## MATHEMATICS

## Undergraduate Study

The program in mathematics offers training for students planning to enter secondary education teaching, to work in mathematics and computation for industry, or to continue their studies in graduate school. Students may satisfy the major requirements in several ways, which are designed to meet these various career objectives. Graduates will understand a broad range of mathematical topics, acquire skills for solving problems in diverse situations, and they will be able to construct and effectively communicate rigorous arguments to demonstrate mathematical facts.

## Curriculum

All students are required to earn credit for the following core courses:

| MATH 101 | Orientation in Mathematics | 1 |
| :--- | :--- | ---: |
| MATH 165 | Calculus I | 4 |
| MATH 166 | Calculus II | 4 |
| MATH 201 | Introduction to Proofs | 3 |
| MATH 265 | Calculus III | 4 |
| One of the following: | $3-4$ |  |
| MATH 317 | Theory of Linear Algebra |  |
| MATH 407 | Applied Linear Algebra |  |

Total Credits
19-20

To complete the major, leading to a Bachelor of Science degree, students must choose from one of the following four pathways:

## Mathematics Major

This degree program is designed for students planning to work in industry or those who plan to continue their studies mathematics at the graduate level. Students are required to earn credit for the following courses:

| One of the following: | $3-4$ |  |
| :--- | :--- | ---: |
| MATH 266 | Elementary Differential Equations |  |
| MATH 267 | Elementary Differential Equations and Laplace |  |
|  | Transforms | 3 |
| MATH 301 | Abstract Algebra I | 3 |
| MATH 414 | Analysis I | 2 |
| MATH 492 | Undergraduate Seminar | 15 |
| Additional MATH courses at the 300, 400, or 500 level |  |  |

$\begin{array}{ll}\text { Total Credits } & \text { 26-27 }\end{array}$
Additionally, the courses must include one of the following sequences:

| MATH 301 | Abstract Algebra I | 6 |
| :--- | :--- | :---: |
| \& MATH 403X | Intermediate Abstract Algebra |  |
| MATH 304 | Combinatorics | 6 |
| \& MATH 314 | and Graph Theory |  |
| MATH 373 | Introduction to Scientific Computing | 6 |
| \& MATH 481 | and Numerical Methods for Differential Equations |  |
| MATH 414 | Analysis I | 6 |
| \& MATH 415 | and Analysis II |  |
| MATH 435 | Geometry I | 6 |
| \& MATH 436 | and Geometry II |  |

## Mathematics Major with Actuarial Science Certificate

This degree program is designed for students pursuing a career as an actuary or in the financial sector. Students are required to earn credit for the following courses:

| MATH 240 | Mathematics of Investment and Credit | 3 |
| :--- | :--- | ---: |
| MATH 341 | Introduction to the Theory of Probability and | 4 |
|  | Statistics I |  |
| MATH 414 | Analysis I | 3 |
| MATH 441 | Life Contingencies I | 3 |
| MATH 442 | Life Contingencies II | 3 |
| MATH 492 | Undergraduate Seminar | 2 |
| Total Credits |  | $\mathbf{1 8}$ |

Additionally, students must meet the requirements for the Actuarial Science Certificate (see /collegeofbusiness/actuarialscience/ \#certificatetext (http://catalog.iastate.edu/previouscatalogs/2020-2021/ collegeofbusiness/actuarialscience/\#certificatetext)).

## Mathematics Major with Applications

This degree program is for students who want to specialize in the application of mathematics to an area of study. It is recommended for those who plan to work in industry or those who plan to continue studying their specialization area at the graduate level. Students are required to earn credit for the following courses:

| One of the following: |
| :--- |
| MATH 266 | | Elementary Differential Equations | $3-4$ |
| :--- | :--- |
| MATH 267 | Elementary Differential Equations and Laplace <br> Transforms |
| One of the following: |  |
| MATH 304 | Combinatorics |
| MATH 314 | Graph Theory |
| Three of the following: | 9 |

MATH 301 Abstract Algebra I

| MATH 341 | Introduction to the Theory of Probability and <br> Statistics I |
| :--- | :--- | :--- |
| MATH 350 | Number Theory |
| MATH 365 | Complex Variables with Applications |
| MATH 373 | Introduction to Scientific Computing |
| MATH 385 | Introduction to Partial Differential Equations |
| MATH 414 | Analysis I |
| MATH 424 | Introduction to High Performance Computing |
| MATH 481 | Numerical Methods for Differential Equations |
| MATH 492 | Undergraduate Seminar |
| Courses at the 300, 400, or 500 level from the following designations: | 12 |
| AER E, A B E, ASTRO, BBMB, BCB, BCBIO, BIOL, B M E, B M S, CH E, |  |
| CHEM, C E, CPR E, COM S, CON E, DS, ECON, E E, E M, ENSCI, GEN, |  |
| GEOL, I E, MAT E, M E, MTEOR, MICRO, NUC E, PHIL, PYSCH, PHYS, S |  |
| E, SOC, STAT |  |

Total Credits
29-31

## Mathematics Major for Teacher Preparation

This degree program prepares students for a career in secondary education. Students are required to earn credit for the following courses:

| One of the following: |  | 3-4 |
| :---: | :---: | :---: |
| COM S 107 | Windows Application Programming |  |
| COM S 207 | Fundamentals of Computer Programming |  |
| COM S 227 | Object-oriented Programming |  |
| EDUC 203 - Educational Technology Sequence |  | 1 |
| EDUC 204 | Social Foundations of Education in the United States: Secondary | 3 |
| EDUC 219 | Orientation to Teacher Education: FCS Education, History, Math and Science Majors | 1 |
| EDUC 280A | Pre-Student Teaching Experience I: Core Experience | 1-2 |
| EDUC 280J | Pre-Student Teaching Experience I: Mathematics Clinic | 1 |
| EDUC 303 - Educational Technology Sequence |  | 1 |
| EDUC 395 | Teaching Disciplinary Literacy | 3 |
| EDUC 403 - Educational Technology Sequence |  | 1 |
| EDUC 406 | Social Justice Education and Teaching: Secondary | 3 |
| EDUC 417C | Student Teaching: Mathematics | rr |
| EDUC 480C | Pre-Student Teaching Experience III: Mathematics0.5-2 |  |
| EDUC 513 | Mathematical Problem Solving in K-12 Classrooms | 3 |
| One of the following: |  | 3-4 |
| MATH 266 | Elementary Differential Equations |  |


| MATH 267 | Elementary Differential Equations and Laplace |  |
| :--- | :--- | :--- |
|  | Transforms |  |
| MATH 301 | Abstract Algebra I | 3 |
| MATH 341 | Introduction to the Theory of Probability and <br>  <br>  <br> MATH 397 <br>  <br>  <br>  <br>  <br> Statistics I <br> Teaching Secondary Mathematics Using University | 3 |
| Mathematics | 4 |  |
| MATH 414 | Analysis I | 3 |
| MATH 435 | Geometry I | 3 |
| MATH 436 | Geometry II | 3 |
| MATH 497 | Teaching Secondary School Mathematics | 3 |
| STAT 201 | Introduction to Statistical Concepts and Methods | 4 |
| SP ED 401 | Teaching Secondary Students with | 3 |
|  | Exceptionalities in General Education |  |

Total Credits 53.5-58

## † Arranged with instructor.

Additionally, students must meet the professional teaching education requirements established by the University Teacher Education Program (see http://education.iastate.edu/undergraduate-studies/secondaryeducation/)

