOL 300 or BIOL 306 and MATH 201 or MATH 307 or consent of instructor.

MATH 321. Fundamentals of Analysis I. 3 Units.
Abstract mathematical reasoning in the context of analysis in Euclidean space. Introduction to formal reasoning, sets and functions, and the number systems. Sequences and series; Cauchy sequences and convergence. Required for all mathematics majors. Additional work required for graduate students. (May not be taken for graduate credit by graduate students in the Department of Mathematics.) Offered as MATH 321 and MATH 421. Prereq: MATH 223 or MATH 227.

MATH 322. Fundamentals of Analysis II. 3 Units.
Continuation of MATH 321. Point-set topology in metric spaces with attention to n-dimensional space; completeness, compactness, connectedness, and continuity of functions. Topics in sequences, series of functions, uniform convergence, Fourier series and polynomial approximation. Theoretical development of differentiation and Riemann integration. Required for all mathematics majors. Additional work required for graduate students. (May not be taken for graduate credit by graduate students in the Department of Mathematics.) Offered as MATH 322 and MATH 422. Prereq: MATH 321.

MATH 324. Introduction to Complex Analysis. 3 Units.

MATH 327. Convexity and Optimization. 3 Units.
Introduction to the theory of convex sets and functions and to the extremes in problems in areas of mathematics where convexity plays a role. Among the topics discussed are basic properties of convex sets (extreme points, facial structure of polytopes), separation theorems, duality and polars, properties of convex functions, minima and maxima of convex functions over convex set, various optimization problems. Offered as MATH 327, MATH 427, and OPRE 427. Prereq: MATH 223 or MATH 227.

MATH 330. Introduction of Scientific Computing. 3 Units.
An introductory survey to Scientific Computing from principles to applications. Topics which will be covered in the course include: solution of linear systems and least squares, approximation and interpolation, solution of nonlinear systems, numerical integration and differentiation, and numerical solution of differential equations. Projects where the numerical methods are used to solve problems from various application areas will be assigned throughout the semester. Prereq: MATH 224 or MATH 228.

MATH 332. Equations that Changed the World. 3 Units.
This course will introduce students to some of the fundamental equations that changed the worlds. One equation a week, the students will investigate the mathematics behind some of the most influential equations or ideas, e.g., the Fourier Transform, Maxwell’s equations, Schrödinger’s equation and the wave equation. Students will research the scientific and social climate in which the equations emerged, and report the impact that the equations have had on the way we see the world and live our lives today. The class will alternate between lectures, where the instructor introduce the mathematical background needed to state and understand for the equation, and presentations, in which the students will present the results of their investigations. The students will be required to write a term paper related to a particular equation and to give a final presentation. The grading will address both the mathematical maturity of the students and the organization and presentation of the paper. Counts as SAGES Departmental Seminar. Prereq: (MATH 223 or MATH 227) and (MATH 224 or 228).

MATH 333. Mathematics and Brain. 3 Units.
This course is intended for upper level undergraduate students in Mathematics, Cognitive Science, Biomedical Engineering, Biology or Neuroscience who have an interest in quantitative investigation of the brain and its functions. Students will be introduced to a variety of mathematical techniques needed to model and simulate different brain functions, and to analyze the results of the simulations and of available measured data. The mathematical exposition will be followed—when appropriate—by the corresponding implementation in Matlab. The course will cover some basic topics in the mathematical aspects of differential equations, electromagnetism, Inverse problems and imaging related to brain functions. Validation and falsification of the mathematical models in the light of available experimental data will be addressed. This course will be a first step towards organizing the different brain investigatory modalities within a unified mathematical framework. Lectures will include a discussion portion. A final presentation and written report are part of the course requirements. Counts as SAGES Departmental Seminar. Prereq: MATH 224 or MATH 228.
MATH 338. Introduction to Dynamical Systems. 3 Units.
Nonlinear discrete dynamical systems in one and two dimensions.
Chaotic dynamics, elementary bifurcation theory, hyperbolicity, symbolic
dynamics, structural stability, stable manifold theory. Prereq: MATH 223 or
MATH 227.

MATH 343. Theoretical Computer Science. 3 Units.
Introduction to different classes of automata and their correspondence
to different classes of formal languages and grammars, computability,
complexity and various proof techniques. Offered as EECS 343 and
MATH 343. Prereq: MATH 304 and EECS 340.

MATH 351. Senior Project for the Mathematics and Physics Program. 2
Units.
A two-semester course (2 credits per semester) in the joint B.S. in
Mathematics and Physics program. Project based on numerical and/
or theoretical research under the supervision of a mathematics faculty
member, possibly jointly with a faculty member from physics. Study of
the techniques utilized in a specific research area and of recent literature
associated with the project. Work leading to meaningful results which
are to be presented as a term paper and an oral report at the end of
the second semester. Supervising faculty will review progress with the
student on a regular basis, including detailed progress reports made
twice each semester, to ensure successful completion of the work.
Counts as SAGES Senior Capstone.

MATH 352. Mathematics Capstone. 3 Units.
Mathematics Senior Project. Students pursue a project based on
experimental, theoretical or teaching research under the supervision of
a mathematics faculty member, a faculty member from another Case
department or a research scientist or engineer from another institution.
A departmental Senior Project Coordinator must approve all project
proposals and this same person will receive regular oral and written
progress reports. Final results are presented at the end of the second
semester as a paper in a style suitable for publication in a professional
journal as well as an oral report in a public Mathematics Capstone
symposium. Counts as SAGES Senior Capstone.

MATH 357. Mathematical Modeling Across the Sciences. 3 Units.
A three credit course on mathematical modeling as it applies to the
origins sciences. Students gain practical experience in a wide range of
techniques for modeling research questions in cosmology and
astrophysics, integrative evolutionary biology (including physical
anthropology, ecology, paleontology, and evolutionary cognitive science),
and planetary science and astrobiology. Offered as ORIG 301, ORIG 401
and MATH 357. Prereq: ORIG 201, ORIG 202, BIOL 225, MATH 122,
CHEM 106 and (PHYS 122 or PHYS 124).

