Mathematics

Mathematics is a subject of great intrinsic power and beauty. It is the universal language of science, and is essential for a clear and complete understanding of virtually all phenomena. Mathematical training prepares a student to express and analyze problems and relationships in a logical manner in a wide variety of disciplines including the physical, engineering, social, biological, and medical sciences, business, and pure mathematics itself. This is a principal reason behind the perpetual need and demand for mathematicians in education, research centers, government, and industry.

The department offers three major programs leading to the degrees of bachelor of arts in mathematics, bachelor of science in mathematics (with a general mathematics and an applied mathematics option), and bachelor of science in statistics. It also offers several minor programs for undergraduates.

At the graduate level, it offers programs leading to the degrees of master of science in mathematics, master of science in applied mathematics, master of science in statistics, doctor of philosophy in mathematics, and doctor of philosophy in applied mathematics.

The Division of Applied Mathematics and Statistics is a part of the Department of Mathematics.

CALCULUS SEQUENCES

Many degree programs throughout the university include a mathematics requirement consisting of a sequence in calculus. The Department of Mathematics offers three calculus sequences:

<table>
<thead>
<tr>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
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</thead>
<tbody>
<tr>
<td>MATH 021</td>
<td>MATH 022</td>
<td>MATH 023</td>
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<tr>
<td>&amp; MATH 022</td>
<td>&amp; MATH 023</td>
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<td>&amp; MATH 023</td>
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<tr>
<td>MATH 031</td>
<td>MATH 032</td>
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<td>&amp; MATH 032</td>
<td>&amp; MATH 033</td>
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<td>&amp; MATH 033</td>
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<tr>
<td>MATH 051</td>
<td>MATH 052</td>
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<td>&amp; MATH 052</td>
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</table>

The MATH 021, MATH 022, MATH 023 sequence is a systematic development of calculus. Most students of mathematics, science, engineering, and business will take some or all of this sequence.

As an honors sequence, the MATH 031, MATH 032, MATH 033 sequence covers essentially the same material but in greater depth and with more attention to rigor and proof. This sequence should be considered by students who have demonstrated exceptional ability in mathematics. Students who are contemplating a major in mathematics are strongly encouraged to consider this sequence.

The MATH 051, MATH 052 sequence is a survey of calculus. MATH 081 is a survey course with business applications. This sequence is not sufficient preparation for most subsequent mathematics courses. Students contemplating further study in mathematics should consider MATH 021, MATH 022 instead.

MATH 075, MATH 076 is a two-semester sequence that substitutes for MATH 021, covering the same material but at a slower pace.

The MATH 031, MATH 032, MATH 033 sequence will be accepted in place of the other two sequences. MATH 021, MATH 022 will be accepted in place of MATH 051, MATH 052. Credit will be awarded for only one course in each of the following groups:

- **MATH 023** Calculus III  4
- **MATH 033** Honors Calculus III  4

If two courses in the same group are taken, credit will be awarded for the more advanced course; 3x is the most advanced, while 5x is the least advanced.

**Professors.** Huai-Dong Cao, PhD (Princeton University); Donald M Davis, PhD (Stanford University); Bennett Eisenberg, PhD (Massachusetts Institute of Technology); Wei-Min Huang, PhD (University of Rochester); Garth Isaak, PhD (Rutgers University); David L. Johnson, PhD (Massachusetts Institute of Technology); Terence J. Napier, PhD (University of Chicago); Lee J. Stanley, PhD (University of California Berkeley); Steven H. Weintraub, PhD (Princeton University); Joseph E. Yuih, PhD (Massachusetts Institute of Technology)

**Associate Professors.** Soutir Bandopadhyay, PhD (Texas A&M University); Daniel Conus, PhD (Swiss Federal Institute of Technology); Bruce A. Dodson, PhD (Stony Brook University); Robert W. Neel, PhD (Harvard University); Mark Skandera, PhD (Massachusetts Institute of Technology); Xiaofeng Sun, PhD (Stanford University); Susan Szczepanski, PhD (Rutgers University New Brunswick); Ping-Shi Wu, PhD (University of California Davis); Linghai Zhang, PhD (University of Minnesota)

**Assistant Professors.** Angela Hicks, PhD (University of California San Diego); Yue Yu, DA (Brown University)

**Professors Of Practice.** Vincent E Coll, PhD (University of Pennsylvania); Miranda Ijang Teboh Ewungkem, PhD (Lehigh University)

**Emeriti.** Samir A. Khabbaz, PhD (University of Kansas); Jerry P. King, PhD (University of Kentucky Fort Knox); Clifford S. Queen, PhD (Ohio State University); Eric P. Salatke, PhD (Brown University); Andrew K Snyder, PhD (Lehigh University); Ramamirtham Venkataraman, PhD (Brown University)

UNDERGRADUATE DEGREE PROGRAMS

The Department of Mathematics offers degree programs in Mathematics and Statistics. These programs have the flexibility and versatility needed to prepare students for a wide variety of careers in government, industry, research and education.

Students in the degree programs in mathematics must satisfy three types of requirements beyond those required by the college: Core Mathematics Requirements, Major Requirements and General Electives. The Core Mathematics Requirement ensures a common core of knowledge appropriate for students in each program. The Major Program Electives consist of courses with specific mathematical or statistical content chosen by the student in consultation with the major advisor to complement the student’s interest and career aspirations. With these further breadth and greater depth of knowledge are achieved. The General Electives consist of additional courses chosen from among those offered by the university faculty. Students can use these electives to pursue interests beyond the major, or may use these to expand upon the basic requirements of the degree program. Students are strongly encouraged to use some of these electives to earn a minor in another discipline.

Students in the degree program in statistics must satisfy four types of requirements beyond those required by the college: Required Major Courses, Major Electives, Professional Electives and Free Electives. Each student is provided a faculty advisor to guide an individual program and supervise the selection of electives.