## University and College Requirements

In addition to the core and pathway courses, students are also required to earn credit for the following courses:

| Courses from General Education Area I-Arts and Humanities ${ }^{1}$ |  | 12 |
| :---: | :---: | :---: |
| Courses from General Education Area IIB - Natural Sciences ${ }^{1}$ |  | 8 |
| Courses from General Education Area III - Social Sciences ${ }^{\text {1,2 }}$ |  | 9 |
| Courses meeting the international perspectives requirement ${ }^{3}$ |  | 3 |
| Courses meeting the U.S. diversity requirement ${ }^{3}$ |  | 3 |
| LIB 160 | Information Literacy | 1 |
| ENGL 150 | Critical Thinking and Communication | 3 |
| ENGL 250 | Written, Oral, Visual, and Electronic Composition ${ }^{4}$ | 3 |
| One of the following: ${ }^{5}$ |  | 3 |
| ENGL 302 | Business Communication |  |
| ENGL 303 | Free-Lance Writing for Popular Magazines |  |
| ENGL 305 | Creative Writing: Nonfiction |  |
| ENGL 309 | Proposal and Report Writing |  |
| ENGL 314 | Technical Communication |  |
| MATH 491 | Undergraduate Thesis ${ }^{6}$ |  |
| 1 Possible choices can be found here: https://las.iastate.edu/ students/academics/general-education/ |  |  |

Furthermore, students must earn a minimum of 120 credits, including a minimum of 45 credits at the 300 or 400 level, and including at least 8 credits in the major at the 300/400 level with a grade of $C$ or better. At least 55 of these credits must be earned at a four-year institution, and the last 32 credits must be earned at lowa State University. A maximum of 16 technical credits are allowed, and a maximum of 9 P-NP credits of free electives may apply. Students must also meet the LAS World Language requirement and have a minimum 2.00 ISU cumulative Grade Point Average.

## Undergraduate Minor

The department offers a minor in mathematics. All minors require at least 15 credits, including at least 6 credits in the courses numbered 300 or above taken at lowa State University. The minor must include at least 9 credits that are not used to meet any other department, college or university requirement. Students are required to earn credit for the following courses:

| MATH 201 | Introduction to Proofs | 3 |
| :---: | :---: | :---: |
| MATH 265 | Calculus III | 4 |
| One of the following: |  | 3-4 |
| MATH 266 | Elementary Differential Equations |  |
| MATH 267 | Elementary Differential Equations and Laplace Transforms |  |
| One of the following: |  | 3-4 |
| MATH 317 | Theory of Linear Algebra |  |
| MATH 407 | Applied Linear Algebra |  |
| One of the following: |  | 3-4 |
| MATH 301 | Abstract Algebra I |  |
| MATH 304 | Combinatorics |  |
| MATH 314 | Graph Theory |  |
| MATH 331 | Topology |  |
| MATH 341 | Introduction to the Theory of Probability and Statistics I |  |
| MATH 350 | Number Theory |  |
| MATH 365 | Complex Variables with Applications |  |


| MATH 373 | Introduction to Scientific Computing |  |
| :--- | :--- | :--- |
| MATH 414 | Analysis I |  |
| MATH 421 | Logic for Mathematics and Computer Science |  |
| MATH 435 | Geometry I |  |
| MATH 436 | Geometry II | $16-19$ |
| Total Credits |  |  |
| FOUr Year PlanS |  |  |
| Mathematics Major |  |  |


| Freshman |  |  |
| :--- | :---: | ---: |
| Fall | Credits Spring | Credits |
| MATH 101 | 1 MATH 166 | 4 |
| MATH 165 | 4 Arts \& Humanities Choice | 3 |
| ENGL 150 | 3 Natural Science Choice | 4 |
| LIB 160 | 1 Social Science Choice | 3 |
| Natural Science Choice | 4 | $\mathbf{1 4}$ |
| Electives | 3 |  |
|  | $\mathbf{1 6}$ |  |

## Sophomore

| Fall | Credits Spring | Credits |
| :--- | :---: | ---: |
| MATH 201 | 3 MATH 266 or 267 | $3-4$ |
| MATH 265 | 4 MATH 317 | 4 |
| Arts \& Humanities Choice | 3 ENGL 250 | 3 |
| Social Science Choice | 3 Social Science Choice | 3 |
| Electives | 3 | $13-14$ |
|  | 16 | Credits |
| Junior |  | 3 |
| Fall | Credits Spring | 3 |
| MATH Sequence Course I | 3 MATH Sequence Course II | 3 |
| MATH 301 or 414 | 3 Communication Choice | 3 |
| Arts \& Humanities Choice | 6 Electives/World Language | 6 |
| Electives/World Language | $\mathbf{1 5}$ | $\mathbf{1 5}$ |

## Senior

| Fall | Credits Spring | Credits |
| :--- | :---: | ---: |
| MATH 300+ | 3 MATH 300+ | 6 |
| MATH 492 | 2 Electives | 9 |
| Arts \& Humanities Choice | 3 |  |
| Electives | 6 | $\mathbf{1 5}$ |


| Mathematics Major with Actuarial Science Certificate |  |  |
| :--- | :---: | ---: |
| Freshman |  |  |
| Fall | Credits Spring | Credits |
| MATH 101 | 1 MATH 166 | 4 |
| MATH 165 | 4 ECON 102 | 3 |
| ENGL 150 | 3 STAT 226 | 3 |
| LIB 160 | 1 ACCT 284 | 3 |
| ECON 101 | 3 Electives | 3 |
| Electives | 3 | $\mathbf{1 6}$ |


| Sophomore |  |  |
| :--- | :---: | ---: |
| Fall | Credits Spring | Credits |
| MATH 201 | 3 MATH 240 | 3 |
| MATH 265 | 4 MATH 317 | 4 |
| FIN 301 | 3 ENGL 250 | 3 |
| Arts \& Humanities Choice | 3 FIN 320 | 3 |
| Electives | 3 Arts \& Humanities Choice | 3 |
|  | $\mathbf{1 6}$ | $\mathbf{1 6}$ |


| Junior |  |  |
| :--- | :---: | ---: |
| Fall | Credits Spring | Credits |
| STAT 341 | 4 FIN 424 | 3 |
| STAT 301 or 326 | $3-4$ STAT 342 | 4 |
| Natural Science Choice | 4 Communication Choice | 3 |
| Electives/World Language | 3 Natural Science Choice | 4 |
|  | Electives/World Language | 3 |
|  | $\mathbf{1 4 - 1 5}$ | $\mathbf{1 7}$ |


| Senior |  |  |
| :--- | :---: | ---: |
| Fall | Credits Spring | Credits |
| MATH 414 | 3 MATH 442 | 3 |
| MATH 441 | 3 MATH 492 | 2 |
| Arts \& Humanities Choice | 3 Social Science Choice | 3 |
| Electives | 6 Electives | 6 |
|  | $\mathbf{1 5}$ | $\mathbf{1 4}$ |

## Mathematics Major with Applications

| Freshman |  |
| :--- | :---: |
| Fall | Credits Spring |
| MATH 101 | 1 MATH 166 |
| MATH 165 | 4 Arts \& Humanities Choice |
| ENGL 150 | 3 Natural Science Choice |
| LIB 160 | 1 Social Science Choice |
| Natural Science Choice | 4 Specialization Area Prereq. |