MATH 361. Geometry I. 3 Units.
An introduction to the various two-dimensional geometries, including
Euclidean, spherical, hyperbolic, projective, and affine. The course
will examine the axiomatic basis of geometry, with an emphasis on
transformations. Topics include the parallel postulate and its alternatives,
isometrics and transformation groups, tilings, the hyperbolic plane and
its models, spherical geometry, affine and projective transformations,
and other topics. We will examine the role of complex and hypercomplex
numbers in the algebraic representation of transformations. The course
is self-contained. Counts as SAGES Departmental Seminar. Prereq:
MATH 224.

MATH 363. Knot Theory. 3 Units.
An introduction to the mathematical theory of knots and links, with
emphasis on the modern combinatorial methods. Reidemeister moves
on link projections, ambient and regular isotopies, linking number
tricolorability, rational tangles, braids, torus knots, seifert surfaces and
genus, the knot polynomials (bracket, X, Jones, Alexander, HOMFLY),
crossing numbers of alternating knots and amphicheirality. Connections
to theoretical physics, molecular biology, and other scientific applications
will be pursued in term projects, as appropriate to the background and
interests of the students. Prereq: MATH 223 or MATH 227.

MATH 365. Introduction To Algebraic Geometry. 3 Units.
This is a first introduction to algebraic geometry - the study of solutions
of polynomial equations - for advanced undergraduate students. Recent
applications of this large and important area include number theory,
combinatorics, theoretical physics, coding theory, and robotics. In this
course we will learn the basic objects and notions of algebraic geometry.
Topics that are planned to be covered are affine and projective varieties,
the Zariski topology, the correspondence between ideals and varieties,
the sheaf of regular functions, regular and rational maps, dimensions and
tangent spaces. Examples such as Grassmannians, curves, and blow-
ups will be discussed. Depending on time constraints, we may also touch
upon the modern language of schemes, line bundles and the Riemann
Roch formula, and algorithmic techniques such as Groebner bases.
Prereq: MATH 307 and Coreq: MATH 308.

MATH 376. Mathematical Analysis of Biological Models. 3 Units.
This course focuses on the mathematical methods used to analyze
biological models, with examples drawn largely from ecology but also
from epidemiology, developmental biology, and other areas. Mathematical
topics include equilibrium and stability in discrete and continuous time,
some aspects of transient dynamics, and reaction-diffusion equations
(steady state, diffusive instabilities, and traveling waves). Biological
topics include several "classic" models, such as the Lotka-Volterra model,
the Ricker model, and Michaelis-Menten/type II/saturating responses.
The emphasis is on approximations that lead to analytic solutions, not
numerical analysis. An important aspect of this course is translating
between verbal and mathematical descriptions: the goal is not just to
solve mathematical problems but to extract biological meaning from the
answers we find. Offered as BIOL 306 and MATH 376. Prereq: BIOL 300 or
MATH 224 or consent of instructor.

MATH 378. Computational Neuroscience. 3 Units.
Computer simulations and mathematical analysis of neurons and
neural circuits, and the computational properties of nervous systems.
Students are taught a range of models for neurons and neural circuits,
and are asked to implement and explore the computational and dynamic
properties of these models. The course introduces students to dynamical
systems theory for the analysis of neurons and neural learning, models
of brain systems, and their relationship to artificial and neural networks.
Term project required. Students enrolled in MATH 478 will make
arrangements with the instructor to attend additional lectures and
complete additional assignments addressing mathematical topics related
to the course. Recommended preparation: MATH 223 and MATH 224
or BIOL 300 and BIOL 306. Offered as BIOL 378, COGS 378, MATH 378,
BIOL 478, EBME 478, EECS 478, MATH 478 and NEUR 478.
MATH 380. Introduction to Probability. 3 Units.

MATH 382. High Dimensional Probability. 3 Units.
Behavior of random vectors, random matrices, and random projections in high dimensional spaces, with a view toward applications to data sciences. Topics include tail inequalities for sums of independent random variables, norms of random matrices, concentration of measure, and bounds for random processes. Applications may include structure of random graphs, community detection, covariance estimation and clustering, randomized dimension reduction, empirical processes, statistical learning, and sparse recovery problems. Additional work is required for graduate students. Offered as MATH 382, MATH 482, STAT 382 and STAT 482. Prereq: MATH 307 and (MATH 380 or STAT 345 or STAT 445).

MATH 383. Topics in Probability. 3 Units.
This is a second undergraduate course in probability. Topics may include: Stochastic processes, Markov chains, Brownian motion, martingales, measure-theoretic foundations of probability, quantitative limit theory/rates of convergence, coupling methods, Fourier methods, and ergodic theory. Prereq: MATH 380.

MATH 394. Introduction to Information Theory. 3 Units.
This course is intended as an introduction to information and coding theory with emphasis on the mathematical aspects. It is suitable for advanced undergraduate and graduate students in mathematics, applied mathematics, statistics, physics, computer science and electrical engineering. Course content: Information measures-entropy, relative entropy, mutual information, and their properties. Typical sets and sequences, asymptotic equipartition property, data compression. Channel coding and capacity channel coding theorem. Differential entropy, Gaussian channel, Shannon-Nyquist theorem. Information theory inequalities (400 level). Additional topics, which may include compressed sensing and elements of quantum information theory. Prereq: MATH 394, EBME 419, MATH 419, PHOL 419, and SYBB 419.}

MATH 401. Abstract Algebra I. 3 Units.
Basic properties of groups, rings, modules and fields. Isomorphism theorems for groups; Sylow theorem; nilpotency and solvability of groups; Jordan-Holder theorem; Gauss lemma and Eisenstein's criterion; finitely generated modules over principal ideal domains with applications to abelian groups and canonical forms for matrices; categories and functors; tensor product of modules, bilinear and quadratic forms; field extensions; fundamental theorem of Galois theory, solving equations by radicals. Prereq: MATH 308.

