

## Key to Course Listings

**Catalog numbers** are part of a University-wide numbering system. Generally, courses numbered 100 to 199 are introductory, 200-299 are intermediate, and 300-499 are advanced (upper-level).

**Reorganized or renumbered courses** are denoted by a parenthetical number in boldface following the course number. When renumbering or reorganization has left the SUBJECT unchanged, only the previous catalog number is given; if the SUBJECT has also changed, the previous SUBJECT name and course number appear. A reorganized or renumbered course cannot be repeated for credit without special permission.

**Cross-listed courses** are sponsored by more than one department or program and may be elected in any of the participating units. Cross-listings appear in boldface and are denoted by a slash between the participating units.

**Course titles** appear in boldface after the catalog number.

**Prerequisites** appear in italics after the course title. Some prerequisites are advisory. They suggest the assumed background or level of academic experience, and students should be guided by these statements. Some prerequisites are mandatory and are enforced at the point of registration. The *Course Guide* and the *LS&A Bulletin* indicate the cases when prerequisites are enforced.

Prerequisites are of three types:

- *Courses*. Unless otherwise stated, the phrase "or equivalent" may be considered an implicit part of the prerequisite for any course. When a student has satisfactorily completed a course(s) at the required level of competency and when that course is believed to be substantially equivalent to one listed as a prerequisite, the student must consult the instructor or department. If equivalency is determined to have been satisfied, election may be approved by issuance of electronic permission.
- *Class standing* (first year, sophomore, junior, senior). A course might be appropriate for "first and second year students only," or for "juniors and seniors."
- *Permission of instructor*. The phrase "or permission of instructor" may be considered an implicit part of the statement of prerequisites for any course. When permission is a stated requirement, or when a student does not have the stated prerequisite for a course but can give evidence of sufficient background, the student should obtain approval from the instructor or department concerned and an electronic permission issued.

**The Credit Symbol**, an Arabic numeral in parentheses, denotes the credits earned for the course. Credit is granted in semester hours. Except for small seminars where the reading and/or writing requirements are intensive, one credit represents no less than one hour of class meeting time each week of the term, and usually represents two hours of work outside of class for each class hour.

**Area distribution designation** is approved by the LS&A Curriculum Committee on a yearly basis. A course may be approved with the designation natural science (*NS*), social science (*SS*), humanities (*HU*), mathematical and symbolic analysis (*MSA*), creative expression (*CE*), interdisciplinary (*ID*), or excluded from distribution (*Excl*).

**Courses meeting certain college requirements** are so listed. Language other than English (*LR*) courses may be used toward meeting the Language Requirement. The First-Year Writing Requirement may be met by courses designated (Introductory Composition). Courses approved with the designation "Language Requirement" or "Introductory Composition" may not be used as part of an area distribution plan. If an introductory language course is designated "Excluded" (*Excl*), it may not be used to satisfy the LS&A language requirement. (*BS*) means that the course may be used toward the 60 approved credits required for the B.S. degree. Courses meeting or partially meeting the Quantitative Reasoning

requirement are designated (*QR/1*) or (*QR/2*). Courses with standard approval for meeting the Race & Ethnicity (*R&E*) requirement are so indicated. Other courses may meet the R&E or QR requirements on a term-by-term basis and are listed on the LS&A website (<http://www.lsa.umich.edu/>).

**Experiential, Independent Study, and Tutorial** courses are so designated. (See Experiential and Directed Reading/Independent Study Courses in *Chapter IV*.)

**Repetition** of a course that varies in content from term to term is permitted only under certain conditions. When a department or program has a policy about the repetition of a course for credit, that policy is included in the course listing. The general statement "May be repeated for credit with permission" usually means "With permission of a concentration advisor." In all other instances, a student must get permission from both the department or program and the Academic Standards Board to repeat a course for credit. Generally, a course may be elected for credit once only.

**Excluded combinations of course elections** are designated in the listing of affected courses.

**Special Grading pattern** for a course is indicated in the course listing. Some LS&A courses are offered *mandatory credit/no credit*. (See Non-Graded Courses in *Chapter IV*.)

**The Term Symbol**, a Roman numeral, denotes the term(s) some courses are offered. The University year is divided into three terms: Fall (I), Winter (II), and Spring-Summer (III). The Spring-Summer Term is further divided: Spring-Half (IIIa) and Summer-Half (IIIb).

### Courses That Count Toward Graduate Programs

*Courses Approved for Regular Rackham Graduate Credit*. All courses taken in fulfillment of Rackham degree requirements must be approved for Rackham graduate credit. Be certain that any courses you plan to take--especially those numbered in the 400s--are approved for Rackham credit before you enroll in them. The Graduate School policy on courses is as follows: Courses at the 400 level and above are acceptable for graduate credit if they have been approved by the Graduate School.

If you are uncertain whether or not a course is approved for Rackham credit, check with the department offering the course or with the Rackham Course Approval Officer (764-8221).

If you elect a course that has not been approved for Rackham graduate credit, the course will appear on your university transcript with the notation "Not for Graduate Credit. The course grade will appear on the transcript, but it will not be averaged into your cumulative grade point average or your credit toward program (CTP) total.

*Courses Not Approved for Graduate Credit*. Courses at the 300 level and below are not acceptable for graduate credit, without exception. Undergraduate level foreign language courses may occasionally be used in fulfillment of some departmental foreign language requirements.

Under unusual circumstances you may petition to receive graduate credit for a course not normally approved for graduate credit (*e.g.*, such as an undergraduate course where you will be expected to perform more advanced work than the undergraduates). Because there is no guarantee of approval, you should submit your petition to the Graduate School's Office of Academic Records and Dissertations (OARD) before taking the course. Your petition must be endorsed by the course instructor and by the graduate chair of your department or program, and it must include an explanation for requesting the exception. You will be expected to perform graduate level work in the course, and the petition must show how this will be accomplished. You may obtain a petition form from your department, from OARD, or online.

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**Mathematics****Mathematics****Mathematics**    MATH 428

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Mathematics

Mathematics

<http://www.math.lsa.umich.edu/>**Undergraduate Courses**101    **MATH 101.****Explorations in Algebra.**

(2) : May not be repeated for credit.

(Excl).

*A maximum of 4 credits may be earned in MATH 101, 103, 105, and 110. No credit granted to those who have completed or are enrolled in MATH 105.*

This course is designed to explore the procedural skills and underlying concepts of algebra. These skills are the basis for many quantitatively based courses. Students explore topics through data, graphs, and symbolic representations.