Credits
4
3
4
3
3

| Specialization Area Prereq. | 3 |  |
| :---: | :---: | :---: |
|  | 16 | 17 |
| Sophomore |  |  |
| Fall | Credits Spring | Credits |
| MATH 201 | 3 MATH 266 or 267 | 3-4 |
| MATH 265 | 4 MATH 317 | 4 |
| Arts \& Humanities Choice | 3 ENGL 250 | 3 |
| Social Science Choice | 3 Social Science Choice | 3 |
| Specialization Area Prereq. | 3 |  |
|  | 16 | 13-14 |
| Junior |  |  |
| Fall | Credits Spring | Credits |
| MATH 300+ or MATH 304 | 3 MATH 300+ or MATH 314 | 3 |
| Specialization Area 300+ | 3 Specialization Area 300+ | 3 |
| Arts \& Humanities Choice | 3 Communication Choice | 3 |
| Electives/World Language | 6 Electives/World Language | 6 |
|  | 15 | 15 |


| Senior |  |  |
| :--- | :---: | ---: |
| Fall | Credits Spring | Credits |
| MATH 300+ | 3 MATH 300+ | 3 |
| Specialization Area 300+ | 3 MATH 492 | 2 |
| Arts \& Humanities Choice | 3 Specialization Area 300+ | 3 |
| Electives | 6 Electives | 6 |
|  | 15 | 14 |
| Mathematics Major for Teacher Preparation |  |  |
| Freshman | Credits Spring |  |
| Fall | 1 MATH 166 | 4 |
| MATH 101 | 4 STAT 201 | 4 |
| MATH 165 | 3 EDUC 203 | 4 |
| ENGL 150 | 1 EDUC 219 | 1 |
| LIB 160 | 3 EDUC 280J | 1 |
| PSYCH 230 or HD FS 102 | 3 Arts \& Humanities Choice | 6 |
| Arts \& Humanities Choice | 15 | 17 |
|  |  | 1 |

## Sophomore

Fall
MATH 201
MATH 265
ENGL 250
EDUC 204
EDUC 303

| Credits Spring | Credits |
| :--- | ---: |
| 3 MATH 266 or 267 | $3-4$ |
| 4 MATH 317 | 4 |
| 3 PSYCH 333 | 3 |
| 3 COM S 107, 207, or 227 | $3-4$ |
| 1 Natural Science Choice | 4 |


| Natural Science Choice | 4 |  |
| :---: | :---: | :---: |
|  | 18 | 17-19 |
| Junior |  |  |
| Fall | Credits Spring | Credits |
| MATH 301 | 3 MATH 397 | 3 |
| MATH 341 | 4 MATH 436 | 3 |
| MATH 435 | 3 EDUC 280A | 1-2 |
| EDUC 406 | 3 EDUC 403 | 1 |
| Communication Choice | 3 SP ED 401 | 3 |
|  | EDUC 513 | 3 |
|  | 16 | 14-15 |
| Senior |  |  |
| Fall | Credits Spring | Credits |
| MATH 414 | 3 EDUC 417C | 0 |
| MATH 497 | 3 |  |
| EDUC 395 | 3 |  |
| EDUC 480C | 0.5-2 |  |
| Arts \& Humanities Choice | 3 |  |
| Social Sciences Choice | 3 |  |

15.5-17

## Graduate Study

The department offers programs leading to a Master of Science or Doctor of Philosophy degree in mathematics or applied mathematics, as well as minor work for students whose major is in another department. The department also offers a program leading to the degree of Master of School Mathematics (M.S.M.).

Students desiring to undertake graduate work leading to the M.S. or Ph.D. degree should prepare themselves by taking several upper division mathematics courses.

The M.S. degree requires a student to take at least 30 credit hours and to write a creative component or thesis. Additionally, students must pass a comprehensive oral examination over their coursework and their creative component or thesis. See the online Mathematics Graduate Handbook for specific requirements.

The Ph.D. degree requires a student to take 42 credit hours of coursework in addition to research hours, pass written qualifying examinations, pass an oral preliminary exam, and perform an original research project culminating in a dissertation which is defended by an oral exam. Ph.D. candidates must have at least one year of supervised teaching experience. See the on-line Mathematics Graduate Handbook for specific requirements.

The M.S.M. degree is primarily for in-service secondary mathematics teachers. Students desiring to pursue the M.S.M degree should present some undergraduate work in mathematics beyond calculus. Candidates for the M.S.M. degree must write an approved creative component and pass a comprehensive oral examination over their course work and their creative component.

## Courses primarily for undergraduates:

## MATH 010: High School Algebra

(4-0) Cr. 0. F.S.
For students who do not have adequate facility with topics from high school algebra or do not meet the algebra admission requirement. The course is divided into tracks of one- and two-semester lengths. For most students a diagnostic exam will determine which track must be taken. Students will receive a grade in MATH 25 or MATH 30 respectively depending on the level of material covered. Satisfactory completion of MATH 30 is recommended for students planning to take MATH 140, MATH 143, MATH 145, MATH 150, or MATH 151, while MATH 25 is sufficient for MATH 104, MATH 105, MATH 195, STAT 101 or STAT 105. Students must complete MATH 30 to remove a deficiency in the algebra admission requirement. Topics include signed numbers, polynomials, rational and radical expressions, exponential and logarithmic expressions, and equations. Offered on a satisfactory-fail basis only

## MATH 025: High School Algebra

(4-0) Cr. O. F.S.
Students should initially enroll in MATH 10. See description of MATH 10. Offered on a satisfactory-fail basis only.

## MATH 030: High School Algebra

(4-0) Cr. O. F.S.
Students should initially enroll in MATH 10. See description of MATH 10.
Offered on a satisfactory-fail basis only.

## MATH 101: Orientation in Mathematics

(1-0) Cr. 1. F.
A required orientation for all first-year and transfer students in mathematics. Provides information about campus resources and opportunities available to students, assists with transition to the University, and academic planning. Offered on a satisfactory/fail basis only. Offered on a satisfactory-fail basis only.

## MATH 104: Introduction to Probability

(3-0) Cr. 3. F.S.SS.
Prereq: Satisfactory performance on placement assessment, 2 years of high school algebra, 1 year of high school geometry

Permutations, combinations, probability, expected value, and applications. Either MATH 104 or MATH 150 may be counted toward graduation, but not both.

## MATH 105: Introduction to Mathematical Ideas

(3-0) Cr. 3. F.S.SS.
Prereq: Satisfactory performance on placement assessment, 2 years of high school algebra, 1 year of high school geometry.

Introduction to the use of basic mathematics to solve real-world problems in the areas of voting issues, measuring power in situations where people have different numbers of votes, apportionment, fair division, and elementary game theory. No prior background in politics or history is necessary for this course.

## MATH 106: Discovering Mathematics

(3-0) Cr. 3. F.S.
Inquiry-based approach to mathematics, emphasizing the art, history, and beauty of the subject. Typical topics are mathematics from art, music, puzzles, patterns, and reasoning.

## MATH 140: College Algebra

(3-1) Cr. 3. F.S.SS
Prereq: Satisfactory performance on placement assessment, 2 years of high school algebra, 1 year of high school geometry; or MATH 30.

Coordinate geometry, quadratic and polynomial equations, functions, graphing, rational functions, exponential and logarithmic functions, inverse functions, quadratic inequalities, systems of linear equations. Prepares students for MATH 160. Students in the College of Liberal Arts and Sciences may not count MATH 140 toward the General Education Requirements

## MATH 143: Preparation for Calculus

(4-0) Cr. 4. F.S
Prereq: Satisfactory performance on placement assessment, 2 years of high school algebra, 1 year of high school geometry; or MATH 140.
Preparation for MATH 160, MATH 165, and MATH 181. Functions, graphing, basic trigonometry, logarithms, exponentials. Emphasis on co-variational reasoning. Students in the College of Liberal Arts and Sciences may not count MATH 143 toward General Education Requirements. Only one of MATH 143 and MATH 145 may count toward graduation.

## MATH 145: Applied Trigonometry

(3-0) Cr. 3. F.S.
Prereq: Satisfactory performance on placement assessment, 2 years of high school algebra, 1 year of high school geometry; or minimum of C - in MATH 140.