MATH 402. Abstract Algebra II. 3 Units.
A continuation of MATH 401. Prereq: MATH 401.
MATH 422. Fundamentals of Analysis II. 3 Units.
Continuation of MATH 321. Point-set topology in metric spaces with attention to n-dimensional space; completeness, compactness, connectedness, and continuity of functions. Topics in sequences, series of functions, uniform convergence, Fourier series and polynomial approximation. Theoretical development of differentiation and Riemann integration. Required for all mathematics majors. Additional work required for graduate students. (May not be taken for graduate credit by graduate students in the Department of Mathematics.) Offered as MATH 322 and MATH 422. Prereq: MATH 321 or MATH 421.

MATH 423. Introduction to Real Analysis I. 3 Units.

MATH 424. Introduction to Real Analysis II. 3 Units.

MATH 425. Complex Analysis I. 3 Units.
Analytic functions. Integration over paths in the complex plane. Index of a point with respect to a closed path; Cauchy's theorem and Cauchy's integral formula; power series representation; open mapping theorem; singularities; Laurent expansion; residue calculus; harmonic functions; Poisson's formula; Riemann mapping theorem. More theoretical and at a higher level than MATH 324. Prereq: MATH 322 or MATH 422.

MATH 427. Convexity and Optimization. 3 Units.
Introduction to the theory of convex sets and functions and to the extremes in problems in areas of mathematics where convexity plays a role. Among the topics discussed are basic properties of convex sets (extreme points, facial structure of polytopes), separation theorems, duality and polars, properties of convex functions, minima and maxima of convex functions over convex set, various optimization problems. Offered as MATH 327, MATH 427, and OPRE 427.

MATH 431. Introduction to Numerical Analysis I. 3 Units.

MATH 432. Numerical Differential Equations. 3 Units.

MATH 433. Numerical Solutions of Nonlinear Systems and Optimization. 3 Units.
The course provides an introduction to numerical solution methods for systems of nonlinear equations and optimization problems. The course is suitable for upper-undergraduate and graduate students with some background in calculus and linear algebra. Knowledge of numerical linear algebra is helpful. Among the topics which will be covered in the course are Nonlinear systems in one variables; Newton's method for nonlinear equations and unconstrained minimization; Quasi-Newton methods; Global convergence of Newton's methods and line searches; Trust region approach; Secant methods; Nonlinear least squares. Prereq: MATH 223 or MATH 227, and MATH 431 or permission.

MATH 434. Optimization of Dynamic Systems. 3 Units.

MATH 435. Ordinary Differential Equations. 3 Units.
A second course in ordinary differential equations. Existence, uniqueness, and continuation of solutions of ODE. Linear systems, fundamental matrix, qualitative methods (phase plane). Dependence on initial data and parameters (Gronwall's inequality, nonlinearity of parameters). Stability for linear and nonlinear equations, linearization, Poincare-Bendixson theory. Additional topics may include regular and singular perturbation methods, autonomous oscillations, entrainment of forced oscillators, and bifurcations. Prereq: MATH 224 and either MATH 201 or MATH 307.

MATH 439. Bayesian Scientific Computing. 3 Units.
This course will embed numerical methods into a Bayesian framework. The statistical framework will make it possible to integrate a priori information about the unknowns and the error in the data directly into the most efficient numerical methods. A lot of emphasis will be put on understanding the role of the priors, their encoding into fast numerical solvers, and how to translate qualitative or sample-based information--or lack thereof--into a numerical scheme. Confidence on computed results will also be discussed from a Bayesian perspective, at the light of the given data and a priori information. The course should be of interest to anyone working on signal and image processing statistics, numerical analysis and modeling. Recommended Preparation: MATH 431. Offered as MATH 439 and STAT 439.

MATH 440. Computational Inverse Problems. 3 Units.
This course will introduce various computational methods for solving inverse problems under different conditions. First the classical regularization methods will be introduced, and the computational challenges which they pose, will be addressed. Following this, the statistical methods for solving inverse problems will be studied and their computer implementation discussed. We will combine the two approaches to best exploit their potentials. Applications arising from various areas of science, engineering, and medicine will be discussed throughout the course.
MATH 441. Mathematical Modeling. 3 Units.
Mathematics is a powerful language for describing real world phenomena and providing predictions that otherwise are hard or impossible to obtain. The course gives the students pre-requisites for translating qualitative descriptions given in the professional non-mathematical language into the quantitative language for mathematics. While the variety in the subject matter is wide, some general principles and methodologies that a modeler can pursue are similar in many applications. The course focuses on these similarities. The course is based on representative case studies that are discussed and analyzed in the classroom, the emphasis being on general principles of developing and analyzing mathematical models. The examples will be taken from different fields of science and engineering, including life sciences, environmental sciences, biomedical engineering and physical sciences. Modeling relies increasingly on computation, so the students should have basic skills for using computers and programs like Matlab or Mathematica. Prereq: MATH 224 or MATH 228.

MATH 444. Mathematics of Data Mining and Pattern Recognition. 3 Units.
This course will give an introduction to a class of mathematical and computational methods for the solution of data mining and pattern recognition problems. By understanding the mathematical concepts behind algorithms designed for mining data and identifying patterns, students will be able to modify to make them suitable for specific applications. Particular emphasis will be given to matrix factorization techniques. The course requirements will include the implementations of the methods in MATLAB and their application to practical problems. Prereq: MATH 201 or MATH 307.

MATH 445. Introduction to Partial Differential Equations. 3 Units.
Second order equations of elliptic, parabolic, type; initial and boundary value problems. Method of characteristics for linear and quasilinear equations. Separation of variables, eigenfunction expansions, Sturm-Liouville theory. Fourier, Laplace, Hankel transforms; Bessel functions, Legendre polynomials. Green's functions. Examples include: heat diffusion, Laplace's equation, wave equations, one dimensional gas dynamics and others. Appropriate for seniors and graduate students in science, engineering, and mathematics. Prereq: MATH 201 or MATH 307 and MATH 224 or MATH 228.