**B.A. WITH A MAJOR IN MATHEMATICS**

The B.A. program in mathematics emphasizes fundamental principles as well as the mastery of techniques required for the effective use of mathematics. The program provides a solid foundation for those who want to pursue a mathematically oriented career or advanced study in any mathematically oriented field.
### B.S. IN MATHEMATICS

The BS in Mathematics program provides a more extensive and intensive study of mathematics and its applications. Students can pursue the General Mathematics Option or the Applied Mathematics Option. These programs are especially recommended for students intending to pursue advanced study in mathematics or applied mathematics. The General Mathematics Option is recommended for students who wish to pursue mathematics either by itself or in combination with a related field (e.g., physics, computer science or economics). The Applied Mathematics Option provides a broad background in the major areas of applicable mathematics.

#### General Mathematics Option

**Requirements**

**College Distribution Requirements excluding mathematics**

<table>
<thead>
<tr>
<th>Credits</th>
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<tr>
<td>31-34</td>
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**Core Mathematics Requirements**

<table>
<thead>
<tr>
<th>Course</th>
<th>Credits</th>
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</thead>
<tbody>
<tr>
<td>MATH 021 &amp; MATH 022 &amp; MATH 023</td>
<td>12</td>
</tr>
<tr>
<td>MATH 031 &amp; MATH 032 &amp; MATH 033</td>
<td></td>
</tr>
<tr>
<td>MATH 163</td>
<td>3</td>
</tr>
<tr>
<td>MATH 231 or MATH 309</td>
<td>3</td>
</tr>
<tr>
<td>MATH 242 or MATH 309</td>
<td>3-4</td>
</tr>
<tr>
<td>MATH 205 or MATH 320</td>
<td>3</td>
</tr>
<tr>
<td>MATH 301</td>
<td>3-4</td>
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</tbody>
</table>

**Major Requirements**

<table>
<thead>
<tr>
<th>Course</th>
<th>Credits</th>
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</thead>
<tbody>
<tr>
<td>MATH 243</td>
<td>3-4</td>
</tr>
<tr>
<td>Select at least 6 credits in electives at or above the 200-level</td>
<td></td>
</tr>
<tr>
<td>Total Credits</td>
<td>111-123</td>
</tr>
</tbody>
</table>

This program requires a total of 120 credit hours.

A student must achieve an average of 2.0 or higher in major courses.

**General Electives**

Select electives in consultation with faculty advisor

Total Credits: 110-124

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### Applied Mathematics Option

**Requirements**

**College Distribution Requirements excluding mathematics**

<table>
<thead>
<tr>
<th>Credits</th>
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<tbody>
<tr>
<td>31-34</td>
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</table>

**Core Mathematics Requirements**

<table>
<thead>
<tr>
<th>Course</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH 021 &amp; MATH 022 &amp; MATH 023</td>
<td>12</td>
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<tr>
<td>MATH 031 &amp; MATH 032 &amp; MATH 033</td>
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<td>MATH 163</td>
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<td>MATH 205 or MATH 320</td>
<td>3</td>
</tr>
<tr>
<td>MATH 301</td>
<td>3-4</td>
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</tbody>
</table>

**Major Requirements**

Select five elective courses (at least 17 credits) at or above the 200 level chosen in consultation with the major advisor.

Two approved CSE courses. (CSE 1 and CSE 2 are NOT sufficient to satisfy this requirement.)

**General Electives**

Select electives in consultation with faculty advisor

Total Credits: 68-77

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In consultation with the major advisor, a student must establish a concentration in a particular area of applied mathematics. The courses chosen must have specific mathematical or statistical content and together constitute a coherent program. At most two courses may be taken outside the Department of Mathematics. Students, in consultation with the major advisor, can design a concentration which reflects a particular area of interest or choose to pursue one of the following:

#### Concentration in Applied Analysis

Electives must include:

<table>
<thead>
<tr>
<th>Course</th>
<th>Credits</th>
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</thead>
<tbody>
<tr>
<td>MATH 230</td>
<td>3</td>
</tr>
<tr>
<td>MATH 322</td>
<td>3</td>
</tr>
<tr>
<td>MATH 341</td>
<td>3</td>
</tr>
</tbody>
</table>

Total Credits: 9
Statistics provides a body of principles for designing the process of data collection, for summarizing and interpreting data, and for drawing valid conclusions from data. It thus forms a fundamental tool in the areas of research. Mathematical principles, especially probability theory, underlie all statistical analyses.

B.S. IN STATISTICS
A student must achieve an average of 2.0 or higher in major courses.

B. S. IN STATISTICS
Statistics provides a body of principles for designing the process of data collection, for summarizing and interpreting data, and for drawing valid conclusions from data. It thus forms a fundamental tool in the natural and social sciences as well as business, medicine, and other areas of research. Mathematical principles, especially probability theory, underlie all statistical analyses.

College Distribution Requirements excluding mathematics

31-34 credits

Required Major courses

Select one of the following:

12

MATH 021 Calculus I
& MATH 022 and Calculus II
& MATH 023 and Calculus III
MATH 031 Honors Calculus I
& MATH 032 and Honors Calculus II
& MATH 033 and Honors Calculus III
MATH 012 Basic Statistics
or MATH 231 Probability and Statistics

Select one of the following:

3-4

MATH 043 Survey of Linear Algebra
MATH 205 Linear Methods
MATH 242 Linear Algebra
MATH 309 Theory of Probability
MATH 310 Random Processes and Applications
MATH 312 Statistical Computing and Applications
MATH 334 Mathematical Statistics
MATH 338 Linear Models in Statistics with Applications
MATH 374 Statistical Project

Two approved CSE courses. (CSE 1 and CSE 2 are NOT sufficient to satisfy this requirement.)