Mathematical ideas regarding the conception of space. General trigonometry, with an emphasis on the calculation of lengths, areas, and angles. The Law of Sines and the Law of Cosines. Polar, cylindrical, and spherical coordinate systems. Conic sections and quadric surfaces. Students in the College of Liberal Arts and Sciences may not count MATH 145 toward the General Education Requirements. Only one of MATH 143 and MATH 145 may count toward graduation.

## MATH 150: Discrete Mathematics for Business and Social Sciences

 (2-1) Cr. 3. F.S.SS.Prereq: Satisfactory performance on placement assessment, 2 years of high school algebra, 1 year of high school geometry

Linear equations and inequalities, matrix algebra, linear programming, discrete probability. Either MATH 104 or MATH 150 may be counted toward graduation, but not both.

## MATH 151: Calculus for Business and Social Sciences

(2-1) Cr. 3. F.S.SS.
Prereq: Satisfactory performance on placement assessment, 2 years of high school algebra, 1 year of high school geometry

Differential calculus, applications to max-min problems, integral calculus and applications. Will not serve as prerequisite for MATH 265 or MATH 266. Only one of MATH 151, MATH 160, or the sequence MATH 165MATH 166 may be counted towards graduation.

## MATH 160: Survey of Calculus

(4-0) Cr. 4. F.S.
Prereq: Satisfactory performance on placement assessment, 2 years of high school algebra, 1 year of geometry; or minimum of C- in MATH 140; or minimum of C- in MATH 143

Analytic geometry, derivatives and integrals of elementary functions, simple differential equations, and applications. Will not serve as a prerequisite for MATH 265 or MATH 266. Only one of MATH 151, MATH 160, the sequence MATH 165-MATH 166, or MATH 181 may be counted towards graduation.

## MATH 165: Calculus I

(4-0) Cr. 4. F.S.SS.
Prereq: Satisfactory performance on placement assessment, 2 years of high school algebra, 1 year of geometry, 1 semester of trigonometry; or minimum of C- in MATH 143

Differential calculus, applications of the derivative, introduction to integral calculus. Only one of MATH 151 or MATH 160 or the sequence MATH 165-MATH 166 may be counted towards graduation.

MATH 166: Calculus II
(4-0) Cr. 4. F.S.SS.
Prereq: Minimum of C-in MATH 165 or high math placement scores Integral calculus, applications of the integral, parametric curves and polar coordinates, power series and Taylor series. Only one of MATH 151, MATH 160, or the sequence MATH 165-MATH 166 may be counted towards graduation.

## MATH 166H: Calculus II, Honors

(4-0) Cr. 4. F.
Prereq: Permission of instructor and minimum C-in MATH 165 or high math placement scores
Integral calculus, applications of the integral, parametric curves and polar coordinates, power series and Taylor series. Additional material of a theoretical, conceptual, computational, or modeling nature. Some of the work may require more ingenuity than is required for MATH 166. Preference will be given to students in the University Honors Program. Only one of MATH 151 or MATH 160, or the sequence MATH 165-MATH 166 may be counted towards graduation.

MATH 195: Mathematics for Elementary Education I
(2-2) Cr. 3. F.S.
Prereq: Satisfactory performance on placement assessment, 2 years high school algebra, 1 year of high school geometry, enrollment in elementary education or early childhood education
Whole number operations through analysis of properties, theoretical and hands-on models, mathematical analysis of elementary students' thinking; standard and non-standard algorithms; structure of the decimal system; linear measurement; two- and three-dimensional measurement, shapes and spatial sense; number theory; algebra as it relates to elementary curricula/teaching profession. Students in the College of Liberal Arts and Sciences may not count MATH 195 toward General Education Requirements.

## MATH 196: Mathematics for Elementary Education II

(2-2) Cr. 3. F.S.
Prereq: Minimum of C- in MATH 195 and enrollment in elementary education or early childhood education.
Integer, fraction and decimal operations through analysis of properties, theoretical and hands-on models, mathematical analysis of elementary students' thinking; standard and non-standard algorithms; continuation of two- and three-dimensional measurement, shapes and spatial sense; probability and statistics; proportional reasoning; algebra as it relates to elementary curricula/teaching profession.

## MATH 201: Introduction to Proofs

(3-0) Cr. 3. F.S.
Prereq: MATH 166 or MATH 166H
Transition to advanced mathematics. Communicating mathematics. Logical arguments; techniques of proofs regarding sets, numbers (natural and real), functions, relations, and limits.

## MATH 202: Career Development in Math and Statistics

(Cross-listed with STAT). Cr. 1. S.
Career development in the mathematics and statistics disciplines with an emphasis on contemporary social issues. Presentations by professionals in STEM fields about occupations, decision-making strategies, and career goal implementation; development of job searching, resume writing, negotiating, and interviewing techniques. Offered on a satisfactory-fail basis only.

## MATH 207: Matrices and Linear Algebra

(3-0) Cr. 3. F.S.SS.

## Prereq: 2 semesters of calculus

Systems of linear equations, determinants, vector spaces, linear transformations, orthogonality, least-squares methods, eigenvalues and eigenvectors. Emphasis on applications and techniques. Only one of MATH 207 and MATH 317 may be counted toward graduation.

## MATH 230: Discrete Computational Structures

(Cross-listed with COM S). (3-1) Cr. 3. F.S.SS.
Prereq: Minimum of C-in COM S 227 and MATH 165; ENGL 150
Concepts in discrete mathematics as applied to computer science. Logic, set theory, functions, relations, combinatorics, discrete probability, graph theory and number theory. Proof techniques, induction and recursion.

## MATH 240: Mathematics of Investment and Credit

(3-0) Cr. 3. F.S.

## Prereq: MATH 166

Interest rates, time value of money, annuities. Loans, bonds, yield rates.
Term structure of interest rates, asset and liability management. Duration, convexity, immunization.

## MATH 265: Calculus III

(4-0) Cr. 4. F.S.SS.
Prereq: Minimum of C- in MATH 166 or MATH 166H
Geometry of space and vectors, multivariable differential calculus, multivariable integral calculus, vector calculus.

## MATH 265H: Calculus III, Honors

(4-0) Cr. 4. F.S.
Prereq: Permission of the instructor; and minimum of C- in MATH 166 or MATH 166H

Geometry of space and vectors, multivariable differential calculus, multivariable integral calculus, vector calculus. Additional material of a theoretical, conceptual, computational, or modeling nature. Some of the work may require more ingenuity than is required in MATH 265. Preference will be given to students in the University Honors Program.

## MATH 266: Elementary Differential Equations

(3-0) Cr. 3. F.S.SS.
Prereq: Minimum of C- in MATH 166 or MATH 166H
Solution methods for ordinary differential equations. First order equations, linear equations, constant coefficient equations. Eigenvalue methods for systems of first order linear equations. Introduction to stability and phase plane analysis.

MATH 267: Elementary Differential Equations and Laplace Transforms (4-0) Cr. 4. F.S.SS.

Prereq: Minimum of C- in MATH 166 or MATH 166H
Same as MATH 266 but also including Laplace transforms and power series solutions to ordinary differential equations.

## MATH 268: Laplace Transforms

(1-0) Cr. 1. F.S.SS.
Prereq: MATH 266
Laplace transforms and power series solutions to ordinary differential equations. Together, MATH 266 and MATH 268 are the same as MATH 267.

## MATH 269: Systems of Differential Equations

(1-0) Cr. 1. F.S.SS
Prereq: Familiarity with ordinary differential equations of first and second order, permission of department.

Systems portion of MATH 266 and MATH 267: Eigenvalue methods for systems of first order linear equations. Introduction to stability and phase plane analysis. For students supplementing transfer courses in differential equations in order to earn credit in MATH 266 or 267.
Students with credit in MATH 266 or MATH 267 may not earn credit in MATH 269.