MATH 446. Numerical Methods for Partial Differential Equations. 3 Units.
This course is an introduction to numerical methods of PDEs, and in particular, to finite element methods (FEM), emphasizing the interconnection between the functional analytic viewpoint of PDEs and the practical and effective computation of the numerical approximations. In particular, the emphasis is on showing that many of the useful and elegant ideas in finite dimensional linear algebra have a natural counterpart in the infinite dimensional setting of Hilbert spaces, and that the same techniques that guarantee the existence and uniqueness of the solutions in fact provide also stable computational methods to approximate the solutions. The topics covered in this course include Fourier analysis, weak derivatives, weak forms, generalized functions; Sobolev spaces, trace theorem, compact embedding theorems, Poincare inequalities; Riesz theory, Fredholm theory; Finite Element Method (FEM): Grid generation, existence, stability and convergence of solutions for elliptic problems; Semi-discretization of parabolic and hyperbolic equations; Stiffness; Numerical solution of linear systems by iterative methods. A quintessential part of this course comprises numerical implementation of the finite element method. Matlab is used as the programming tool both in demonstrations and examples in the class as well as in home assignments. Recommended Preparation: linear algebra, multivariate calculus, and ordinary differential equations.

MATH 449. Dynamical Models for Biology and Medicine. 3 Units.
Introduction to discrete and continuous dynamical models with applications to biology and medicine. Topics include: population dynamics and ecology; models of infectious diseases; population genetics and evolution; biological motion (reaction-diffusion and chemotaxis); Molecular and cellular biology (biochemical kinetics, metabolic pathways, immunology). The course will introduce students to the basic mathematical concepts and techniques of dynamical systems theory (equilibria, stability, bifurcations, discrete and continuous dynamics, diffusion and wave propagation, elements of system theory and control). Mathematical exposition is supplemented with introduction to computer tools and techniques (Mathematica, Matlab). Prereq: MATH 224 or MATH 228, or BIOL/EBME 300, and MATH 201.

MATH 461. Introduction to Topology. 3 Units.

MATH 462. Algebraic Topology. 3 Units.
The fundamental group and covering spaces; van Kampen's theorem. Higher homotopy groups; long-exact sequence of a pair. Homology theory; chain complexes; short and long exact sequences; Mayer-Vietoris sequence. Homology of surfaces and complexes; applications. Prereq: MATH 461.

MATH 465. Differential Geometry. 3 Units.
Manifolds and differential geometry. Vector fields; Riemannian metrics; curvature; intrinsic and extrinsic geometry of surfaces and curves; structural equations of Riemannian geometry; the Gauss-Bonnet theorem. Prereq: MATH 321.

MATH 467. Differentiable Manifolds. 3 Units.
Differentiable manifolds and structures on manifolds. Tangent and cotangent bundle; vector fields; differential forms; tensor calculus; integration and Stokes' theorem. May include Hamiltonian systems and their formulation on manifolds; symplectic structures; connections and curvature; foliations and integrability. Prereq: MATH 322.

MATH 471. Advanced Engineering Mathematics. 3 Units.

MATH 473. Introduction to Mathematical Image Processing and Computer Vision. 3 Units.
This course introduces fundamental mathematics techniques for image processing and computer vision (IPCV). It is accessible to upper level undergraduate and graduate students from mathematics, sciences, engineering and medicine. Topics include but are not limited to image denoising, contrast enhancement, image compression, image segmentation and pattern recognition. Main tools are discrete Fourier analysis and wavelets, plus some statistics, optimization and a little calculus of variation and partial differential equations if time permitting. Students gain a solid theoretical background in IPCV modeling and computing, and master hands-on application experiences. Upon completion of the course, students will have clear understanding of classical methods, which will help them develop new methodical approaches for imaging problems arising in a variety of fields. Recommended preparation: Some coursework in scientific computing and ability to program in (or willingness to learn) a language such as Matlab or C/C++. Prereq: MATH 330 or MATH 431 or equivalent.
MATH 475. Mathematics of Imaging in Industry and Medicine. 3 Units.
The mathematics of image reconstruction; properties of radon transform, relation to Fourier transform; inversion methods, including convolution, backprojection, rho-filtered layergram, algebraic reconstruction technique (ART), and orthogonal polynomial expansions. Reconstruction from fan beam geometry, limited angle techniques used in MRI; survey of applications. Recommended preparation: PHYS 431 or MATH 471.

MATH 478. Computational Neuroscience. 3 Units.
Computer simulations and mathematical analysis of neurons and neural circuits, and the computational properties of nervous systems. Students are taught a range of models for neurons and neural circuits, and are asked to implement and explore the computational and dynamic properties of these models. The course introduces students to dynamical systems theory for the analysis of neurons and neural learning, models of brain systems, and their relationship to artificial and neural networks. Term project required. Students enrolled in MATH 478 will make arrangements with the instructor to attend additional lectures and complete additional assignments addressing mathematical topics related to the course. Recommended preparation: MATH 223 and MATH 224 or BIOL 300 and BIOL 306. Offered as BIOL 378, COGS 378, MATH 378, BIOL 478, EBMME 478, EEECS 478, MATH 478 and NEUR 478.

MATH 482. High Dimensional Probability. 3 Units.
Behavior of random vectors, random matrices, and random projections in high dimensional spaces, with a view toward applications to data sciences. Topics include tail inequalities for sums of independent random variables, norms of random matrices, concentration of measure, and bounds for random processes. Applications may include structure of random graphs, community detection, covariance estimation and clustering, randomized dimension reduction, empirical processes, statistical learning, and sparse recovery problems. Additional work is required for graduate students. Offered as MATH 382, MATH 482, STAT 382 and STAT 482. Prereq: MATH 307 and (MATH 380 or STAT 345 or STAT 445).