Major Electives

At least three courses with specific mathematical or statistical content chosen with the approval of the faculty advisor

Professional Electives

Courses selected from two or three fields of application of statistics and probability

Free Electives

Select 6-11 credits in free electives

Total Credits

112-127

CONCENTRATION IN ACTUARIAL SCIENCE

Major Electives must include:

MATH 202 Actuarial Exam I
MATH 203 Actuarial Exam II - Financial Mathematics

Professional Electives (21 credit hours) must include:

ACCT 151 Introduction to Financial Accounting
ECO 029 Money, Banking, and Financial Markets
ECO 119 Intermediate Macroeconomic Analysis
FIN 125 Introduction to Finance

DEPARTMENTAL HONORS

Students may earn departmental honors by writing a thesis during their senior year. Students are accepted into the program during their junior year by the department chairperson. This acceptance is based upon the student's grades and a thesis proposal, which the student must prepare in conjunction with a thesis advisor selected by the student. An oral presentation as well as a written thesis are required for completion of the program.

MINOR PROGRAMS

The department offers minor programs in different branches of the mathematical sciences. The requirement consists of MATH 023 or MATH 033 and four additional courses shown below for each of the programs. At most one of these five courses in the minor program may also be required in the major program. For substitutions, the student should consult the chairperson.

Minor in Pure Mathematics

MATH 242 Linear Algebra
MATH 243 Algebra
MATH 301 Principles of Analysis I
MATH 302 Principles of Analysis II
MATH 303 Mathematical Logic
MATH 307 General Topology I
MATH 316 Complex Analysis
MATH 342 Number Theory

Total Credits

12-16

Minor in Applied Mathematics

Select three of the following:

9-10

MATH 205 Linear Methods
MATH 208 Complex Variables
MATH 230 Numerical Methods
MATH 231 Probability and Statistics
MATH 242 Linear Algebra
MATH 320 Ordinary Differential Equations
MATH 322 Methods of Applied Analysis I
MATH 323 Methods of Applied Analysis II
MATH 341 Mathematical Models and Their Formulation

Total Credits

12-13

Minor in Probability and Statistics

MATH 012 Basic Statistics
or MATH 231 Probability and Statistics
MATH 309 Theory of Probability

Select two of the following:

6-8

MATH 310 Random Processes and Applications
The Department of Mathematics offers graduate programs leading to the degrees of master of science in mathematics, applied mathematics, or statistics, and the doctor of philosophy in mathematics or applied mathematics.

The Department does not offer a doctorate in statistics. However, students may choose statistics or mathematical statistics as a concentration in the doctor of philosophy programs in mathematics and applied mathematics. The Department is a part of the interdisciplinary program in Analytical Finance. For details on the Master of Science in Analytical Finance see the Interdisciplinary Graduate Study and Research, Analytical Finance section.

To begin graduate work in mathematics a student must present evidence of adequate undergraduate preparation. The undergraduate program should have included a year of advanced calculus, a semester of linear algebra, and a semester of abstract algebra.

**M.S. in Mathematics or Applied Mathematics**

The master's program requires 30 credit hours of graduate courses with at least 18 hours at the 400 level. With the permission of the chairperson, up to six hours of these courses can be replaced by approved undergraduate courses. All students in the master's program must also pass a comprehensive examination. The M.S. degree can serve both as a final degree in mathematics or as an appropriate background for the Ph.D. degree.

**M.S. in Statistics**

This program requires 30 credit hours of graduate courses with at least 18 hours of 400-level STAT or MATH courses. The choice of courses must be approved by the graduate advisor, and up to six hours of coursework may be replaced with a thesis. All students in the program must also pass a comprehensive examination.

The M.S. program in statistics has two tracks:

**Statistics Track**

The statistics track has recommended courses:

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH 309</td>
<td>Theory of Probability</td>
<td>3</td>
</tr>
<tr>
<td>STAT 412</td>
<td>Statistical Computing and Applications</td>
<td>3</td>
</tr>
<tr>
<td>STAT 434</td>
<td>Mathematical Statistics</td>
<td>3</td>
</tr>
<tr>
<td>MATH 462</td>
<td>Modern Nonparametric Methods in Statistics</td>
<td>3</td>
</tr>
</tbody>
</table>

**Electives**

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>STAT 410</td>
<td>Random Processes and Applications</td>
<td>3</td>
</tr>
<tr>
<td>STAT 438</td>
<td>Linear Models in Statistics with Applications</td>
<td>3</td>
</tr>
<tr>
<td>STAT 461</td>
<td>Topics In Mathematical Statistics</td>
<td>3</td>
</tr>
<tr>
<td>STAT 408</td>
<td>Seminar in Statistics and Probability</td>
<td>3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
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</thead>
<tbody>
<tr>
<td>ISE 332</td>
<td>Product Quality</td>
<td>3</td>
</tr>
<tr>
<td>ISE 409</td>
<td>Time Series Analysis</td>
<td>3</td>
</tr>
<tr>
<td>ISE 410</td>
<td>Design of Experiments</td>
<td>3</td>
</tr>
<tr>
<td>ECO 460</td>
<td>Time Series Analysis</td>
<td>3</td>
</tr>
<tr>
<td>ECO 463</td>
<td>Topics in Game Theory</td>
<td>3</td>
</tr>
<tr>
<td>CSE 411</td>
<td>Advanced Programming Techniques</td>
<td>3</td>
</tr>
<tr>
<td>MECH 445</td>
<td>Nondeterministic Models in Engineering</td>
<td>3</td>
</tr>
</tbody>
</table>

**Total Credits: 30**

For information on examinations of actuarial societies, students may consult their minor advisor.

**Ph.D. in Mathematics**

The plan of work toward the doctor of philosophy degree will include a comprehensive examination, a qualifying examination, and an advanced topic examination. A language examination may be required at the discretion of the department committee. General examination, the doctoral dissertation and its defense complete the work for the Ph.D. degree.

Each candidate's plan of work must be approved by a special committee of the department. A Ph.D. student is required to have 18 credits of approved graduate level course work beyond the master's level. Successful completion of MATH 316 and MATH 307 is required of all students. After completion of 18 credits a student is required to take at least one course per academic year other than MATH 409, MATH 410, and MATH 499.