## MATH 290: Independent Study

Cr. 1-3. Repeatable.
Prereq: Permission of the instructor.
Independent study.

## MATH 290H: Independent Study, Honors

Cr. 1-3. Repeatable
Prereq: Permission of the instructor.
Independent study.

## MATH 297: Intermediate Topics for School Mathematics

(2-2) Cr. 3. F.
Prereq: Enrollment in elementary education and minimum of C- in MATH 196 Mathematical reasoning and topics in Euclidean and non-Euclidean geometry, including transformations, congruence, and similarity; exploration of probability with simulations; linearity and connections to Calculus; fractals and fractal dimension.

## MATH 301: Abstract Algebra I

(3-0) Cr. 3. F.S.
Prereq: MATH 166 or MATH 166H, MATH 317, and grade of C- or better in MATH 201

Basic properties of integers, divisibility and unique factorization. Polynomial rings over a field. Congruence. Introduction to abstract rings, homomorphisms, ideals. Roots and irreducibility of polynomials. Introduction to groups. Emphasis on proofs.

## MATH 304: Combinatorics

(3-0) Cr. 3. F.
Prereq: MATH 166 or MATH 166H; MATH 201 or experience with proofs Enumeration strategies involving permutations, combinations, partitions, binomial coefficients, inclusion-exclusion principle, recurrence relations, generating functions. Additional topics selected from probability, algebraic combinatorics, and applications.

## MATH 314: Graph Theory

(3-0) Cr. 3. S.
Prereq: MATH 166 or MATH 166H; MATH 201 or experience with proofs Structure and extremal properties of graphs. Topics are selected from: trees, networks, colorings, paths and cycles, connectivity, planarity, directed graphs, matchings, Ramsey theory, forbidden structures, enumeration, applications.

## MATH 317: Theory of Linear Algebra

(4-0) Cr. 4. F.S
Prereq: Credit or enrollment in MATH 201
Systems of linear equations, determinants, vector spaces, inner product spaces, linear transformations, eigenvalues and eigenvectors. Emphasis on writing proofs and results. Only one of MATH 207 and MATH 317 may be counted toward graduation.

## MATH 331: Topology

(3-0) Cr. 3. F.
Prereq: MATH 201; MATH 301, 317, 414, or 435.
Set theory, metric spaces, topological spaces, continuity, connectedness, homeomorphisms, compactness, and topological invariants. Examples from surfaces, knots, and various abstract objects. Emphasis on writing proofs.

MATH 341: Introduction to the Theory of Probability and Statistics I
(Cross-listed with STAT). (3-2) Cr. 4. F.S.
Prereq: MATH 265 (or MATH 265H)
Probability; distribution functions and their properties; classical discrete and continuous distribution functions; multivariate probability distributions and their properties; moment generating functions; transformations of random variables; simulation of random variables and use of the R statistical package. Credit for only one of the following courses may be applied toward graduation: STAT 341, STAT 347, STAT 447, or STAT 588.

## MATH 342: Introduction to the Theory of Probability and Statistics II

 (Cross-listed with STAT). (3-2) Cr. 4. F.S.Prereq: STAT 201 or equivalent; STAT 341; MATH 207 or MATH 317
Sampling distributions; confidence intervals and hypothesis testing; theory of estimation and hypothesis tests; linear model theory; resampling methods; introduction to Bayesian inference; use of the R statistical package for simulation and data analysis.

## MATH 350: Number Theory

(Cross-listed with COM S). (3-0) Cr. 3. S.
Prereq: MATH 201 or COM S 230
Divisibility, integer representations, primes and divisors, linear diophantine equations, congruences, and multiplicative functions. Applications to cryptography. Additional topics, chosen at the discretion of the instructor.

## MATH 365: Complex Variables with Applications

(3-0) Cr. 3. S.
Prereq: MATH 265
Functions of a complex variable, including differentiation, integration, series, residues, and conformal mappings.

## MATH 373: Introduction to Scientific Computing

(3-0) Cr. 3. F.
Prereq: MATH 265
Vector and matrix programming and graphing in MATLAB for scientific applications. Polynomial interpolation and approximation. Systems of linear equations and numerical linear algebra. Numerical differentiation and integration. Newton methods for solving nonlinear equations and optimization in one and several variables. Fast Fourier transform. Emphasis on effective use of mathematical software and understanding of its strengths and limitations.

## MATH 385: Introduction to Partial Differential Equations

(3-0) Cr. 3. F.S.
Prereq: MATH 265 and one of MATH 266, MATH 267
Method of separation of variables for linear partial differential equations, including heat equation, Poisson equation, and wave equation. Topics from Fourier series, Sturm-Liouville theory, Bessel functions, spherical harmonics, and method of characteristics.

## MATH 397: Teaching Secondary Mathematics Using University Mathematics

(2-2) Cr. 3. S.
Prereq: MATH 201, MATH 301
Coursework in university mathematics including calculus, abstract algebra, discrete mathematics, geometry, and other topics as it relates to teaching mathematics in grades 5-12.

## MATH 398: Cooperative Education

Cr. R. Repeatable, maximum of 2 times. F.S.SS.
Prereq: Permission of the department cooperative education coordinator; junior classification
Required of all cooperative education students. Students must register for this course prior to commencing each work period.

## MATH 407: Applied Linear Algebra

(Dual-listed with MATH 507). (3-0) Cr. 3. F.
Prereq: MATH 317; or MATH 207 and experience writing proofs
Advanced topics in applied linear algebra including eigenvalues, eigenvalue localization, singular value decomposition, symmetric and Hermitian matrices, nonnegative and stochastic matrices, matrix norms, canonical forms, matrix functions. Applications to mathematical and physical sciences, engineering, and other fields.

## MATH 414: Analysis I

(3-0) Cr. 3. F.S.SS.
Prereq: Minimum of C- in MATH 201
A rigorous development of calculus of functions of one real variable: real number properties and topology, limits, continuity, differentiation, integration, series.

## MATH 415: Analysis II

(3-0) Cr. 3. S.
Prereq: MATH 414; MATH 265; and MATH 317 or MATH 407
Sequences and series of functions of a real variable, uniform convergence, power series, metric spaces, calculus of functions of two or more real variables.

MATH 421: Logic for Mathematics and Computer Science
(Cross-listed with COM S). (3-0) Cr. 3.
Prereq: MATH 301 or MATH 207 or MATH 317 or COM S 230 or CPR E 310
Propositional and predicate logic. Topics selected from Horn logic, equational logic, resolution and unification, foundations of logic programming, reasoning about programs, program specification and verification, model checking and binary decision diagrams, temporal logic and modal logic.

MATH 424: Introduction to High Performance Computing
(Cross-listed with COM S, CPR E). (2-2) Cr. 3. F.
Prereq: MATH 265; MATH 207 or MATH 317; or permission of instructor.
Unix, serial programming of scientific applications, OpenMP for sharedmemory parallelization. No Unix, Fortran or C experience required.

## MATH 435: Geometry I

(3-0) Cr. 3. F.
Prereq: MATH 201; MATH 207 or MATH 317
Euclidean geometry of triangles, circles, and parallelograms, studied from several points of view, chosen from: synthetic, analytic, axiomatic, transformational, complex numbers, or vector methods. Possible and impossible constructions with compass and straightedge.

## MATH 436: Geometry II

(3-0) Cr. 3. S.
Prereq: MATH 201; MATH 207 or MATH 317
Foundations of Euclidean geometry and the axiomatic method, including the use of models. The history, logical consistency, and basic theorems of non-Euclidean geometries, such as hyperbolic, elliptic, and projective geometry.