103    **MATH 103.****Intermediate Algebra.**

(2) : May not be repeated for credit.

(Excl).

*Only open to designated summer half-term Bridge students. A maximum of four credits may be earned in MATH 101, 103, 105, and 110. IIIb.*

Review of elementary algebra; rational and quadratic equations; properties of relations, functions, and their graphs; linear and quadratic functions; inequalities, logarithmic and exponential functions and equations. Equivalent to the first year of Math. 105/106.

105    **MATH 105.****Data, Functions, and Graphs.**

(4,4) : May not be repeated for credit.

(MSA). (QR/1).

*Students with credit for MATH 103 can elect MATH 105 for only 2 credits. No credit granted to those who have completed any Mathematics course numbered 110 or higher. A maximum of four credits may be earned in MATH 101, 103, 105, and 110. I, II, IIIb.*

This is a course on analyzing data by means of functions and graphs. The emphasis is on mathematical modeling of real-world applications. The functions used are linear, quadratic, polynomial, logarithmic, exponential, and trigonometric. Algebra skills are assessed during the term by periodic testing.

107    **MATH 107.****Mathematics for the Information Age.**

(3) : May not be repeated for credit.

(MSA). (QR/1).

*Three to four years high school mathematics.*

The course investigates topics relevant to the information age in which we live. Topics covered include cryptography, error-correcting codes, data compression, fairness in politics, voting systems, population growth, biological modeling.

110    **MATH 110.****Pre-Calculus (Self-Study).**

(2,2) : May not be repeated for credit.

(Excl).

*See Elementary Courses above. Enrollment in MATH 110 is by recommendation of MATH 115 instructor and override only. No credit granted to those who already have 4 credits for pre-calculus mathematics courses. A maximum of four credits may be earned in MATH 101, 103, 105, and 110.*

A condensed half-term version of MATH 105. Offered as a self-study course through the Math Lab and directed toward students who are unable to complete a first calculus course successfully. Students study on their own and consult with tutors in the Math Lab whenever needed.

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- 115 **MATH 115.**  
**Calculus I.**  
 (4,4) : May not be repeated for credit.  
 (MSA). (BS). (QR/1).  
*Four years of high school mathematics. Credit is granted for only one course from among MATH 115, and 185. I, II, IIIa, IIIb.*  
 This course presents calculus from three points of view: geometric (graphs); numerical (tables); and algebraic (formulas). Students develop their reading, writing, and questioning skill. Topics include functions and graphs, derivatives and their application to real-life problems in various fields, and definite integrals.
- 116 **MATH 116.**  
**Calculus II.**  
 (4,4) : May not be repeated for credit.  
 (MSA). (BS). (QR/1).  
*MATH 115. Credit is granted for only one course from among MATH 116, 119, 156, 176, and 186. I, II, IIIa, IIIb.*  
 This course presents calculus from three points of view: geometric (graphs); numerical (tables); and algebraic (formulas). Students develop their reading, writing, and questioning skill. Topics include the indefinite integral, techniques of integration, introduction to differential equations, infinite series.
- 127 **MATH 127.**  
**Geometry and the Imagination.**  
 (4) : May not be repeated for credit.  
 (MSA). (BS). (QR/1).  
*Three years of high school mathematics including a geometry course. Only first-year students, including those with sophomore standing, may pre-register for First-Year Seminars. All others need permission of instructor. No credit granted to those who have completed a 200- (or higher) level mathematics course (except for MATH 385 and 485). II.*  
 This course introduces students to the ideas and some of the basic results in Euclidean and non-Euclidean geometry. The course begins with an historical perspective of how the ancient Greeks influenced the study of geometry prior to the 19th century. Then notions of non-Euclidean geometry and geometry in higher dimensions are introduced and studied.
- 128 **MATH 128.**  
**Explorations in Number Theory.**  
 (4,4) : May not be repeated for credit.  
 (MSA). (BS). (QR/1).  
*High school mathematics through at least Analytic Geometry. Only first-year students, including those with sophomore standing, may pre-register for First-Year Seminars. All others need permission of instructor. No credit granted to those who have completed a 200- (or higher) level mathematics course (except for MATH 385 and 485). I.*  
 Designed for non-science concentrators and students with no intended concentration who want to learn how to think mathematically without having to take calculus first. Students are introduced to the ideas of Number Theory through lectures and experimentation by using software to investigate numerical phenomena, and to make conjectures that they try to prove.
- 147 **MATH 147.**  
**Introduction to Interest Theory.**  
 (3,3) : May not be repeated for credit.  
 (MSA). (BS).  
*Three to four years high school mathematics. No credit granted to those who have completed a 200- (or higher) level mathematics course.*  
 An introduction to the mathematical concepts and techniques used by financial institutions. Topics include rates of simple and compound interest and present and accumulated values; annuity functions and applications to amortization, sinking funds and bond values; depreciation methods; introduction to life tables, life annuities and life insurance value.
- 156 **MATH 156.**  
**Applied Honors Calculus II.**  
 (4,4) : May not be repeated for credit.  
 (MSA). (BS). (QR/1).  
*Score of 4 or 5 on the AB or BC Advanced Placement calculus exam. Credit is granted for only one course among MATH 116, 119, 156, 176, and 186. I.*  
 Second term calculus for engineering and science concentrators. Topics include applications of integral calculus, improper integrals, sequences and series, differential equations. complex numbers, MAPLE.