**Ph.D. in Applied Mathematics**

The plan of work toward the doctor of philosophy degree will include a comprehensive examination, a qualifying examination, and an advanced topic examination. A language examination may be required at the discretion of the department committee. The Ph.D. in Applied Mathematics qualifying examination tests the student's command of Statistics and Applied Probability or of Real Analysis and Differential Equations. The content of the advanced topic examination...
is determined by a department committee. A general examination, the doctoral dissertation and its defense complete the work for the Ph.D. degree.

Each candidate's plan of work must be approved by a special committee of the department. A Ph.D. student is required to have 18 credits of approved graduate level course work beyond the master's level. After completion of 18 credits a student is required to take at least one course per academic year other than MATH 409, MATH 410, and MATH 499.

Mathematics Courses

**MATH 000 Preparation for Calculus 2 Credits**
Intensive review of fundamental concepts in mathematics utilized in calculus, including functions and graphs, exponentials and logarithms, and trigonometry. This course is for students who need to take MATH 51 or 21, but who require remediation in precalculus. In particular, students who fail the MATH 51 Readiness Exam must pass MATH 0 before being admitted to MATH 51. The credits for this course do not count toward graduation, but do count toward GPA and current credit count. Consent of department required.

**Attribute/Distribution:** MA

**MATH 005 Introduction to Mathematical Thought 3 Credits**
Meaning, content, and methods of mathematical thought illustrated by topics that may be chosen from number theory, abstract algebra, combinatorics, finite or non-Euclidean geometries, game theory, mathematical logic, set theory, topology.

**Attribute/Distribution:** MA

**MATH 009 Introduction to Finite Mathematics 4 Credits**
Systems of linear equations, matrices, introduction to linear programming. Sets, counting methods, probability, random variables, introduction to Markov chains.

**Attribute/Distribution:** MA

**MATH 012 Basic Statistics 4 Credits**
A first course in the basic concepts and methods of statistics with illustrations from the social, behavioral, and biological sciences. Descriptive statistics; frequency distributions, mean and standard deviation, two-way tables, correlation and regression; random sampling, rules of probability, probability distributions and parameters, parameter estimation, confidence intervals, hypothesis testing, statistical significance. Note: Mathematics and Statistics majors may not receive credit for both MATH 012 & ECO 045.

**Attribute/Distribution:** MA

**MATH 021 Calculus I 4 Credits**
Functions and graphs; limits and continuity; derivative, differential, and applications; indefinite and definite integrals; trigonometric, logarithmic, exponential, and hyperbolic functions.

**Attribute/Distribution:** MA

**MATH 022 Calculus II 4 Credits**
Applications of integration; techniques of integration; separable differential equations; infinite sequences and series; Taylor's Theorem and other approximations; curves and vectors in the plane.

**Prerequisites:** MATH 021 or MATH 076 or MATH 031 or MATH 097

**Attribute/Distribution:** MA

**MATH 023 Calculus III 4 Credits**
Vectors in space; partial derivatives; Lagrange multipliers; multiple integrals; vector analysis; line integrals; Green's Theorem, Gauss's Theorem.

**Prerequisites:** MATH 022 or MATH 096 or MATH 032

**Attribute/Distribution:** MA

**MATH 031 Honors Calculus I 4 Credits**
Same topics as in MATH 021, but taught from a more thorough and rigorous point of view.

**Attribute/Distribution:** MA

**MATH 032 Honors Calculus II 4 Credits**
Same topics as in MATH 022, but taught from a more thorough and rigorous point of view.

**Prerequisites:** (MATH 031)

**Attribute/Distribution:** MA

**MATH 033 Honors Calculus III 4 Credits**
Same topics as in MATH 023, but taught from a more thorough and rigorous point of view.

**Attribute/Distribution:** MA

**MATH 043 Survey of Linear Algebra 3 Credits**
Matrices, vectors, vector spaces and mathematical systems, special kinds of matrices, elementary matrix transformations, systems of linear equations, convex sets, introduction to linear programming.

**Attribute/Distribution:** MA

**MATH 051 Survey of Calculus I 4 Credits**
Limits. The derivative and applications to extrema, approximation, and related rates. Exponential and logarithm functions, growth and decay. Integration. Trigonometric functions and related derivatives and integrals.

**Attribute/Distribution:** MA

**MATH 052 Survey of Calculus II 3 Credits**

**Prerequisites:** MATH 051 or MATH 021 or MATH 031 or MATH 076 or MATH 097 or MATH 081

**Attribute/Distribution:** MA

**MATH 075 Calculus I, Part A 2 Credits**
Continuation of MATH 075, covering the second half of MATH 021. Meets three hours per week, allowing more class time for each topic than does MATH 021.

**Attribute/Distribution:** MA

**MATH 076 Calculus I, Part B 2 Credits**
Continuation of MATH 075, covering the second half of MATH 021. Meets three hours per week. Final exam for this course is similar to the MATH 021 final.

**Prerequisites:** MATH 075

**Attribute/Distribution:** MA

**MATH 081 Calculus with Business Applications 4 Credits**
Limits and continuity; exponential, logarithmic and trigonometric functions; derivatives; extrema; approximations; indefinite and definite integrals. Applications with emphasis on business and economics.

**Attribute/Distribution:** MA

**MATH 114 (PHIL 114) Symbolic Logic 4 Credits**
A first course in logical theory, introducing the notions of logical consequence and proof, as well as related concepts such as consistency and contingency. Formal systems taught may include: term, sentence logic, and predicate logic.

**Attribute/Distribution:** MA

**MATH 130 (BIOS 130) Biostatistics 4 Credits**
Elements of statistics and probability with emphasis on biological applications. Statistical analysis of experimental and observational data.

**Prerequisites:** MATH 052 or MATH 002

**MATH 163 Introductory Seminar 3 Credits**
An introduction to the discipline of mathematics designed for students considering a major in mathematics. The course will provide an introduction to rigorous mathematical reasoning and will survey some area of mathematics. Topics covered will vary.