## MATH 441: Life Contingencies I

Cr. 3. F.
Prereq: MATH 240, credit or coenrollment in MATH 265
Topics in life insurance for the Actuarial Sciences I: single life annuities, benefits premiums and reserves.

## MATH 442: Life Contingencies II

Cr. 3. S.
Prereq: MATH 441
Topics in life insurance for the Actuarial Sciences II: multiple life functions, multiple decrement models, pension plan valuation, insurance models, applications.

## MATH 481: Numerical Methods for Differential Equations

(Dual-listed with MATH 581). (Cross-listed with COM S). (3-0) Cr. 3. S. Prereq: MATH 265 and either MATH 266 or MATH 267
First order Euler method, high order Runge-Kutta methods, and multistep methods for solving ordinary differential equations. Finite difference and finite element methods for solving partial differential equations. Local truncation error, stability, and convergence for finite difference method. Numerical solution space, polynomial approximation, and error estimate for finite element method. Computer programming required.

## MATH 490: Independent Study

Cr. 1-3. Repeatable, maximum of 9 credits.
Prereq: Permission of instructor.
No more than 9 credits of Math 490 or Math 490 H may be counted toward graduation.

## MATH 490H: Independent Study: Honors

Cr. 1-3. Repeatable, maximum of 9 credits.
Prereq: Permission of the instructor.
No more than 9 credits of Math 490 or 490 H may be counted toward graduation.

## MATH 491: Undergraduate Thesis

Cr. 2-3.
Writing and presenting a formal mathematics paper. Upon approval by the department, the paper will satisfy the departmental advanced English requirement.

## MATH 492: Undergraduate Seminar

(2-0) Cr. 2. F.S.
Prereq: MATH 317 or MATH 407
Introduction to independent mathematical thought, with emphasis on oral communication of an advanced topic. Seminar content varies.

## MATH 495: Special Topics

Cr. arr. Repeatable, maximum of 9 credits.
Prereq: Permission of instructor
Topics of current interest.
MATH 497: Teaching Secondary School Mathematics
(Cross-listed with EDUC). (3-0) Cr. 3. F.
Prereq: 15 credits in college mathematics. .
Develop an understanding of instructional planning, lesson implementation, and assessment in grades 5-12 mathematics, with a focus on reform-based mathematics, equity, and conceptual understanding.

## Courses primarily for graduate students, open to qualified undergraduates:

## MATH 501: Introduction to Real Analysis

(3-0) Cr. 3. F.
Prereq: MATH 265 and (MATH 207 or MATH 317)
A development of the real numbers. Study of metric spaces, completeness, compactness, sequences, and continuity of functions. Differentiation and integration of real-valued functions, sequences of functions, limits and convergence, equicontinuity.

## MATH 502: Topology

(3-0) Cr. 3. S.
Prereq: MATH 414 or MATH 501
Introduction to general topology. Topological spaces, continuous functions, connectedness, compactness. Topics selected from countability and separation axioms, metrization, and complete metric spaces. Topics in algebraic topology.

## MATH 504: Abstract Algebra I

(3-0) Cr. 3. F.
Prereq: MATH 302
Algebraic systems and their morphisms, with emphasis on groups and rings.

## MATH 505: Abstract Algebra II

(3-0) Cr. 3. S.
Prereq: MATH 504
Continuation of Math 504. Algebraic systems and their morphisms, with emphasis on modules and fields.

## MATH 507: Applied Linear Algebra

(Dual-listed with MATH 407). (3-0) Cr. 3. F.
Prereq: MATH 317; or MATH 207 and experience writing proofs
Advanced topics in applied linear algebra including eigenvalues, eigenvalue localization, singular value decomposition, symmetric and Hermitian matrices, nonnegative and stochastic matrices, matrix norms, canonical forms, matrix functions. Applications to mathematical and physical sciences, engineering, and other fields.

## MATH 510: Linear Algebra

(3-0) Cr. 3. S.
Prereq: MATH 317 or MATH 407 or (MATH 207 and one of MATH 301 or MATH 414)

Advanced topics in linear algebra including canonical forms; unitary, normal, Hermitian and positive-definite matrices; variational characterizations of eigenvalues.

## MATH 511: Functions of a Single Complex Variable

(3-0) Cr. 3. S.
Prereq: MATH 414 or MATH 501
Theory of analytic functions, integration, topology of the extended complex plane, singularities and residue theory, maximum principle, conformal mapping, meromorphic functions, argument principle.

## MATH 515: Real Analysis I

(3-0) Cr. 3. F.
Prereq: MATH 414 or MATH 501
Lebesgue measure and Lebesgue integral, one variable differentiation theory, Fubini and Tonelli theorems in $R^{\wedge} n$, Lp spaces.

## MATH 516: Real Analysis II

(3-0) Cr. 3. S.
Prereq: MATH 515
Metric spaces, topological spaces, compactness, abstract theory of measure and integral, differentiation of measures, Banach spaces.

## MATH 517: Finite Difference Methods

(3-0) Cr. 3. S.
Prereq: MATH 481 or MATH 561
Finite difference methods for partial differential equations. Methods for elliptic equations; explicit and implicit methods for parabolic and hyperbolic equations; stability, accuracy, and convergence theory, including von Neumann analysis, modified equations, and the Courant-Friedrichs-Lewy condition.

## MATH 519: Methods of Applied Mathematics I

(3-0) Cr. 3. F.
Prereq: MATH 414 or MATH 501
Techniques of classical and functional analysis with applications to differential equations and integral equations. Vector spaces, metric spaces, Hilbert and Banach spaces, Sobolev spaces and other function spaces, contraction mapping theorem, distributions, Fourier series and Fourier transform.

## MATH 520: Methods of Applied Mathematics II

(3-0) Cr. 3. S.

## Prereq: MATH 519

Continuation of Math 519. Linear operators, spectral theory of differentia and integral operators, Green's functions and boundary value problems, weak solutions of partial differential equations and variational methods, calculus in Banach spaces and applications.

## MATH 525: Numerical Analysis of High Performance Computing

(Cross-listed with COM S, CPR E). (3-0) Cr. 3. S.
Prereq: CPR E 308 or MATH 481; experience in scientific programming; knowledge of FORTRAN or C

Introduction to parallelization techniques and numerical methods for distributed memory high performance computers. A semester project in an area related to each student's research interests is required.

## MATH 533: Cryptography

(Cross-listed with CPR E, INFAS). (3-0) Cr. 3. S.
Prereq: MATH 301 or CPR E 310 or COM S 230
Basic concepts of secure communication, DES and AES, public-key cryptosystems, elliptic curves, hash algorithms, digital signatures,
applications. Relevant material on number theory and finite fields.

## MATH 535: Steganography and Digital Image Forensics

(Cross-listed with CPR E, INFAS). (3-0) Cr. 3. S.
Prereq: E E 524 or MATH 317 or MATH 407 or COM S 230
Basic principles of covert communication, steganalysis, and forensic analysis for digital images. Steganographic security and capacity, matrix embedding, blind attacks, image forensic detection and device identification techniques. Related material on coding theory, statistics, image processing, pattern recognition.

MATH 540: Seminar in Mathematics Education
(1-0) Cr. 1. SS.
Prereq: Enrollment in the Master of School Mathematics program or professional studies in education

Research studies in mathematics learning and teaching, exemplary practices in mathematics education, and current state and national trends in the mathematics curriculum in grades $\mathrm{K}-12$. Students in MSM take each of 540A, 540B, and 540C. Topics are offered on a 3 -year cycle. A. Assessment, equity, and teaching of statistics. Offered SS 2017. B. Geometry and discrete mathematics, and problem solving. Offered SS 2018. C. Teaching of analysis, algebra, and the use of technology. Offered SS 2016.