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- 174 **MATH 174.**  
**Plane Geometry: An Introduction to Proofs.**  
 (4) : May not be repeated for credit.  
 (MSA). (BS). (QR/1).  
*Consent of department (Prerequisites enforced at registration). Permission of Honors advisor. Only first-year students, including those with sophomore standing, may pre-register for First-Year Seminars. All others need permission of instructor. No credit granted to those who have completed a 200-level or higher Mathematics course.*  
 This course introduces students to rigorous mathematical thinking, and writing proofs using plane geometry.
- 175 **MATH 175.**  
**An Introduction to Cryptology.**  
 (4,4) : May not be repeated for credit.  
 (MSA). (BS). (QR/1).  
*A strong mathematical background is helpful. Permission of department required. Only first-year students, including those with sophomore standing, may pre-register for First-Year Seminars. All others need permission of instructor. No credit granted to those who have completed a 200-level or higher Mathematics course. I.*  
 Introduces students to the science of constructing and attacking secret codes. An important goal is to present the mathematical tools – from combinatorics, number theory, and probability – that underlie cryptologic methods.
- 185 **MATH 185.**  
**Honors Calculus I.**  
 (4,4) : May not be repeated for credit.  
 (MSA). (BS). (QR/1).  
*Permission of the Honors advisor. Credit is granted for only one course from among MATH 115, and 185. I.*  
 Topics covered include functions and graphs, derivatives, differentiation of algebraic and trigonometric functions and applications, definite and indefinite integrals and applications. Other topics are included at the discretion of the instructor.
- 186 **MATH 186.**  
**Honors Calculus II.**  
 (4,4) : May not be repeated for credit.  
 (MSA). (BS). (QR/1).  
*Permission of the Honors advisor. Credit is granted for only one course from among MATH 116, 119, 156, 176, and 186. II.*  
 Topics covered include transcendental functions, techniques of integration, introduction to differential equations, conic sections, and infinite sequences and series. Other topics included at the discretion of the instructor.
- 214 **MATH 214.**  
**Linear Algebra and Differential Equations.**  
 (4,4) : May not be repeated for credit.  
 (MSA). (BS). (QR/1).  
*MATH 115 and 116. Credit can be earned for only one of MATH 214, 217, 417, or 419. No credit granted to those who have completed or are enrolled in MATH 513. Most students take only one course from among MATH 214, 217, 417, 419, and 513.*  
 This course is an alternative to MATH 216 (Differential Equations) in that it emphasizes linear algebra including the geometry of two, three and n-dimensional space, and has a lighter treatment of differential equations. It is particularly designed for students who are planning to take a course in linear programming.
- 215 **MATH 215.**  
**Calculus III.**  
 (4,4) : May not be repeated for credit.  
 (MSA). (BS). (QR/1).  
*MATH 116. Credit can be earned for only one of MATH 215, 255, or 285. I, II, IIIa, IIIb.*  
 Topics include vector algebra and vector functions; analytic geometry of planes, surfaces, and solids; functions of several variables and partial differentiation; line, surface, and volume integrals and applications; vector fields and integration; Green's Theorem and Stokes' Theorem. There is a weekly computer lab using MAPLE software.

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- 216 **MATH 216.**  
**Introduction to Differential Equations.**  
 (4,4) : May not be repeated for credit.  
 (MSA). (BS). (QR/1).  
*MATH 116, 119, 156, 176, 186, or 296. Credit can be earned for only one of MATH 216, 256, 286, or 316. I, II, IIIa, IIIb.*  
 MATH 216 is a basic course on differential equations, intended for engineers and other scientists who need to apply the techniques in their work. The lectures are accompanied by a computer lab and recitation section where students have the opportunity to discuss problems and work through computer experiments to further develop their understanding of the concepts of the class. Topics covered include some material on complex numbers and matrix algebra, first and second order linear and non-linear systems with applications, introductory numerical methods, and elementary Laplace transform techniques.
- 217 **MATH 217.**  
**Linear Algebra.**  
 (4,4) : May not be repeated for credit.  
 (MSA). (BS). (QR/1).  
*MATH 215, 255, or 285. Credit can be earned for only one of MATH 214, 217, 417, or 419. No credit granted to those who have completed or are enrolled in MATH 513. Most students take only one course from among MATH 214, 217, 417, 419, and 513.*  
 The topics covered include: systems of linear equations; matrix algebra; vectors, vector spaces, and subspaces; geometry of  $\mathbb{R}^n$ ; linear dependence, bases, and dimension; linear transformations; Eigenvalues and Eigenvectors; diagonalization; inner products.
- 255 **MATH 255.**  
**Applied Honors Calculus III.**  
 (4,4) : May not be repeated for credit.  
 (MSA). (BS). (QR/1).  
*MATH 156. Credit can be earned for only one of MATH 215, 255, or 285. II.*  
 Multivariable calculus, line, surface and volume integrals, vector fields, Green's theorem, Stokes theorem, divergence theorem, applications, MAPLE.
- 256 **MATH 256.**  
**Applied Honors Calculus IV.**  
 (4,4) : May not be repeated for credit.  
 (MSA). (BS). (QR/1).  
*MATH 255. Credit can be earned for only one of MATH 216, 256, 286, or 316. I.*  
 Linear algebra, matrices, systems of differential equations, initial and boundary value problems, qualitative theory of dynamical systems, nonlinear equations, numerical methods, MAPLE.
- 285 **MATH 285.**  
**Honors Calculus III.**  
 (4,4) : May not be repeated for credit.  
 (MSA). (BS). (QR/1).  
*MATH 176 or 186, or permission of the Honors advisor. Credit can be earned for only one of MATH 215, 255, or 285. I.*  
 Topics covered include vector algebra and vector functions; analytic geometry of planes, surfaces, and solids; function of several variables and partial differentiation; line surface and volume integrals and applications; vector fields and integration; Green's Theorem; Stokes' Theorem.
- 286 **MATH 286.**  
**Honors Differential Equations.**  
 (3,3) : May not be repeated for credit.  
 (MSA). (BS). (QR/1).  
*MATH 285. Credit can be earned for only one of MATH 216, 256, 286, or 316. II.*  
 Topics include first-order differential equations, higher-order linear differential equations with constant coefficients; linear systems.

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- 288 **MATH 288.**  
**Math Modeling Workshop.**  
 (1,1) : May be repeated for credit for a maximum of 3 credits.  
 (Excl).  
*MATH 216, 256, 286, or 316; and MATH 214, 217, 417, or 419. Offered mandatory credit/no credit.*  
 Each weekly session describes formulation and solution of a real-world problem, using array of techniques from undergraduate mathematics.
- 289 **MATH 289.**  
**Problem Seminar.**  
 (1,1) : May be repeated for credit. Repetition requires permission of the department.  
 (Excl). (BS).  
 Focuses on the development of mathematical problem-solving skills. Problems are taken from classical analysis, elementary number theory, and geometry. For students with outstanding problem-solving ability.
- 295 **MATH 295.**  
**Honors Mathematics I.**  
 (4,4) : May not be repeated for credit.  
 (MSA). (BS). (QR/1).  
*Prior knowledge of first year calculus and permission of the Honors advisor. I.*  
 Introduction to mathematical analysis with emphasis on proofs and theory. Covers such topics as set theory, construction of the real number field, limits of sequences and functions, continuity, elementary functions, derivatives and integrals. Additional topics may include countability, topology of real numbers, infinite series, uniform continuity.
- 296 **MATH 296.**  
**Honors Mathematics II.**  
 (4,4) : May not be repeated for credit.  
 (Excl). (BS). (QR/1).  
*MATH 295. II.*  
 Topics generally include infinite series, power series, Taylor expansion, metric spaces. Other topics may include applications of analysis, Weierstrass Approximation theorem, elements of topology, introduction to linear algebra, complex numbers.
- 310 **MATH 310.**  
**Elementary Topics in Mathematics.**  
 (3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*Two years of high school mathematics.*  
 A course for students that conveys the spirit, ideas, and some methods of mathematics through the study of a few elementary problems in depth. The course is designed for students who like mathematics and may be interested in taking further mathematics courses.
- 312 **MATH 312.**  
**Applied Modern Algebra.**  
 (3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 217. Only one credit granted to those who have completed MATH 412. II.*  
 Groups, rings, and fields, including modular arithmetic, polynomial rings, linear algebra over finite fields, and permutation groups. Applications from areas such as error-correcting codes, cryptography, computational algebra, and the Pólya method of enumeration.
- 316 **MATH 316.**  
**Differential Equations.**  
 (3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 215 and 217. Credit can be earned for only one of MATH 216, 256, 286, or 316.*  
 First-order equations: solutions, existence and uniqueness, and numerical techniques; linear systems: eigenvector-eigenvalue solutions of constant coefficient systems, fundamental matrix solutions, nonhomogeneous systems; higher-order equations, reduction of order, variation of parameters, series solutions; qualitative behavior of systems, equilibrium points, stability.