MATH 491. Probability I. 3 Units.

MATH 492. Probability II. 3 Units.

MATH 494. Introduction to Information Theory. 3 Units.
This course is intended as an introduction to information and coding theory with emphasis on the mathematical aspects. It is suitable for advanced undergraduate and graduate students in mathematics, applied mathematics, statistics, physics, computer science and electrical engineering. Course content: Information measures-entropy, relative entropy, mutual information, and their properties. Typical sets and sequences, asymptotic equipartition property, data compression. Channel coding and capacity: channel coding theorem. Differential entropy, Gaussian channel, Shannon-Nyquist theorem. Information theory inequalities (400 level). Additional topics, which may include compressed sensing and elements of quantum information theory. Recommended preparation: MATH 201 or MATH 307. Offered as MATH 394, EECS 394, MATH 494 and EECS 494.

MATH 497. Stochastic Models: Time Series and Markov Chains. 3 Units.
Introduction to stochastic modeling of data. Emphasis on models and statistical analysis of data with a significant temporal and/or spatial structure. This course will analyze time and space dependent random phenomena from two perspectives: Stationary Time Series: Spectral representation of deterministic signals, autocorrelation. Power spectra. Transmission of stationary signals through linear filters. Optimal filter design, signal-to-noise ratio. Gaussian signals and correlation matrices. Spectral representation and computer simulation of stationary signals. Discrete Markov Chains: Transition matrices, recurrences and the first step analysis. Steady rate. Recurrence and ergodicity, empirical averages. Long run behavior, convergence to steady state. Time to absorption. Eigenvalues and nonhomogeneous Markov chains. Introduction to Gibbs fields and Markov Chain Monte Carlo (MCMC). This course is related to STAT 538 but can be taken independently of it. Offered as: MATH 497 and STAT 437. Prereq: STAT 243/244 (as a sequence) or STAT 312 or STAT 312R or STAT 313 or STAT 332 or STAT 333 or STAT 345 or MATH 380 or MATH 491 or Requisites Not Met permission.

MATH 499. Special Topics. 3 Units.
Special topics in mathematics.

MATH 528. Analysis Seminar. 1 - 3 Units.
Continuing seminar on areas of current interest in analysis. Allows graduate and advanced undergraduate students to become involved in research. Topics will reflect interests and expertise of the faculty and may include functional analysis, convexity theory, and their applications. May be taken more than once for credit. Consent of department required.

MATH 535. Applied Mathematics Seminar. 1 - 3 Units.
Continuing seminar on areas of current interest in applied mathematics. Allows graduate and advanced undergraduate students to become involved in research. Topics will reflect interests and expertise of the faculty and may include topics in applied probability and stochastic processes, continuum mechanics, numerical analysis, mathematical physics or mathematical biology. May be taken more than once for credit.

MATH 549. Mathematical Life Sciences Seminar. 1 - 3 Units.
Continuing seminar on areas of current interest in the applications of mathematics to the life sciences. Allows graduate and advanced undergraduate students to become involved in research. Topics will reflect interests and expertise of the faculty and may include mathematical biology, computational neuroscience, mathematical modeling of biological systems, models of infectious diseases, computational cell biology, mathematical ecology and mathematical biomedicine broadly constructed. May be taken more than once for credit.

Department of Mathematics, Applied Mathematics, and Statistics
MATH 598. Stochastic Models: Diffusive Phenomena and Stochastic Differential Equations. 3 Units.
Introduction to stochastic modeling of data. Emphasis on models and statistical analysis of data with significant temporal and/or spatial structure. This course will analyze time and space dependent random phenomena from two perspectives: Brownian motion and diffusive processes: Classification of stochastic processes, finite dimensional distributions, random walks and their scaling limits, Brownian motion and its paths properties, general diffusive processes, Fokker-Planck-Kolmogorov equations, Poisson and point processes, heavy tail diffusions, Levy processes, tempered stable diffusions. Stochastic calculus and stochastic differential equations: Wiener random integrals, mean-square theory, Brownian stochastic integrals and Ito formula, stochastic integrals for Levy processes, martingale property, basic theory and applications of stochastic differential equations. This course is related to STAT 437 but can be taken independently of it. Offered as MATH 598 and STAT 538.

MATH 601. Reading and Research Problems. 1 - 18 Units.
Presentation of individual research, discussion, and investigation of research papers in a specialized field of mathematics.

MATH 651. Thesis (M.S.). 1 - 18 Units.
(Credit as arranged.)

MATH 701. Dissertation (Ph.D.). 1 - 9 Units.
(Credit as arranged.) Prerequisite: Predoctoral research consent or advanced to Ph.D. candidacy milestone.

STAT Courses

STAT 201. Basic Statistics for Social and Life Sciences. 3 Units.
Designed for undergraduates in the social sciences and life sciences who need to use statistical techniques in their fields. Descriptive statistics, probability models, sampling distributions. Point and confidence interval estimation, hypothesis testing. Elementary regression and analysis of variance. Not for credit toward major or minor in Statistics. Counts for CAS Quantitative Reasoning Requirement.

STAT 201R. Basic Statistics for Social and Life Sciences Using R Programming. 3 Units.
Designed for undergraduates in the social sciences and life sciences who need to use statistical techniques in their fields. Descriptive statistics, probability models, sampling distributions. Point and confidence interval estimation, hypothesis testing. Elementary regression and analysis of variance. Not for credit toward major or minor in Statistics. Students may earn credit for only one of the following courses: STAT 201, STAT 201R, ANTH 319, PSCL 282 or SYBB 201R. Offered as STAT 201R and SYBB 201R. Counts for CAS Quantitative Reasoning Requirement.

STAT 243. Statistical Theory with Application I. 3 Units.