MATH 540A: Seminar in Mathematics Education: Assessment, equity, and teaching of statistics.
(1-0) Cr. 1.
Prereq: Enrollment in the Master of School Mathematics program or professional studies in education
Research studies in mathematics learning and teaching, exemplary practices in mathematics education, and current state and national trends in the mathematics curriculum in grades K -12. Topics are offered on a 3-year cycle. Offered SS 2017.

MATH 540B: Seminar in Mathematics Education: Geometry and discrete mathematics, and problem solving.
(1-0) Cr. 1.
Prereq: Enrollment in the Master of School Mathematics program or professional studies in education
Research studies in mathematics learning and teaching, exemplary practices in mathematics education, and current state and national trends in the mathematics curriculum in grades K -12. Offered on a 3-year cycle. Offered SS 2018.

MATH 540C: Seminar in Mathematics Education: Teaching of analysis, algebra, and the use of technology.
(1-0) Cr. 1.
Prereq: Enrollment in the Master of School Mathematics program or professional studies in education

Research studies in mathematics learning and teaching, exemplary practices in mathematics education, and current state and national trends in the mathematics curriculum in grades $\mathrm{K}-12$. Topics are offered on a 3-year cycle. Offered SS 2016.

## MATH 545: Intermediate Calculus

(4-0) Cr. 4.
Prereq: 3 semesters of calculus and enrollment in the master of school mathematics program

Offered on a 3 -year cycle, offered SS. 2016. The fundamental concepts of calculus which are critical to the effective understanding of the material in first year calculus. Emphasis is on a constructivist approach to learning, cooperative groups, problem solving, and use of technology.

MATH 546: Algorithms in Analysis and Their Computer Implementation (2-2) Cr. 3.
Prereq: 3 semesters in calculus or concurrent enrollment in 545 and enrollment in the master of school mathematics program Offered on a 3- year cycle, offered SS. 2016. The use of technology in secondary mathematics with an emphasis on the exploration, creation, and implementation of algorithms.

## MATH 547: Discrete Mathematics and Applications

(4-0) Cr. 4.
Prereq: Enrollment in the master of school mathematics program
Offered on a 3 -year cycle, offered SS. 2018. Applications of graph theory, game theory, voting theory, recursion, combinatorics, and algebraic structures. Issues in integrating discrete topics into the secondary curriculum. Use of the computer to explore discrete mathematics.

## MATH 549: Intermediate Geometry

(3-0) Cr. 3.
Prereq: MATH 435 or equivalent and enrollment in the master of school mathematics program

Offered on a 3-year cycle, offered SS. 2018. A study of geometry with emphasis on metrics, the group of isometries, and the group of similarities. Specific spaces studied normally include the Euclidean plane, the 2-sphere, projective 2-space, and hyperbolic geometry. Emphasis on analytical methods. Incorporation of geometry software.

## MATH 554: Stochastic Process Models

(Cross-listed with STAT). (3-0) Cr. 3. F.
Prereq: STAT 542
Markov chains on discrete spaces in discrete and continuous time (random walks, Poisson processes, birth and death processes) and their long-term behavior. Optional topics may include branching processes, renewal theory, introduction to Brownian motion.

## MATH 557: Ordinary Differential Equations and Dynamical Systems

 (3-0) Cr. 3. F.Prereq: MATH 415 or MATH 501
The initial-value problem, existence and uniqueness theorems, continuous dependence on parameters, linear systems, stability and asymptotic behavior of solutions, linearization, dynamical systems, bifurcations, and chaotic behavior.

## MATH 561: Numerical Analysis I

(3-0) Cr. 3. F.
Prereq: MATH 414 or MATH 501
Approximation theory, including polynomial interpolation, spline interpolation and best approximation; numerical differentiation and integration; numerical methods for ordinary differential equations.

## MATH 562: Numerical Analysis II

(3-0) Cr. 3. S.
Prereq: MATH 317
Numerical linear algebra including LU factorization, QR factorization, linear least squares, singular value decomposition, eigenvalue problems, and iterative methods for large linear systems.

## MATH 565: Continuous Optimization

(3-0) Cr. 3. S.
Prereq: MATH 265 and one of MATH 317, 507, 510
Theory and methods for constrained and unconstrained optimization. Steepest-descent, conjugate gradient, Newton and quasi-Newton, line search and trust-region, first and second order necessary and sufficient conditions, linear, quadratic and general nonlinear programming.

## MATH 566: Discrete Optimization

(3-0) Cr. 3. F
Prereq: MATH 317 or MATH 507 or MATH 510
Algorithms for linear programming, integer and combinatorial optimization. Linear programming, duality theory, simplex algorithm; the solution of the shortest-path, minimum spanning tree, max-flow/mincut, minimum cost flow, maximum matching, and traveling salesman problems; integer linear programming, branch-and-bound, local and global search algorithms; matroids and greedy algorithms.

## MATH 567: Graph Theory

(3-0) Cr. 3. F.
Prereq: MATH 317 or MATH 507 or MATH 510
Structural theory of graphs. Topics include basic structures (trees, paths, cycles and matchings), networks, colorings, connectivity, topological graph theory, Ramsey and Turan theory, spectral graph theory, introduction to probabilistic methods.

## MATH 568: Enumerative Combinatorics and Ordered Sets

(3-0) Cr. 3. S.
Prereq: MATH 302 or MATH 504
Enumeration methods. Generating functions and sieve methods. Partially ordered sets, lattices, and Moebius inversion. Extremal set theory.

## MATH 577: Linear Systems

(Cross-listed with AER E, E E, M E). (3-0) Cr. 3. F.
Prereq: E E 324 or AER E 331 or MATH 415; and MATH 207
Linear algebra review. Least square method and singular value decomposition. State space modeling of linear continuous-time systems. Solution of linear systems. Controllability and observability. Canonical description of linear equations. Stability of linear systems. State feedback and pole placements. Observer design for linear systems.

## MATH 578: Nonlinear Systems

(Cross-listed with AER E, E E, M E). (3-0) Cr. 3. S.
Prereq: E E 577
Linear vs nonlinear systems. Phase plane analysis. Bifurcation and center manifold theory. Lyapunov stability. Absolute stability of feedback systems. Input-output stability. Passivity theory and feedback linearization. Nonlinear control design techniques.

## MATH 581: Numerical Methods for Differential Equations

(Dual-listed with MATH 481). (3-0) Cr. 3. S.
Prereq: MATH 265 and either MATH 266 or MATH 267
First order Euler method, high order Runge-Kutta methods, and multistep methods for solving ordinary differential equations. Finite difference and finite element methods for solving partial differential equations. Local truncation error, stability, and convergence for finite difference method. Numerical solution space, polynomial approximation, and error estimate for finite element method. Computer programming required.

## MATH 590: Independent Study

Cr. arr. Repeatable.
MATH 591: Orientation for Mathematics Graduate Students I
(0.5-0) Cr. 0.5. F.

Fall semester orientation seminar. Required for graduate students in Mathematics and Applied Mathematics. Topics include teaching at the university level and communication of mathematics. Offered on a satisfactory-fail basis only.

MATH 592: Orientation for Mathematics Graduate Students II
(0.5-0) Cr. 0.5. S.

Spring semester orientation seminar. Required for graduate students in Mathematics and Applied Mathematics. Topics include teaching at the university level and communication of mathematics. Offered on a satisfactory-fail basis only

## MATH 595: Special Topics

Cr. arr. Repeatable.
MATH 599: Creative Component
Cr. arr.