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- 327 **MATH 327.**  
**Evolution of Mathematical Concepts.**  
 (3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 116 or 186.*  
 This course follows the historical evolution of three fundamental mathematical ideas, in geometry, analysis and algebra – Euclid's parallels postulate and the development of non-Euclidean geometries, the notion of limit and infinitesimals, and the development of the theory of equations culminating with Galois theory.
- 333 **MATH 333.**  
**Directed Tutoring.**  
 (1-3,1-3) : May be repeated for credit for a maximum of 3 credits.  
 (Excl). (EXPERIENTIAL).  
*Consent of instructor required (Prerequisites enforced at registration). Enrollment in the secondary teaching certificate program with concentration in mathematics. Offered mandatory credit/no credit. I, II, IIIa.*  
 An experiential mathematics course for students enrolled in the Secondary Teaching Certificate Program with a concentration in mathematics. Students would tutor pre-calculus (MATH 105) or calculus (MATH 115) in the Math. Lab. They would also participate in a weekly seminar to discuss mathematical and methodological questions.
- 351 **MATH 351.**  
**Principles of Analysis.**  
 (3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 215 and 217. No credit granted to those who have completed or are enrolled in MATH 451.*  
 An examination of some of the fundamental ideas of Calculus. Analysis of the real line, rational and irrational numbers, infinity - large and small limits, convergence, infinite sequences and series, continuous functions, power series, differentiation.
- 354 **MATH 354.**  
**Fourier Analysis and its Applications.**  
 (3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 216, 256, 286, or 316. No credit granted to those who have completed or are enrolled in MATH 450 or 454.*  
 Fourier series; discrete Fourier transforms, and continuous Fourier transforms, with applications to subjects such as signal processing and filtering; Fourier optics; partial differential equations (Poisson, heat, and wave equations); probability theory (random walks); and Weyl's theorem on equidistribution of arithmetic sequences.
- 371 **MATH 371 / ENGR 371.**  
**Numerical Methods for Engineers and Scientists.**  
 (3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*ENGR 101; one of MATH 216, 256, 286, or 316; and one of MATH 215, 217, 417, or 419. No credit granted to those who have completed or are enrolled in Math 471 or 472. CAEN lab access fee required for non-Engineering students.*  
 A survey course of the basic numerical methods which are used to solve scientific problems. In addition, concepts such as accuracy, stability and efficiency are discussed. The course provides an introduction to MATLAB, an interactive program for numerical linear algebra as well as practice in computer programming.
- 385 **MATH 385.**  
**Mathematics for Elementary School Teachers.**  
 (3,3) : May not be repeated for credit.  
 (Excl).  
*One year each of high school algebra and geometry. No credit granted to those who have completed or are enrolled in MATH 485.*  
 The history, development, and logical foundations of the real number system and of numeration systems including scales of notation; simple algebra, functions and graphs; and geometric relations.

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- 389 **MATH 389.**  
**Explorations in Mathematics.**  
 (3) : May not be repeated for credit.  
 (Excl). (BS).  
*Consent of instructor required (Prerequisites enforced at registration). MATH 215 and familiarity with Maple or other math modeling computer program.*  
 This course is designed to show students how new mathematics is actually created: how to take a problem, make models and experiment with them, and search for underlying structure. Students also learn how to explain their findings clearly and how to work effectively in a group.
- 395 **MATH 395.**  
**Honors Analysis I.**  
 (4,4) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 296 or permission of the Honors advisor. I.*  
 Functions of several real variables. Topics are chosen from elementary linear algebra, elementary topology, differential and integral calculus of scalar- and vector-valued functions and vector valued mappings, implicit and inverse function theorems.
- 396 **MATH 396.**  
**Honors Analysis II.**  
 (4,4) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 395. II.*  
 Differential and integral calculus of functions on Euclidean spaces. Designed primarily for mathematics Honors students who have had MATH 295, 296 and 395.
- 399 **MATH 399.**  
**Independent Reading.**  
 (1-6,1-6) : May be repeated for credit.  
 (Excl). (INDEPENDENT).  
*Consent of instructor required (Prerequisites enforced at registration). I, II, III, IIIa, IIIb.*  
 Designed especially for honors students.
- 429 **MATH 429.**  
**Internship.**  
 (1,1) : May be elected up to three times for credit.  
 (Excl). (EXPERIENTIAL).  
*Concentration in Mathematics. Internship credit is not retroactive and must be prearranged. May not apply toward a Mathematics concentration. May be used to satisfy the Curriculum Practical Training (CPT) required of foreign students. Offered mandatory credit/no credit.*  
 Credits is granted for a full-time internship of at least eight weeks that is used to enrich a student's academic experience and/or allows the student to explore careers related to his/her academic studies.
- 145 **MATH 145.**  
**Houghton Scholars Calculus Workshop I.**  
 (2) : May not be repeated for credit.  
 (Excl).  
*Consent of department (Prerequisites enforced at registration). Concurrent enrollment in MATH 115. Offered mandatory credit/no credit.*  
 An intensive supplemental workshop experience for students in the Douglass Houghton Scholars Program. In a small-class setting, students work in small groups on problems more challenging than those in the regular section of Math 115. The goal is to develop the students' problem-solving capabilities and promote their interest in challenging problems.