**Attribute/Distribution:** MA

**MATH 171 Readings 1-3 Credits**
Study of a topic in mathematics under individual supervision. Intended for students with specific interests in areas not covered in the listed courses. Consent of department chair required.

**Attribute/Distribution:** MA

**MATH 201 Problem Solving 1 Credit**
Practice in solving problems from mathematical contests using a variety of techniques. Permission of instructor required.

**Repeat Status:** Course may be repeated.

**Attribute/Distribution:** MA
MATH 202 Actuarial Exam I 1 Credit
Preparation for the first actuarial exam – probability. Problems in calculus and probability with insurance applications.
Prerequisites: (MATH 023 or MATH 033) and (MATH 231)
Attribute/Distribution: MA

MATH 203 Actuarial Exam II - Financial Mathematics 2 Credits
Preparation for the second actuarial exam - financial mathematics.
Mathematics of interest and investments, interest rate measurement, present value, annuities, loan repayment schemes, bond valuation, introduction to derivative securities. Practice in solving problems from past exams.
Prerequisites: MATH 022
Attribute/Distribution: MA

MATH 205 Linear Methods 3 Credits
Linear differential equations and applications; matrices and systems of linear equations; vector spaces; eigenvalues and application to linear systems of differential equations.
Prerequisites: MATH 022 or MATH 096 or MATH 032
Attribute/Distribution: MA

MATH 208 Complex Variables 3 Credits
Functions of a complex variable; calculus of residues; contour integration; applications to conformal mapping and Laplace transforms.
Prerequisites: MATH 023 or MATH 033
Attribute/Distribution: MA

MATH 214 (PHIL 214) Topics in Philosophical Logic 4 Credits
Topics may include the many systems of non-classical logic, truth theory, the impact of incompleteness and undecidability results on philosophy, the foundational projects of various philosophers/mathematicians, or the work of an important figure in the history of philosophical logic. Consent of instructor required.
Repeat Status: Course may be repeated.
Attribute/Distribution: MA

MATH 229 Geometry 3-4 Credits
Discussion of geometry as an axiomatic system. Euclid's postulates. History of and equivalent versions of Euclid's fifth postulate. Finite projective geometries. Non-Euclidean geometries based upon negation of the fifth postulate: Geometry on the sphere; Hyperbolic and elliptic geometries. Examination of the concepts of “straight”, angle, parallel, symmetry and duality in each of these geometries. Applications of the different geometries will be considered.
Attribute/Distribution: MA

MATH 230 Numerical Methods 3 Credits
Representation of numbers and rounding error; polynomial and spline interpolation; numerical differentiation and integration; numerical solution of nonlinear systems; Fast Fourier Transformation; numerical solution of initial and boundary value problems; Monte Carlo methods.
Knowledge of MATLAB or PYTHON or C required.
Prerequisites: MATH 205
Attribute/Distribution: MA

MATH 231 Probability and Statistics 3 Credits
Probability and distribution of random variables; populations and random sampling; chisquare and t distributions; estimation and tests of hypotheses; correlation and regression theory of two variables.
Prerequisites: MATH 022 or MATH 096 or MATH 032 or MATH 052
Attribute/Distribution: MA

MATH 234 Algebra 3,4 Credits
Introduction to basic concepts of modern algebra: groups, rings, and fields.
Prerequisites: (MATH 163 or MATH 261 or CSE 261) and (MATH 242 or MATH 205)
Attribute/Distribution: MA

MATH 261 (CSE 261) Discrete Structures 3 Credits
Topics in discrete mathematical structures chosen for their applicability to computer science and engineering. Sets, propositions, induction, recursion; combinatorics; binary relations and functions; ordering, lattices and Boolean algebra; graphs and trees; groups and homomorphisms.
Prerequisites: (MATH 021 or MATH 031 or MATH 076)
Attribute/Distribution: MA

MATH 271 Readings 1-3 Credits
Study of a topic in mathematics under individual supervision. Intended for students with specific interests in areas not covered in the listed courses. Consent of department chair required.
Repeat Status: Course may be repeated.
Attribute/Distribution: MA

MATH 301 Principles of Analysis I 3-4 Credits
Continuation of MATH 301. Functions of several variables; the implicit function theorem, and further topics with applications to analysis and geometry.
Prerequisites: MATH 301
Attribute/Distribution: MA

MATH 302 Principles of Analysis II 3-4 Credits
Continuation of MATH 301. Functions of several variables; the implicit function theorem, and further topics with applications to analysis and geometry.
Prerequisites: MATH 301
Attribute/Distribution: MA

MATH 303 (PHIL 303) Mathematical Logic 3-4 Credits
Detailed proofs are given for the basic mathematical results relating the syntax and semantics of firstorder logic (predicate logic): the Soundness and Completeness (and Compactness) Theorems, followed by a brief exposition of the celebrated limitative results of Gödel, Turing, and Church on incompleteness and undecidability. The material is conceptually rigorous and mathematically mature; the necessary background is a certain degree of mathematical sophistication or a basic knowledge of symbolic logic. Consent of instructor required.
Attribute/Distribution: MA

MATH 304 Axiomatic Set Theory 3-4 Credits
A development of set theory from axioms; relations and functions; ordinal and cardinal arithmetic; recursion theorem; axiom of choice; independence questions. Consent of instructor required.
Attribute/Distribution: MA

MATH 305 Enumerative Combinatorics 3 Credits
An introduction to basic theoretical results and techniques of enumerative combinatorics such as combinatorial identities, generating functions, inclusion/exclusion, recurrence relations, bijective proofs and permutations. Additional topics will be covered as time permits.
Prerequisites: MATH 242 and (MATH 163 or MATH 261 or CSE 261)
Attribute/Distribution: MA
MATH 306 Introduction to Biomedical Engineering and Mathematical Biology 3 Credits
Prerequisites: MATH 205
Attribute/Distribution: MA