Courses for graduate students:

## MATH 601: Mathematical Logic

(3-0) Cr. 3. Alt. F., offered odd-numbered years.
Prereq: MATH 504
Model theory of propositional and predicate logic, the Soundness
Theorem, the Compactness Theorem, the Goedel-Henkin Completeness Theorem, the Incompleteness Theorem, computability theory. As time permits: modal and temporal logic, set theory (the continuum hypothesis). Emphasis on the relationship between `provable' and `true' and the relationship between `computable' and `definable'.

MATH 605: Design Theory and Association Schemes
(3-0) Cr. 3. Alt. S., offered odd-numbered years.
Prereq: MATH 504
Combinatorial designs and algebraic codes. Construction methods including finite fields. Error-correcting codes. Adjacency matrices and algebraic combinatorics.

## MATH 608: Extremal Graph Theory

(3-0) Cr. 3. Alt. S., offered even-numbered years.
Prereq: MATH 567
Study of extremal graph problems and methods. Topics include probabilistic methods, generalizations of Turan's theorem, Szemeredi's regularity lemma, random graph theory.

## MATH 610: Seminar

Cr. arr.

## MATH 615: General Theory of Algebraic Structures I

(3-0) Cr. 3. Alt. F., offered even-numbered years.
Prereq: MATH 504
First semester of full-year course. Subalgebras, homomorphisms, congruence relations, and direct products. Lattices and closure operators. Varieties and quasivarieties of algebras, free algebras, Birkhoff's theorems, clones, Mal'cev conditions. Advanced topics.

## MATH 616: General Theory of Algebraic Structures II

(3-0) Cr. 3. Alt. S., offered odd-numbered years.
Prereq: MATH 615
Continuation of MATH 615.

## MATH 617: Category Theory

(3-0) Cr. 3. Alt. F., offered even-numbered years.
Prereq: MATH 504
Categories and functors and their applications.

## MATH 618: Representation Theory

(3-0) Cr. 3. Alt. S., offered odd-numbered years. Prereq: MATH 504

Representations of algebraic structures. Content varies by semester.

## MATH 624: Manifolds, Tensors and Differential Geometry

(3-0) Cr. 3. Alt. S., offered odd-numbered years.
Prereq: MATH 501 or MATH 515
Topics selected from: Geometry of curves and surfaces. Manifolds, coordinate systems. Tangent and cotangent vectors, vector fields. Tensors, differential forms, Riemannian metrics. Connections, covariant differentiation, curvature tensors. Applications to physics and engineering.

## MATH 631: Harmonic Analysis

Cr. 3. Alt. F., offered even-numbered years.
Prereq: MATH 515
Fourier Series on an interval, approximate identities and summation, Gibb's phenomenon, Fourier transform on the line, uncertainty principle. Additional topics may include distributions, Hardy-Littlewood maximal function, boundedness of singular integral operators, arithmetic combinatorics, wavelet theory.

## MATH 633: Functional Analysis

(3-0) Cr. 3. Alt. F., offered odd-numbered years.
Prereq: MATH 515
Fundamental theory of normed linear spaces and algebras, such as topology and continuity, duality and spectral theory, emphasizing aspects that provide a framework for the study of the spectrum of an operator, analytic function theory, and modern operator theory.

## MATH 641: Foundations of Probability Theory

(Cross-listed with STAT). (3-0) Cr. 3. F.
Prereq: MATH 414 or MATH 501 or equivalent course.
Sequences and set theory; Lebesgue measure, measurable functions. Absolute continuity of functions, integrability and the fundamental theorem of Lebesgue integration. General measure spaces, probability measure, extension theorem and construction of Lebesgue-Stieljes measures on Euclidean spaces. Measurable transformations and random variables, induced measures and probability distributions. General integration and expectation, Lp-spaces and integral inequalities. Uniform integrability and absolute continuity of measures. Probability densities and the Radon-Nikodym theorem. Product spaces and Fubini-Tonelli theorems.

## MATH 642: Advanced Probability Theory

(Cross-listed with STAT). (3-0) Cr. 3. S.
Prereq: STAT 641, or STAT 543 and MATH 515.
Probability spaces and random variables. Kolmogorov's consistency theorem. Independence, Borel-Cantelli lemmas and Kolmogorov's 0 1 Law. Comparing types of convergence for random variables. Sums of independent random variables, empirical distributions, weak and strong laws of large numbers. Convergence in distribution and its characterizations, tightness, characteristic functions, central limit theorems and Lindeberg-Feller conditions. Conditional probability and expectation. Discrete parameter martingales and their properties and applications

## MATH 645: Advanced Stochastic Processes

(Cross-listed with STAT). (3-0) Cr. 3. S.
Weak convergence. Random walks and Brownian motion. Martingales.
Stochastic integration and Ito's Formula. Stochastic differential equations and applications.

MATH 646: Mathematical Modeling of Complex Physical Systems
(Cross-listed with PHYS). (3-0) Cr. 3. S.
Modeling of the dynamics of complex systems on multiple scales:
Classical and dissipative molecular dynamics, stochastic modeling and Monte-Carlo simulation; coarse grained nonlinear dynamics, interface propagation and spatial pattern formation.

MATH 655: Partial Differential Equations I
(3-0) Cr. 3. F.
Prereq: MATH 515 or MATH 519
Study of model problems of elliptic, parabolic and hyperbolic types, first order equations, conservation laws, transform methods, introduction to linear partial differential equations of arbitrary order, fundamental solutions.

## MATH 656: Partial Differential Equations II

(3-0) Cr. 3. S.
Prereq: MATH 655
Sobolev spaces, general theory of second order linear elliptic, parabolic and hyperbolic partial differential equations, first order linear hyperbolic systems, variational methods, fixed point methods.

## MATH 666: Finite Element Methods

(3-0) Cr. 3. Alt. F., offered even-numbered years.

## Prereq: MATH 516 or MATH 520 or MATH 561 or MATH 656

Weak and variational formulations of elliptic problems; weak derivatives and Sobolev spaces; Lax-Milgram theorem, Bramble-Hilbert lemma; examples of finite element spaces; polynomial approximation theory; error estimates for finite element methods; implementation issues; mixed finite element methods for Stokes problems; applications.

MATH 667: Computational Methods for Hyperbolic Partial Differential Equations (PDE)

Cr. 3. Alt. F., offered odd-numbered years.
Prereq: MATH 561, MATH 562
Mathematical theory of weak/entropy solutions of nonlinear hyperbolic conservation laws; shock speed and Riemann problems; numerical methods for scalar equations and systems including Euler equations; conservative methods; approximate Riemann solvers; total variation stability; DG method.

## MATH 680: Advanced Topics

Cr. 3. Repeatable.

## MATH 680A: Advanced Topics: Algebra

Cr. 3. Repeatable.

## MATH 680B: Advanced Topics: Analysis

Cr. 3. Repeatable
MATH 680C: Advanced Topics: Applied Mathematics Cr. 3. Repeatable

MATH 680D: Advanced Topics: Combinatorics
Cr. 3. Repeatable.
MATH 680E: Advanced Topics: Differential Equations
Cr. 3. Repeatable.
MATH 680F: Advanced Topics: Linear Algebra
Cr. 3. Repeatable.
MATH 680G: Advanced Topics: Logic and Foundations
Cr. 3. Repeatable.
MATH 680H: Advanced Topics: Number Theory
Cr. 3. Repeatable.
MATH 680I: Advanced Topics: Numerical Analysis
Cr. 3. Repeatable

MATH 680J: Advanced Topics: Optimization
Cr. 3. Repeatable.
MATH 680K: Advanced Topics: Probability
Cr. 3. Repeatable.
MATH 680L: Advanced Topics: Topology
Cr. 3. Repeatable.
MATH 699: Research
Cr. arr. Repeatable.