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- 146 **MATH 146**  
**Houghton Scholars Calculus Workshop II**  
 (2) : May not be repeated for credit.  
 (Excl).  
*Consent of department (Prerequisites enforced at registration). Concurrent enrollment in MATH 116. Offered mandatory credit/no credit.*  
 For students in the Douglass Houghton Scholars Program. Continuation of MATH 145.

### Undergraduate and Graduate Courses

- 404 **MATH 404.**  
**Intermediate Differential Equations and Dynamics.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 216, 256 or 286, or 316.*  
 Geometric representations of solutions, autonomous systems, flows and evolution, linear systems and phase portraits, nonlinear systems, local and global behavior, linearization, stability, conservation laws, periodic orbits. Applications: free and forced oscillations, resonance, relaxation oscillations, competing species, Zeeman's models of heartbeat and never impulse, chaotic orbits, strange attractors.
- 412 **MATH 412.**  
**Introduction to Modern Algebra.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 215, 255, or 285; and 217. No credit granted to those who have completed or are enrolled in MATH 512. Students with credit for MATH 312 should take MATH 512 rather than 412. One credit granted to those who have completed MATH 312.*  
 Sets, functions (mapping, relations, and the common number systems (integers to complex numbers). These are then applied to the study of groups and rings. These structures are presented as abstractions from many examples. Notions such as generator, subgroup, direct product, isomorphism and homomorphism.
- 416 **MATH 416.**  
**Theory of Algorithms.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 312 or 412 or EECS 203, and EECS 281.*  
 Sorting, searching, matrix multiplication, graph problems (flows, traveling salesman), and primality and pseudoprimality testing (in connection with coding). Algorithm types as divide and conquer, backtracking, greedy and dynamic programming are analyzed using generating functions, recurrence relations, induction and recursion, graphs and trees, and permutations. A possible section on complexity theory and NP completeness.
- 417 **MATH 417.**  
**Matrix Algebra I.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*Three courses beyond MATH 110. Credit can be earned for only one of MATH 214, 217, 417, or 419. No credit granted to those who have completed or are enrolled MATH 513. Most students take only one course from among MATH 214, 217, 417, 419, and 513. I, II, IIIa, IIIb.*  
 Matrix operations, vector spaces, Gaussian and Gauss-Jordan algorithms for linear equations, subspaces of vector spaces, linear transformations, determinants, orthogonality, characteristic polynomials, eigenvalue problems and similarity theory. Applications include linear networks, least squares method, discrete Markov Processes, linear programming.

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- 419 **MATH 419.**  
**Linear Spaces and Matrix Theory.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*Four courses beyond MATH 110. Credit can be earned for only one of MATH 214, 217, 417, or 419. No credit granted to those who have completed or are enrolled in MATH 513. Most students take only one course from among MATH 214, 217, 417, 419, and 513. I and II. I, II, IIIb.*  
 Finite dimensional linear spaces and matrix representation of linear transformations; bases, subspaces, determinants, eigenvectors, and canonical forms; and structure of solutions of systems of linear equations. Applications to differential and difference equations. The course provides more depth and content than MATH 417. MATH 513 is the proper election for students contemplating research in mathematics.
- 422 **MATH 422 / BE 440.**  
**Risk Management and Insurance.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 115, junior standing, and permission of instructor. Business School Network fee may be required for non-Business students.*  
 We explore how much insurance affects the lives of students (automobile insurance, social security, health insurance, theft insurance) as well as the lives of other family members (retirements, life insurance, group insurance). While the mathematical models are important, an ability to articulate why the insurance options exist and how they satisfy the consumer's needs are equally important. In addition, there are different options available (e.g., in social insurance programs) that offer the opportunity of discussing alternative approaches.
- 423 **MATH 423.**  
**Mathematics of Finance.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 217 and 425; EECS 183.*  
 Introduction to mathematical models in finance and economics with particular emphasis on models for pricing derivative instruments such as options and futures. Topics include risk and return theory, portfolio theory, capital asset pricing model, random walk model, stochastic processes, Black-Scholes Analysis, numerical methods and interest rate models.
- 424 **MATH 424.**  
**Compound Interest and Life Insurance.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 215, 255, or 285.*  
 Rates used in compound interest theory; annuities-certain and their application to amortization, sinking funds, and bond values; and introduction to life annuities and life insurance. Both the discrete and the continuous approach are used.
- 425 **MATH 425 / STATS 425.**  
**Introduction to Probability.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 215, 255, or 285. I, II, IIIa, IIIb.*  
 Basic concepts of probability, discrete sample spaces, conditional probabilities and independence of events, random variables, expectation and variance, binomial and Poisson distribution, DeMoivre-Laplace limit theorem, and introduction to continuous probability.
- 427 **MATH 427.**  
**Retirement Plans and Other Employee Benefit Plans.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*Junior standing.*  
 The development of employee benefit plans, both public and private. Particular emphasis is laid on modern pension plans and their relationships to current tax laws and regulations, benefits under the federal social security system, and group insurance.

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- 431 **MATH 431.**  
**Topics in Geometry for Teachers.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl).  
*MATH 215, 255, or 285. I.*  
 Investigation of Euclidean geometry based on the Birkhoff or SMSG metric axiom system and reference to contemporary high school texts. Comparison with synthetic Euclid-Hilbert foundations. Historical development of absolute and hyperbolic geometry. Other non-Euclidean geometries. New directions in high school geometry, transformation groups especially isometries of the Euclidean plane as generated by reflections, similarities, and affine transformations.
- 433 **MATH 433.**  
**Introduction to Differential Geometry.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 215 (or 255 or 285), and 217. I.*  
 Curves and surfaces in three-space, using calculus. Curvature and torsion of curves. Curvature, covariant differentiation, parallelism, isometry, geodesics, and area on surfaces. Gauss-Bonnet Theorem. Minimal surfaces.
- 450 **MATH 450.**  
**Advanced Mathematics for Engineers I.**  
 (4,4;4,4) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 215, 255, or 285. No credit granted to those who have completed or are enrolled in MATH 354 or 454. I, II, IIIb.*  
 Topics covered include: Fourier series and integrals; the classical partial differential equations (the heat, wave, and Laplace's equations) solved by separation of variables; an introduction to complex variables and conformal mapping with applications to potential theory. A review of series and series solutions of ODEs are included as needed. A variety of basic diffusion, oscillation, and fluid flow problems are discussed.
- 451 **MATH 451.**  
**Advanced Calculus I.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*Previous exposure to abstract mathematics (MATH 217 and 412). No credit granted to those who have completed or are enrolled in MATH 351. I, II, IIIa.*  
 Calculus of functions of one variable, including their expansions into power series, and foundations of calculus of functions of two or more variables.
- 452 **MATH 452.**  
**Advanced Calculus II.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 217, 419, or 513; and MATH 451. II.*  
 Partial derivatives and differentiability; gradients, directional derivatives, and the chain rule; implicit function theorem; surfaces, tangent plane; max-min theory; multiple integration, change of variable; Green's and Stokes' theorems, differential forms, exterior surfaces; intro to differential geometry.
- 454 **MATH 454.**  
**Boundary Value Problems for Partial Differential Equations.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 216, 256, 286, or 316. Students with credit for MATH 354 can elect MATH 454 for one credit. No credit granted to those who have completed or are enrolled in MATH 450. I, II, IIIa.*  
 Classical representation and convergence theorems for Fourier series; method of separation of variables for the solution of the one-dimensional heat and wave equations in higher dimensions; eigen-function expansions; spherical and cylindrical Bessel functions; Legendre polynomials; methods for evaluating asymptotic integrals (Laplace's method, steepest descent); Laplace's equation and harmonic functions, including the maximum principle.