MATH 307 General Topology I 3-4 Credits
An introductory study of topological spaces, including metric spaces, separation and countability axioms, connectedness, compactness, product spaces, quotient spaces, function spaces.
Prerequisites: MATH 301
Attribute/Distribution: MA

MATH 309 Theory of Probability 3 Credits
Probabilities of events on discrete and continuous sample spaces; random variables and probability distributions; expectations; transformations; simplest kind of law of large numbers and central limit theorem. The theory is applied to problems in physical and biological sciences.
Prerequisites: MATH 023 or MATH 033 or MATH 052
Attribute/Distribution: MA

MATH 310 Random Processes and Applications 3-4 Credits
Prerequisites: MATH 309 or MATH 231
Attribute/Distribution: MA

MATH 311 Graph Theory 3 Credits
An introduction to basic theoretical results and techniques of graph theory such as trees, connectivity, matchings, coloring, planar graphs and Hamiltonicity. Additional topics will be covered as time permits.
Prerequisites: MATH 163 or MATH 261
Attribute/Distribution: MA

MATH 312 Statistical Computing and Applications 3-4 Credits
Use of statistical computing packages; exploratory data analysis; Monte Carlo methods; randomization and resampling, application and interpretation of a variety of statistical methods in real world problems.
Prerequisites: MATH 012 or MATH 231
Attribute/Distribution: MA

MATH 316 Complex Analysis 3-4 Credits
Concept of analytic function from the points of view of the CauchyRiemann equations, power series, complex integration, and conformal mapping.
Prerequisites: MATH 301
Attribute/Distribution: MA

MATH 320 Ordinary Differential Equations 3-4 Credits
The analytical and geometric theory of ordinary differential equations, including such topics as linear systems, systems in the complex plane, oscillation theory, stability theory, geometric theory of nonlinear systems, finite difference methods, general dynamical systems.
Prerequisites: MATH 205 or (MATH 242 and (MATH 023 or MATH 033).)
Attribute/Distribution: MA

MATH 321 Topics in Discrete Mathematics 3 Credits
Selected topics in areas of discrete mathematics. Consent of department chair required.
Repeat Status: Course may be repeated.
Attribute/Distribution: MA

MATH 322 Methods of Applied Analysis I 3 Credits
Fourier series, eigenfunction expansions, Sturm-Liouville problems, Fourier integrals and their application to partial differential equations; special functions. Emphasis is on a wide variety of formal applications rather than logical development.
Prerequisites: MATH 205
Attribute/Distribution: MA

MATH 323 Methods of Applied Analysis II 3 Credits
Green's functions; integral equations; variational methods; asymptotic expansions, method of saddle points; calculus of vector fields, exterior differential calculus.
Prerequisites: MATH 322
Attribute/Distribution: MA

MATH 327 Groups and Rings 3-4 Credits
An intensive study of the concepts of group theory including the Sylow theorems, and of ring theory including unique factorization domains and polynomial rings.
Prerequisites: MATH 242 and MATH 243
Attribute/Distribution: MA

MATH 329 Computability Theory 3-4 Credits
Core development of classical computability theory: enumeration, index and recursion theorems, various models of computation and Church's Thesis, uncomputability results, introduction to reducibilities and their degrees (in particular, Turing degrees, or degrees of uncomputability), computable operators and their fixed points.
Attribute/Distribution: MA

MATH 331 Differential Geometry of Curves and Surfaces 3 Credits
Local and global differential geometry of curves and surfaces in Euclidean 3space. Frenet formulas for curves, isoperimetric inequality, 4vertex theorem; regular surfaces, first fundamental form, Gauss map, second fundamental form; curvatures for curves and surfaces and their relations; The GaussBonnet theorem.
Prerequisites: MATH 023 or MATH 033
Attribute/Distribution: MA

MATH 334 Mathematical Statistics 3-4 Credits
Populations and random sampling; sampling distributions; theory of statistical estimation; criteria and methods of point and interval estimation; theory of testing statistical hypotheses.
Prerequisites: MATH 309
Attribute/Distribution: MA

MATH 338 Linear Models in Statistics with Applications 3-4 Credits
Least square principles in multiple regression and their interpretations; estimation, hypotheses testing, confidence and prediction intervals, modeling, regression diagnostic, multicollinearity, model selection, analysis of variance and covariance; logistic regression. Introduction to topics in time series analysis such as ARMA, ARCH, and GARCH models. Applications to natural sciences, finance and economics. Use of computer packages.
Prerequisites: (MATH 012 or MATH 231) and (MATH 043 or MATH 205 or MATH 242)
Attribute/Distribution: MA

MATH 340 (CSE 340) Design and Analysis of Algorithms 3 Credits
Algorithms for searching, sorting, manipulating graphs and trees, finding shortest paths and minimum spanning trees, scheduling tasks, etc.: proofs of their correctness and analysis of their asymptotic runtime and memory demands. Designing algorithms: recursion, divide-and-conquer, greediness, dynamic programming. Limits on algorithm efficiency using elementary NP-completeness theory. Credit will not be given for both MATH 340 (CSE 340) and MATH 441 (CSE 441).
Prerequisites: (MATH 022 or MATH 096 or MATH 032) and (CSE 261 or MATH 261)

MATH 341 Mathematical Models and Their Formulation 3 Credits
Mathematical modeling of engineering and physical systems with examples drawn from diverse disciplines. Emphasis is on building models of real world problems rather than learning mathematical techniques.
Prerequisites: MATH 205
Attribute/Distribution: MA
MATH 342 Number Theory 3-4 Credits
Basic concepts and results in number theory, including such topics as primes, the Euclidean algorithm, Diophantine equations, congruences, quadratic residues, quadratic reciprocity, primitive roots, number-theoretic functions, distribution of primes, Pell’s equation, Fermat’s theorem, partitions. Consent of instructor required.