STAT 244. Statistical Theory with Application II. 3 Units.
Extension of inferences to continuous-valued random variables. Common continuous-valued distributions. Expectation operator. Maximum likelihood estimators for the continuous case. Simple linear, multiple and polynomial regression. Properties of regression estimators when errors are Gaussian. Regression diagnostics. Class or student projects gathering real data or generating simulated data, fitting models and analyzing residuals from fit. Prerequisite: STAT 243.

STAT 312. Basic Statistics for Engineering and Science. 3 Units.
For advanced undergraduate students in engineering, physical sciences, life sciences. Comprehensive introduction to probability models and statistical methods of analyzing data with the object of formulating statistical models and choosing appropriate methods for inference from experimental and observational data and for testing the model's validity. Balanced approach with equal emphasis on probability, fundamental concepts of statistics, point and interval estimation, hypothesis testing, analysis of variance, design of experiments, and regression modeling. Note: Credit given for only one (1) of STAT 312, 312R, 313; SYBB 312R. Prerequisite: MATH 122 or equivalent.

STAT 312R. Basic Statistics for Engineering and Science Using R Programming. 3 Units.
For advanced undergraduate students in engineering, physical sciences, life sciences. Comprehensive introduction to probability models and statistical methods of analyzing data with the object of formulating statistical models and choosing appropriate methods for inference from experimental and observational data and for testing the model's validity. Balanced approach with equal emphasis on probability, fundamental concepts of statistics, point and interval estimation, hypothesis testing, analysis of variance, design of experiments, and regression modeling. Note: Credit given for only one (1) of STAT 312, 312R, STAT 313 or SYBB 312R. Offered as STAT 312R and SYBB 312R. Prerequisite: MATH 122 or equivalent.

STAT 313. Statistics for Experimenters. 3 Units.
For advanced undergraduate students in engineering, physical sciences, life sciences. Comprehensive introduction to modeling data and statistical methods of analyzing data. General objective is to train students in formulating statistical models, in choosing appropriate methods for inference from experimental and observational data and to test the validity of these models. Focus on practicalities of inference from experimental data. Inference for curve and surface fitting to real data sets. Design for experiments and simulations. Student generation of experimental data and application of statistical methods for analysis. Critique of model; use of regression diagnostics to analyze errors. Note: Credit given for only one (1) of STAT 312, 312R, 313; SYBB 312R. Prerequisite: MATH 122 or equivalent.

STAT 317. Actuarial Science I. 3 Units.
Practical knowledge of the theory of interest in both finite and continuous time. That knowledge should include how these concepts are used in the various annuity functions, and apply the concepts of present and accumulated value for various streams of cash flows as a basis for future use in: reserving, valuation, pricing, duration, asset/liability management, investment income, capital budgeting, and contingencies. Valuation of discrete and continuous streams of payments, including the case in which the interest conversion period differs from the payment period will be considered. Application of interest theory to amortization of lump sums, fixed income securities, depreciation, mortgages, etc., as well as annuity functions in a broad finance context will be covered. Topics covered include areas examined in the American Society of Actuaries Exam 2. Offered as STAT 317 and STAT 417. Prerequisite: MATH 122 or MATH 126 or requisites not met permission.
STAT 318. Actuarial Science II. 3 Units.
Theory of life contingencies. Life table analysis for simple and multiple decrement functions. Life and special annuities. Life insurance and reserves for life insurance. Statistical issues for prediction from actuarial models. Topics covered include areas examined in the American Society of Actuaries Exam 3. Offered as STAT 318 and STAT 418. Prereq: STAT 312 or STAT 312R or STAT 317 or STAT 345 or requisites not met permission.

STAT 325. Data Analysis and Linear Models. 3 Units.
Basic exploratory data analysis for univariate response with single or multiple covariates. Graphical methods and data summarization, model-fitting using S-plus computing language. Linear and multiple regression. Emphasis on model selection criteria, on diagnostics to assess goodness of fit and interpretation. Techniques include transformation, smoothing, median polish, robust/resistant methods. Case studies and analysis of individual data sets. Notes of caution and some methods for handling bad data. Knowledge of regression is helpful. Offered as STAT 325 and STAT 425. Prereq: STAT 243 or STAT 312 or STAT 312R or PQHS/EPBI 431 or PQHS/EPBI 441 or PQHS/EPBI 458.

STAT 326. Multivariate Analysis and Data Mining. 3 Units.

STAT 332. Statistics for Signal Processing. 3 Units.
For advanced undergraduate students or beginning graduate students in engineering, physical sciences, life sciences. Introduction to probability models and statistical methods. Emphasis on probability as relative frequencies. Derivation of conditional probabilities and memoryless channels. Joint distribution of random variables, transformations, autocorrelation, series of irregular observations, stationarity. Random harmonic signals with noise, random phase and/or random amplitude. Gaussian and Poisson signals. Modulation and averaging properties. Transmission through linear filters. Power spectra, bandwidth, white and colored noise. ARMA processes and forecasting. Optimal linear systems, signal-to-noise ratio, Wiener filter. Completion of additional assignments required from graduate students registered in this course. Offered as STAT 332 and STAT 432. Prereq: MATH 122.

STAT 333. Uncertainty in Engineering and Science. 3 Units.
Phenomena of uncertainty appear in engineering and science for various reasons and can be modeled in different ways. The course integrates the mainstream ideas in statistical data analysis with models of uncertain phenomena stemming from three distinct viewpoints: algorithmic/computational complexity; classical probability theory; and chaotic behavior of nonlinear systems. Descriptive statistics, estimation procedures and hypothesis testing (including design of experiments). Random number generators and their testing. Monte Carlo Methods. Mathematica notebooks and simulations will be used. Graduate students are required to do an extra project. Offered as STAT 333 and STAT 433. Prereq: MATH 122 or MATH 223.