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- 462 **MATH 462.**  
**Mathematical Models.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 216, 256, 286, or 316; and MATH 214, 217, 417, or 419. Students with credit for MATH 362 must have department permission to elect MATH 462.*  
 Construction and analysis of mathematical models involving probability, combinatorics, decision theory, optimization, games, and dynamics. Applications to some of the physical, social, life, and decision sciences.
- 463 **MATH 463.**  
**Mathematical Modeling in Biology.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 214, 217, 417, or 419; MATH 216, 256, 286, or 316.*  
 An introduction to the use of continuous and discrete differential equations in the biological sciences. Modeling in biology, physiology, and medicine.
- 471 **MATH 471.**  
**Introduction to Numerical Methods.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 216, 256, 286, or 316; and 214, 217, 417, or 419; and a working knowledge of one high-level computer language. No credit granted to those who have completed or are enrolled in MATH 371 or 472. I, II, IIIb.*  
 Computer arithmetic; Newton's method for nonlinear equations; polynomial interpolation, numerical integration, systems of linear equations; initial value problems for ordinary differential equations; quadrature; partial pivoting, spline approximations, partial differential equations; Monte Carlo methods.
- 472 **MATH 472.**  
**Numerical Methods with Financial Applications.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 256, 286 or 316; MATH 217, 417, or 419; and working knowledge of a high-level computer language. MATH 425 is recommended. No credit granted to those who have completed or are enrolled in MATH 471 or 371.*  
 Theoretical study and practical implementation of numerical methods for scientific problems, with emphasis on financial applications. Topics: Newton's method for nonlinear equations; systems of linear equations; numerical integration; interpolation and polynomial approximation; ordinary differential equations; partial differential equations, in particular the Black-Scholes equation; Monte Carlo simulation; numerical modeling.
- 475 **MATH 475.**  
**Elementary Number Theory.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*At least three terms of college mathematics are recommended. II.*  
 Theory of congruences, Euler's phi-function, diophantine equations, and quadratic domains.
- 476 **MATH 476.**  
**Computational Laboratory in Number Theory.**  
 (1,1;1,1) : May not be repeated for credit.  
 (Excl). (BS).  
*Prior or concurrent enrollment in MATH 475 or 575. II.*  
 Students conduct numerical explorations using software tailored for the purpose.

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- 481 **MATH 481.**  
**Introduction to Mathematical Logic.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 412 or 451 or equivalent experience with abstract mathematics. I.*  
 In the first third of the course the notion of a formal language is introduced and propositional connectives, tautologies and tautological consequences are studied. The heart of the course is the study of 1st order predicative languages and their models. New elements here are quantifiers. Notions of truth, logical consequences and probability lead to completeness and compactness. Applications.
- 485 **MATH 485.**  
**Mathematics for Elementary School Teachers and Supervisors.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl).  
*One year of high school algebra. No credit granted to those who have completed or are enrolled in MATH 385. May not be included in a concentration plan in mathematics. Does not apply to any math degree programs. I and IIIb.*  
 The history, development, and logical foundations of the real number system and of numeration systems including scales of notation, cardinal numbers, and the cardinal concept; and the logical structure of arithmetic (field axioms) and relations to the algorithms of elementary school instruction. Simple algebra, functions, and graphs. Geometric relationships. For persons teaching in or preparing to teach in the elementary school.
- 486 **MATH 486.**  
**Concepts Basic to Secondary Mathematics.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 215, 255, or 285. II.*  
 Foundations of algebra and geometry with implications for secondary teaching. Modern approaches to trigonometry and analytic geometry.
- 489 **MATH 489.**  
**Mathematics for Elementary and Middle School Teachers.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl).  
*MATH 385 or 485. May not be used in any graduate program in mathematics. Not to apply on any graduate program in mathematics.*  
 The second course in a two-course sequence required of elementary teaching certificate candidates. Topics covered include: the real-number system, probability, and statistics, geometry and measurement.
- 490 **MATH 490.**  
**Introduction to Topology.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 451 or equivalent experience with abstract mathematics. II.*  
 The topics covered are fairly constant but the presentation and emphasis varies significantly with the instructor. Point-set topology, examples of topological spaces, orientable and non-orientable surfaces, fundamental groups, homotopy, covering spaces. Metric and Euclidean spaces are emphasized.
- 497 **MATH 497.**  
**Topics in Elementary Mathematics.**  
 (3,3;3,3) : May be repeated for credit for a maximum of 6 credits.  
 (Excl). (BS).  
*MATH 489. I.*  
 Selected topics in geometry, algebra, computer programming, logic, and combinatorics for prospective and in-service teachers of elementary, middle, or junior high school mathematics. Content may vary from term to term.