Attribute/Distribution: MA

MATH 343 Introduction To Cryptography 3,4 Credits
Classical elementary cryptography: Caesar cipher, other substitution ciphers, block ciphers, general linear ciphers. Fast random encryption (DES and AES: Advanced Encryption Standard); Public key systems (RSA and discrete logs). Congruences, modular arithmetic, fast exponentiation, polynomials, matrices. Distinction between polynomial time (primality), Subexponential time (factoring) and fully Exponential computation (elliptic curves). Introduction to sieving and distributed computation. Consent of instructor required.

Attribute/Distribution: MA

MATH 350 Special Topics 3 Credits
A course covering special topics not sufficiently covered in listed courses. Consent of department chair required.
Repeat Status: Course may be repeated.

MATH 371 Readings 1-3 Credits
The study of a topic in mathematics under appropriate supervision, designed for the individual student who has studied extensively and whose interests lie in areas not covered in the listed courses. Consent of department chair required.
Repeat Status: Course may be repeated.

MATH 374 Statistical Project 3 Credits
 Supervised field project or independent reading in statistics or probability. Consent of department chair required.
Attribute/Distribution: MA

MATH 391 Senior Honors Thesis 3 Credits
Independent research under faculty supervision, culminating in a thesis presented for departmental honor. Consent of department chair required.
Repeat Status: Course may be repeated.

MATH 404 Topics in Mathematical Logic 3 Credits
Field theory, including an introduction to Galois theory; the theory of fields and differential forms, de Rham cohomology, Stokes’ theorem, the Hodge theorem. Must have completed MATH 301, or MATH 243 or MATH 205 with permission of instructor.

MATH 405 Partial Differential Equations I 3-4 Credits
Continuation of MATH 404. Emphasis on second order equations with variable coefficients and systems of first order partial differential equations.
Prerequisites: MATH 405

MATH 406 Partial Differential Equations II 3 Credits
 Continuation of MATH 405. Emphasis on second order equations with variable coefficients and systems of first order partial differential equations.
Prerequisites: MATH 405

MATH 408 Algebraic Topology I 3 Credits
Polyhedra; fundamental groups; simplicial and singular homology.

MATH 409 Mathematics Seminar 1-6 Credits
An intensive study of some field of mathematics not offered in another course. Consent of department chair required.

MATH 410 Mathematics Seminar 1-6 Credits
Continuation of the field of study in MATH 409 or the intensive study of a different field. Consent of department chair required.

MATH 416 Complex Function Theory 3 Credits
Continuation of MATH 316.
Prerequisites: MATH 316

MATH 421 Introduction To Wavelets 3 Credits
Continuous and discrete signals; review of Fourier analysis; discrete wavelets; time frequency spaces; Haar and Walsh systems; multiresolution analysis; Hilbert spaces; quadratic mirror filters; fast wavelet transforms; computer code; applications to filtering, compression, and imaging.
Prerequisites: ECE 108 or MATH 205

MATH 423 Differential Geometry I 3 Credits
Differential manifolds, tangent vectors and differentials, submanifolds and the implicit function theorem. Lie groups and Lie algebras, homogeneous spaces. Tensor and exterior algebra, tensor fields and differential forms, de Rham cohomology, Stokes’ theorem, the Hodge theorem. Must have completed MATH 301, or MATH 243 or MATH 205 with permission of instructor.

MATH 424 Differential Geometry II 3 Credits
Curves and surfaces in Euclidean space; mean and Gaussian curvatures, covariant differentiation, parallelism, geodesics, GaussBonnet formula. Riemannian metrics, connections, sectional curvature, generalized GaussBonnet theorem. Further topics.
Prerequisites: MATH 423

MATH 425 Fields And Modules 3 Credits
Continuation of the field of study in MATH 409 or the intensive study of a different field. Consent of department chair required.

MATH 426 Functional Analysis I 3 Credits
Continuation of MATH 425. Emphasis on second order equations with variable coefficients and systems of first order partial differential equations.
Prerequisites: MATH 405

MATH 427 Functional Analysis II 3 Credits
Continuation of MATH 426. Emphasis on second order equations with variable coefficients and systems of first order partial differential equations.
Prerequisites: MATH 405

MATH 428 Fields And Modules 3 Credits
Field theory, including an introduction to Galois theory; the theory of modules, including tensor products and classical algebras.
Prerequisites: MATH 327

MATH 430 Numerical Analysis 3 Credits
Multistep methods for ordinary differential equations; finite difference methods for partial differential equations; numerical approximation of functions. Use of computer required.
Prerequisites: MATH 230

MATH 435 Functional Analysis I 3 Credits
Banach spaces and linear operators; separation and extension theorems; open mapping and uniform boundedness principle; weak topologies; local convexity and duality; Banach algebras; spectral theory of operators; and compact operators.
Prerequisites: MATH 307 and MATH 401

MATH 441 (CSE 441) Advanced Algorithms 3 Credits
Algorithms for searching, sorting, manipulating graphs and trees, scheduling tasks, finding shortest path, matching patterns in strings, cryptography, matroid theory, linear programming, max-flow, etc., and their correctness proofs and analysis of their time and space complexity. Strategies for designing algorithms, e.g. recursion, divide-and-conquer, greediness, dynamic programming. Limits on algorithm efficiency are explored through NP completeness theory. Quantum computing is briefly introduced. Credit will not be given for both CSE 340 (MATH 340) and CSE 441 (MATH 441).

MATH 444 Algebraic Topology II 3 Credits
Continuation of MATH 408. Cohomology theory, products, duality.
Prerequisites: MATH 408

MATH 445 Topcs in Algebraic Topology 3 Credits
Selected topics reflecting the interests of the professor and the students.
Prerequisites: MATH 444
MATH 449 Topics In Algebra 3 Credits
Intensive study of topics in algebra with emphasis on recent developments. Consent of department chair required.
Repeat Status: Course may be repeated.

MATH 450 Special Topics 3 Credits
Intensive study of some field of the mathematical sciences not covered in listed courses. Consent of department chair required.
Repeat Status: Course may be repeated.