STAT 345. Theoretical Statistics I. 3 Units.
Topics provide the background for statistical inference. Random variables; distribution and density functions; transformations, expectation. Common univariate distributions. Multiple random variables; joint, marginal and conditional distributions; hierarchical models, covariance. Distributions of sample quantities, distributions of sums of random variables, distributions of order statistics. Methods of statistical inference. Offered as STAT 345, STAT 445, and PQHS 481. Prereq: MATH 122 or MATH 223 or Coreq: PQHS/EPBI 431.

STAT 346. Theoretical Statistics II. 3 Units.
Point estimation: maximum likelihood, moment estimators. Methods of evaluating estimators including mean squared error, consistency, "best" unbiased and sufficiency. Hypothesis testing; likelihood ratio and union-intersection tests. Properties of tests including power function, bias. Interval estimation by inversion of test statistics, use of pivotal quantities. Application to regression. Graduate students are responsible for mathematical derivations, and full proofs of principal theorems. Offered as STAT 346, STAT 446 and PQHS 482. Prereq: STAT 345 or STAT 445 or PQHS/EPBI 481.

STAT 382. High Dimensional Probability. 3 Units.
Behavior of random vectors, random matrices, and random projections in high dimensional spaces, with a view toward applications to data sciences. Topics include tail inequalities for sums of independent random variables, norms of random matrices, concentration of measure, and bounds for random processes. Applications may include structure of random graphs, community detection, covariance estimation and clustering, randomized dimension reduction, empirical processes, statistical learning, and sparse recovery problems. Additional work is required for graduate students. Offered as MATH 382, MATH 482, STAT 382 and STAT 482. Prereq: MATH 307 and (MATH 380 or STAT 345 or STAT 445).

STAT 395. Senior Project in Statistics. 3 Units.
An individual project done under faculty supervision involving the investigation and statistical analysis of a real problem encountered in university research or an industrial setting. Written report. Counts as SAGES Senior Capstone.

STAT 417. Actuarial Science I. 3 Units.
Practical knowledge of the theory of interest in both finite and continuous time. That knowledge should include how these concepts are used in the various annuity functions, and apply the concepts of present and accumulated value for various streams of cash flows as a basis for future use in: reserving, valuation, pricing, duration, asset/liability management, investment income, capital budgeting, and contingencies. Valuation of discrete and continuous streams of payments, including the case in which the interest conversion period differs from the payment period will be considered. Application of interest theory to amortization of lump sums, fixed income securities, depreciation, mortgages, etc., as well as annuity functions in a broad finance context will be covered. Topics covered include areas examined in the American Society of Actuaries Exam 2. Offered as STAT 317 and STAT 417. Prereq: MATH 122 or MATH 126 or requisites not met permission.

STAT 418. Actuarial Science II. 3 Units.
Theory of life contingencies. Life table analysis for simple and multiple decrement functions. Life and special annuities. Life insurance and reserves for life insurance. Statistical issues for prediction from actuarial models. Topics covered include areas examined in the American Society of Actuaries Exam 3. Offered as STAT 318 and STAT 418. Prereq: STAT 312 or STAT 312R or STAT 317 or STAT 345 or requisites not met permission.
STAT 425. Data Analysis and Linear Models. 3 Units.
Basic exploratory data analysis for univariate response with single or multiple covariates. Graphical methods and data summarization, model-fitting using S-plus computing language. Linear and multiple regression. Emphasis on model selection criteria, on diagnostics to assess goodness of fit and interpretation. Techniques include transformation, smoothing, median polish, robust/resistant methods. Case studies and analysis of individual data sets. Notes of caution and some methods for handling bad data. Knowledge of regression is helpful. Offered as STAT 325 and STAT 425.

STAT 426. Multivariate Analysis and Data Mining. 3 Units.

STAT 432. Statistics for Signal Processing. 3 Units.
For advanced undergraduate students or beginning graduate students in engineering, physical sciences, life sciences. Introduction to probability models and statistical methods. Emphasis on probability as relative frequencies. Derivation of conditional probabilities and memoryless channels. Joint distribution of random variables, transformations, autocorrelation, series of irregular observations, stationarity. Random harmonic signals with noise, random phase and/or random amplitude. Gaussian and Poisson signals. Modulation and averaging properties. Transmission through linear filters. Power spectra, bandwidth, white and colored noise. ARMA processes and forecasting. Optimal linear systems, signal-to-noise ratio, Wiener filter. Completion of additional assignments required from graduate students registered in this course. Offered as STAT 332 and STAT 432. Prereq: MATH 122.

STAT 433. Uncertainty in Engineering and Science. 3 Units.
Phenomena of uncertainty appear in engineering and science for various reasons and can be modeled in different ways. The course integrates the mainstream ideas in statistical data analysis with models of uncertain phenomena stemming from three distinct viewpoints: algorithmic/computational complexity; classical probability theory; and chaotic behavior of nonlinear systems. Descriptive statistics, estimation procedures and hypothesis testing (including design of experiments). Random number generators and their testing. Monte Carlo Methods. Mathematica notebooks and simulations will be used. Graduate students are required to do an extra project. Offered as STAT 333 and STAT 433. Prereq: MATH 122 or MATH 223.

STAT 437. Stochastic Models: Time Series and Markov Chains. 3 Units.
Introduction to stochastic modeling of data. Emphasis on models and statistical analysis of data with a significant temporal and/or spatial structure. This course will analyze time and space dependent random phenomena from two perspectives: Stationary Time Series: Spectral representation of deterministic signals, autocorrelation. Power spectra. Transmission of stationary signals through linear filters. Optimal filter design, signal-to-noise ratio. Gaussian signals and correlation matrices. Spectral representation and computer simulation of stationary signals. Discrete Markov Chains: Transition matrices, recurrences and the first step analysis. Steady rate. Recurrence and ergodicity, empirical averages. Long run behavior, convergence to steady state. Time to absorption. Eigenvalues and nonhomogeneous Markov chains. Introduction to Gibbs fields and Markov Chain Monte Carlo (MCMC). This course is related to STAT 538 but can be taken independently of it. Offered as: MATH 497 and STAT 437. Prereq: STAT 243/244 (as a sequence) or STAT 312 or STAT 313 or STAT 332 or STAT 333 or STAT 345 or MATH 380 or MATH 491 or Requisites Not Met permission.