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- 501 **MATH 501.**  
**Applied & Interdisciplinary Mathematics Student Seminar.**  
 (1,1;1,1) : May be repeated for credit for a maximum of 6 credits.  
 (Excl).  
*At least two 300 or above level math courses, and graduate standing; Qualified undergraduates with permission of instructor only.*  
*Offered mandatory credit/no credit.*  
 MATH 501 is an introductory and overview seminar course in the methods and applications of modern mathematics. The seminar has two key components: (1) participation in the Applied & Interdisciplinary Math Research Seminar; and (2) preparatory and post-seminar discussions based on these presentations. Topics vary by term.
- 512 **MATH 512.**  
**Algebraic Structures.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 451 or 513. II.*  
 Description and in-depth study of the basic algebraic structure groups, rings, fields including: set theory, relations, quotient groups, permutation groups, Sylow's Theorem, quotient rings, field of fractions, extension fields, roots of polynomials, straight-edge and compass solutions, and other topics.
- 513 **MATH 513.**  
**Introduction to Linear Algebra.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 412 or equivalent experience with abstract mathematics. Two credits granted to those who have completed MATH 214, 217, 417, or 419.*  
 Vector spaces, linear transformations and matrices, equivalence of matrices and forms, canonical forms, and application to linear differential equations.
- 520 **MATH 520.**  
**Life Contingencies I.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 424 and 425. I.*  
 The comprehensive study of annuity and insurance functions for single lives, population theory, topics in actuarial practice.
- 521 **MATH 521.**  
**Life Contingencies II.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 520. II.*  
 The comprehensive study of annuity and insurance functions for joint lives; multiple decrement theory and applications to accidental death and disability insurances; topics in actuarial practice.
- 523 **MATH 523.**  
**Risk Theory.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 425.*  
 Topics include utility theory, application to buying general insurance to reduce risk, compound distribution models for risk portfolios, application of stochastic processes to the ruin problem and to reinsurance.
- 524 **MATH 524.**  
**Topics in Actuarial Science II.**  
 (3,3;3,3) : May be repeated for credit for a maximum of 9 credits.  
 (Excl). (BS).  
*MATH 424 and 425.*  
 Topics vary by term. Mathematics of Demography; Mathematics of Graduation; Survival Modes and Construction of Mortality Tables.

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- 525 **MATH 525 / STATS 525.**  
**Probability Theory.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 451 (strongly recommended) or 450. MATH 425 would be helpful.*  
 Axiomatic probability; combinatorics; random variables and their distributions; expectation; the mean, variance, and moment generating function; induced distributions; sums of independent random variables; the law of large numbers; the central limit theorem. Optional topics drawn from: random walks, Markov chains, and/or martingales.
- 526 **MATH 526 / STATS 526.**  
**Discrete State Stochastic Processes.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 525 or EECS 501.*  
 Review of discrete distributions; generating functions; compound distributions, renewal theorem; modeling of systems as Markov chains; Markov chains: first properties; Chapman-Kolmogorov equations; return and first passage times; classification of states and periodicity; absorption probabilities and the forward equation; stationary distributions and the backward equation; ergodicity; limit properties; application to branching and queueing processes; examples from engineering, biological, and social sciences; Markov chains in continuous time; embedded chains; the M/G/1 queue; Markovian decision processes; application to inventory problems; other topics at instructor's discretion.
- 528 **MATH 528.**  
**Topics in Casualty Insurance.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 217, 417, or 419.*  
 An introduction to property and casualty insurance including policy forms, underwriting, product design and modification, rate making and claim settlement.
- 531 **MATH 531.**  
**Transformation Groups in Geometry.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 451 or equivalent experience with abstract mathematics.*  
 Isometries and congruences in the Euclidean plane as generated by reflections, translations, and half-turns. Tilings, affine and hyperbolic geometries, and Poincaré model of the hyperbolic plane. Selected applications to ornamental design, crystallography, and regular polytopes.
- 555 **MATH 555.**  
**Introduction to Functions of a Complex Variable with Applications.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 451 or equivalent experience with abstract mathematics.*  
 Intended primarily for students of engineering and of other cognate subjects. Doctoral students in mathematics elect MATH 596. Complex numbers, continuity, derivative, conformal representation, integration, Cauchy theorems, power series, singularities, and applications to engineering and mathematical physics.
- 556 **MATH 556.**  
**Methods of Applied Mathematics I.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 217, 419, or 513; 451 and 555. I.*  
 A study of some of the differential equations of mathematical physics and methods for their solution. Separation of variables for heat, wave, Laplace's and Schrödinger's equations; special functions and their integral representations and asymptotic properties; and eigenvalues as solutions of variational problems.

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- 557 **MATH 557.**  
**Methods of Applied Mathematics II.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 217, 419, or 513; 451 and 555. II.*  
 Elementary distributions, Green's functions and integral solutions for nonhomogeneous problems, Fourier and Hankel transforms, and Fredholm alternative and elementary methods of solution of integral equations, with additional topics as time permits.
- 558 **MATH 558.**  
**Ordinary Differential Equations.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 450, 451, or 454.*  
 Existence and uniqueness theorems for flows, linear systems, Floquet theory, Poincaré-Bendixson theory, Poincaré maps, periodic solutions, stability theory, Hopf bifurcations, chaotic dynamics.
- 559 **MATH 559.**  
**Selected Topics in Applied Mathematics.**  
 (3,3;3,3) : May be repeated for credit for a maximum of 6 credits.  
 (Excl). (BS).  
*MATH 451; and MATH 217, 419, or 513.*  
 Covers a branch of mathematics which has been strongly influenced by another science. The instructor educates the student in the intuitions of that science as well as present mathematical proofs.
- 561 **MATH 561 / IOE 510 / OMS 518.**  
**Linear Programming I.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 217, 417, or 419. CAEN lab access fee required for non-Engineering students. Business School Network fee may be required for non-Business students. I, II, IIIa.*  
 Formulation of problems from the private and public sectors using the mathematical model of linear programming. Development of the simplex algorithm; duality theory and economic interpretations. Postoptimality (sensitivity) analysis and applications and interpretations. Introduction to transportation and assignment problems and special purpose algorithms and advanced computational techniques. Students have an opportunity to formulate and solve models developed from more complex case studies and to use various computer programs.
- 562 **MATH 562 / IOE 511.**  
**Continuous Optimization Methods.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 217, 417, or 419. CAEN lab access fee required for non-Engineering students. I.*  
 Survey of continuous optimization problems. Unconstrained optimization problems: unidirectional search techniques including conjugate directions and gradient and variable metric methods. Constrained optimization problems: unconstrained techniques including penalty and barrier methods and constraint techniques including methods of feasible directions, gradient projection method, and linear constraint methods. Practical applications are emphasized.
- 565 **MATH 565.**  
**Combinatorics and Graph Theory.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 412 or 451 or equivalent experience with abstract mathematics. I.*  
 Graph Theory: trees, k-connectivity; Eulerian and Hamiltonian graphs; tournaments; graph coloring; planar graphs, Euler's formula, 5-color theorem, Kuratowski's theorem and matrix-tree theorem; Enumeration; fundamental principles, bijections, generating functions, binomial theorem, partitions and 1 series, linear recurrences, generating functions and Pólya theory.