MATH 455 Topics In Number Theory 3 Credits
Selected topics in algebraic and/or analytic number theory. Consent of instructor required.
Repeat Status: Course may be repeated.
Prerequisites: MATH 334 and MATH 401

MATH 460 Modern Nonparametric Methods in Statistics 3 Credits
Classical and modern methods of nonparametric statistics; order and rank statistics; tests based on runs, signs, ranks, and order statistics; distribution free statistical procedures for means, variances, correlations, and trends; relative efficiency; Kolmogorov-Smirnov statistics; statistical applications of Brownian process; modern techniques such as robust methods, nonparametric smoothing, and bootstrapping; additional topics such as nonparametric regression and dimension reduction.
Prerequisites: (MATH 334 or STAT 334) and (MATH 338 or STAT 338)

MATH 463 (STAT 463) Advanced Probability 3 Credits
Measure theoretic foundations; random variables, integration in a measure space, expectations; convergence of random variables and probability measures; conditional expectations; characteristic functions; sums of random variables, limit theorems.
Prerequisites: MATH 309 and MATH 401

MATH 464 Advanced Stochastic Process 3 Credits
Theory of stochastic processes; stopping times; martingales; Markov processes; Brownian motion; stochastic calculus; Brownian bridge, laws of suprema; Gaussian processes.
Prerequisites: MATH 309 and MATH 401

MATH 465 Topics In Probability 3 Credits
Selected topics in probability. Consent of department chair required.
Repeat Status: Course may be repeated.

MATH 466 Financial Calculus 3 Credits
Basic mathematical concepts behind derivative pricing and portfolio management of derivative securities. Development of hedging and pricing by arbitrage in the discrete time setting of binary trees and Black-Scholes model. Introduction to the theory of Stochastic Calculus, Martingale representation theorem, and change of measure. Applications of the developed theory to a variety of actual financial instruments.
Prerequisites: MATH 231 or MATH 309

MATH 467 Financial Calculus II 3 Credits
Models and mathematical concepts behind interest rates markets. Heath-Jarrow-Morton model for random evolution of the term structure of interest rates and short rate models. Applications of the theory to a variety of interest rates contracts including swaps, caps, floors, swaptions. Development of multidimensional stochastic calculus and applications to multiple stock models, quants, and foreign currency interestrate models.
Prerequisites: MATH 467

MATH 470 Proseminar 3 Credits
Preparation for entering the mathematics profession. Seminar will concentrate on methods of teaching mathematics, and will include other topics such as duties of a professor and searching for a job. Consent of department chair required.

MATH 471 Homological Algebra 3 Credits
Modules, tensor products, categories and functors, homology functors, projective and injective modules.
Prerequisites: MATH 428

MATH 472 Group Representations 3 Credits
Linear representations and character theory with emphasis on the finite and compact cases.
Prerequisites: MATH 428

MATH 473 Topics In Geometry 3 Credits
Selected topics in geometry, such as geometric analysis, algebraic geometry, complex geometry, characteristic classes, geometric flows or geometric measure theory, with emphasis on recent developments. Consent of department chair required.
Repeat Status: Course may be repeated.

MATH 480 Topics In Financial Mathematics 3 Credits
Selected topics in financial mathematics. Consent of department chair required.
Repeat Status: Course may be repeated.

MATH 490 Thesis 1-6 Credits
Repeat Status: Course may be repeated.

Statistics Courses

STAT 342 Linear Algebra 3 Credits
Solution of systems of linear equations, matrices, vector spaces, bases, linear transformations, eigenvalues, eigenvectors, additional topics as time permits. Restricted to graduate students in the MS in Statistics program. Prerequisites as noted below or consent of instructor. Credit may not be received for both MATH 242 and STAT 342.

STAT 408 Seminar in Statistics and Probability 1-6 Credits
Intensive study of some field of statistics or probability not offered in another course. Consent of department required.

STAT 409 Seminar in Statistics and Probability 1-6 Credits
Intensive study of some field of statistics or probability not offered in another course. Consent of department required.

STAT 410 Random Processes and Applications 3 Credits
See MATH 310.

STAT 412 Statistical Computing and Applications 3 Credits
See MATH 312.

STAT 434 Mathematical Statistics 3 Credits
See MATH 334.

STAT 438 Linear Models in Statistics with Applications 3 Credits
See MATH 338.
Prerequisites: (MATH 012 or MATH 231) and (MATH 043 or MATH 205 or MATH 242)

STAT 461 Topics In Mathematical Statistics 3 Credits
See MATH 461.

STAT 462 Modern Nonparametric Methods in Statistics 3 Credits
See MATH 462.

STAT 463 (MATH 463) Advanced Probability 3 Credits
Intensive study of some field of statistics or probability not offered in another course. Consent of department required.

STAT 464 Advanced Stochastic Processes 3 Credits
See MATH 464.

STAT 465 Topics In Probability 3 Credits
Selected topics in probability. Consent of department chair required.
Repeat Status: Course may be repeated.

STAT 466 Financial Calculus 3 Credits
Basic mathematical concepts behind derivative pricing and portfolio management of derivative securities. Development of hedging and pricing by arbitrage in the discrete time setting of binary trees and Black-Scholes model. Introduction to the theory of Stochastic Calculus, Martingale representation theorem, and change of measure. Applications of the developed theory to a variety of actual financial instruments.
Prerequisites: MATH 231 or MATH 309

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Prerequisites: MATH 467

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Prerequisites: MATH 428

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Prerequisites: MATH 428

STAT 473 Topics In Geometry 3 Credits
Selected topics in geometry, such as geometric analysis, algebraic geometry, complex geometry, characteristic classes, geometric flows or geometric measure theory, with emphasis on recent developments. Consent of department chair required.
Repeat Status: Course may be repeated.

STAT 480 Topics In Financial Mathematics 3 Credits
Selected topics in financial mathematics. Consent of department chair required.
Repeat Status: Course may be repeated.

STAT 490 Thesis 1-6 Credits
Repeat Status: Course may be repeated.

Mathematics 9