STAT 439. Bayesian Scientific Computing. 3 Units.
This course will embed numerical methods into a Bayesian framework. The statistical framework will make it possible to integrate a priori information about the unknowns and the error in the data directly into the most efficient numerical methods. A lot of emphasis will be put on understanding the role of the priors, their encoding into fast numerical solvers, and how to translate qualitative or sample-based information—lack thereof—into a numerical scheme. Confidence on computed results will also be discussed from a Bayesian perspective, at the light of the given data and a priori information. The course should be of interest to anyone working on signal and image processing statistics, numerical analysis and modeling. Recommended Preparation: MATH 431. Offered as MATH 439 and STAT 439.

STAT 445. Theoretical Statistics I. 3 Units.
Topics provide the background for statistical inference. Random variables; distribution and density functions; transformations, expectation. Common univariate distributions. Multiple random variables; joint, marginal and conditional distributions; hierarchical models, covariance. Distributions of sample quantities, distributions of sums of random variables, distributions of order statistics. Methods of statistical inference. Offered as STAT 345, STAT 445, and PQHS 481. Prereq: MATH 122 or MATH 223 or Coreq: PQHS/EPBI 431.

STAT 446. Theoretical Statistics II. 3 Units.
Point estimation: maximum likelihood, moment estimators. Methods of evaluating estimators including mean squared error, consistency, "best" unbiased and sufficiency. Hypothesis testing; likelihood ratio and union-intersection tests. Properties of tests including power function, bias. Interval estimation by inversion of test statistics, use of pivotal quantities. Application to regression. Graduate students are responsible for mathematical derivations, and full proofs of principal theorems. Offered as STAT 346, STAT 446 and PQHS 482. Prereq: STAT 345 or STAT 445 or PQHS/EPBI 481.

STAT 448. Bayesian Theory with Applications. 3 Units.
Principles of Bayesian theory, methodology and applications. Methods for forming prior distributions using conjugate families, reference priors and empirically-based priors. Derivation of posterior and predictive distributions and their moments. Properties when common distributions such as binomial, normal or other exponential family distributions are used. Hierarchical models. Computational techniques including Markov chain, Monte Carlo and importance sampling. Extensive use of applications to illustrate concepts and methodology. Recommended preparation: STAT 445.
STAT 455. Linear Models. 3 Units.
Prereq: MATH 201 and STAT 346 or STAT 446

STAT 482. High Dimensional Probability. 3 Units.
Behavior of random vectors, random matrices, and random projections in high dimensional spaces, with a view toward applications to data sciences. Topics include tail inequalities for sums of independent random variables, norms of random matrices, concentration of measure, and bounds for random processes. Applications may include structure of random graphs, community detection, covariance estimation and clustering, randomized dimension reduction, empirical processes, statistical learning, and sparse recovery problems. Additional work is required for graduate students. Offered as MATH 382, MATH 482, STAT 382 and STAT 482. Prereq: MATH 307 and (MATH 380 or STAT 345 or STAT 445).

STAT 491. Graduate Student Seminar. 1 - 2 Units.
Seminar run collaboratively by graduate students to investigate an area of current research, the topic chosen each semester. All graduate students participate in presentation of material each semester. Satisfies requirement for every full-time graduate student to enroll in a participatory seminar every semester while registered in any graduate degree program. Recommended preparation: Graduate standing.

STAT 495A. Consulting Forum. 1 - 3 Units.
This course unifies what students have learned in their course work to apply their knowledge in consulting. It recognizes the fact that the essence of the statistical profession is continuing interaction with practitioners in the sciences, engineering, medicine, economics, etc. The course presents the views of prominent experts in the field as obtained from the literature and other sources. The responsibilities of the consultant and the client are discussed. Sample consulting problems are presented and strategies for solving them are provided. Prereq: STAT 325 or STAT 425.

STAT 538. Stochastic Models: Diffusive Phenomena and Stochastic Differential Equations. 3 Units.
Introduction to stochastic modeling of data. Emphasis on models and statistical analysis of data with significant temporal and/or spatial structure. This course will analyze time and space dependent random phenomena from two perspectives: Brownian motion and diffusive processes: Classification of stochastic processes, finite dimensional distributions, random walks and their scaling limits, Brownian motion and its paths properties, general diffusive processes, Fokker-Planck-Kolmogorov equations, Poisson and point processes, heavy tail diffusions, Levy processes, tempered stable diffusions. Stochastic calculus and stochastic differential equations: Wiener random integrals, mean-square theory, Brownian stochastic integrals and Ito formula, stochastic integrals for Levy processes, martingale property, basic theory and applications of stochastic differential equations. This course is related to STAT 437 but can be taken independently of it. Offered as MATH 598 and STAT 538. Prereq: STAT 312 or equivalent.

STAT 601. Reading and Research. 1 - 9 Units.
Individual study and/or project work.

STAT 621. M.S. Research Project. 1 - 9 Units.
Completion of statistical design and/or analysis of a research project in a substantive field which requires substantial and/or nonstandard statistical techniques and which leads to results suitable for publication. Written project report must present the context of the research, justify the statistical methodology used, draw appropriate inferences and interpret these inferences in both statistical and substantive scientific terms. Oral presentation of research project may be given in either graduate student seminar or consulting forum.

STAT 651. Thesis M.S.. 1 - 18 Units.
(Credit as arranged.) May be used as alternative to STAT 621 (M.S. Research Project) in fulfillment of requirements for M.S. degree in Statistics.

STAT 701. Dissertation Ph.D.. 1 - 9 Units.
(Credit as arranged.) Prereq: Predoctoral research consent or advanced to Ph.D. candidacy milestone.