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- 566 **MATH 566.**  
**Combinatorial Theory.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 412 or 451 or equivalent experience with abstract mathematics.*  
 Permutations, combinations, generating functions, and recurrence relations. The existence and enumeration of finite, discrete configurations. Systems of representatives, Ramsey's theorem, and external problems. Construction of combinatorial designs.
- 567 **MATH 567.**  
**Introduction to Coding Theory.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*One of MATH 217, 419, 513.*  
 This course is an introduction to coding for error correction. Topics include: linear codes and their parameters, decoding algorithms, asymptotically good sequences of codes.
- 571 **MATH 571.**  
**Numerical Methods for Scientific Computing I.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 214, 217, 417, 419, or 513; and one of MATH 450, 451, or 454.*  
 Topics covered usually include direct and iterative methods for solving systems of linear equations, least squares methods, and computation of eigenvectors and eigenvalues.
- 572 **MATH 572.**  
**Numerical Methods for Scientific Computing II.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 214, 217, 417, 419, or 513; and one of MATH 450, 451, or 454. II.*  
 Topics include one step, multistep, and stiff methods for initial value problems for ODE's, stability and convergence, hyperbolic, elliptic, and parabolic PDE's, CFL condition, von Neumann stability, finite element methods, spectral methods.
- 575 **MATH 575.**  
**Introduction to Theory of Numbers I.**  
 (1-3,1-3;1-3,1-3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 451 and 513. Students with credit for MATH 475 can elect MATH 575 for 1 credit. I.*  
 Elementary theory of congruences, the quadratic reciprocity law, and properties of number theoretic functions.
- 582 **MATH 582.**  
**Introduction to Set Theory.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 412 or 451 or equivalent experience with abstract mathematics. II.*  
 The main topics are set algebra (union, intersection), relations and functions, orderings (partial-, linear-, well-), the natural numbers, finite and denumerable sets, the Axiom of Choice, and ordinal and cardinal numbers.
- 591 **MATH 591.**  
**General and Differential Topology.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 451. I.*  
 Topological and metric spaces, continuity, subspaces, products and quotient topology, compactness and connectedness, extension theorems, topological groups, topological and differential manifolds, tangent spaces vector fields, submanifolds, inverse function theorem, immersions, submersions, partitions of unity, Sard's theorem, embedding theorems, transversality, classification of surfaces.

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- 592 **MATH 592.**  
**Introduction to Algebraic Topology.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 591. II.*  
 Fundamental group, covering spaces, simplicial complexes, graphs and trees, applications to group theory, singular and simplicial homology, Eilenberg-MacLane axioms, Brouwer's and Lefschetz's fixed point theorems and other topics.
- 593 **MATH 593.**  
**Algebra I.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 513. I.*  
 Rings and modules. Euclidean rings, PIDs, classification of modules over a PID. Jordan and rational canonical forms. Structure of bilinear forms. Tensor products of modules; exterior algebras.
- 594 **MATH 594.**  
**Algebra II.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 593. II.*  
 Group theory. Permutation representations, simplicity of alternating groups for  $n > 4$ . Sylow theorems. Series in groups; solvable and nilpotent groups. Jordan-Hoelder for groups with operators. Free groups and presentations. Field extensions, norm and trace, algebraic closures. Galois theory. Transcendence degree.
- 596 **MATH 596.**  
**Analysis I.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 451. Students with credit for MATH 555 may elect MATH 596 for two credits only.*  
 Review of analysis in several variables including metric spaces, differentiable maps, Cauchy-Riemann equations, automorphisms. Analytic functions, Cauchy integral formula. Power series and Laurent expansions, fundamental theorem of algebra, harmonic functions. Functions analytic in a disk. Global properties of analytic functions. Riemann mapping theorem. Normal families.
- 597 **MATH 597.**  
**Analysis II.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 451 and 513. II.*  
 Lebesgue measure on the real line. Measurable functions and integration of  $\mathbb{R}$ . Differentiation theory, fundamental theory of calculus. Function spaces,  $L^p(\mathbb{R})$ ,  $C(K)$ , Holder and Minkowski inequalities, duality. General measure spaces, product measures, Fubini's theorem. Radon-Nikodym theorem, conditional expectation, signed measures.

### Graduate Courses

- 499 **MATH 499.**  
**Independent Reading.**  
 (1-4,1-4) : May not be repeated for credit.  
 (Excl). (INDEPENDENT).  
*Consent of instructor required (Prerequisites enforced at registration). Graduate standing in a field other than mathematics. Permission of instructor required.*  
 This course is intended for graduate students in fields other than mathematics who require mathematical skills not otherwise available through existing courses.

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- 537 **MATH 537.**  
**Introduction to Differentiable Manifolds.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 513, and 590 or 591. I.*  
 Manifolds, maps, and vector bundles with applications to flows, the Frobenius theorem, Riemannian manifolds, Stokes' theorem, Sard's theorem, embedding theorems, and the tubular neighborhood theorem.
- 542 **MATH 542 / IOE 552.**  
**Financial Engineering Seminar I.**  
 (3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 423, IOE 452 or IOE 453; and a solid background in basic probability theory.*  
 Theory and applications of financial engineering. Designing, structuring and pricing financial engineering products (including options, futures, swaps and other derivative securities) and their applications to financial and investment risk management. Mathematical methodology that forms the basis of financial engineering, applied stochastic processes and numerical methods in particular.
- 543 **MATH 543 / IOE 553.**  
**Financial Engineering Seminar II.**  
 (3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 542 or IOE 552 (Prerequisites enforced at registration).*  
 Advanced issues in financial engineering: stochastic interest rate modeling and fixed income markets, derivatives trading and arbitrage, international finance, risk management methodologies include in Value-at-Risk and credit risk. Multivariate stochastic calculus methodology in finance: multivariate Ito's lemma, Ito's stochastic integrals, the Feynman-Kac theorem and Girsanov's theorem.
- 547 **MATH 547 / STATS 547 / BIOINF 547.**  
**Probabilistic Modeling in Bioinformatics.**  
 (3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 425 or MCDB 427 or BIOLCHEM 415; basic programming skills desirable. Graduate standing and permission of instructor.*  
 Probabilistic models of proteins and nucleic acids. Analysis of DNA/RNA and protein sequence data. Algorithms for sequence alignment, statistical analysis of similarity scores, hidden Markov models, neural networks, training, gene finding, protein family profiles, multiple sequence alignment, sequence comparison and structure prediction. Analysis of expression array data.
- 548 **MATH 548 / STATS 548.**  
**Computations in Probabilistic Modeling in Bioinformatics.**  
 (1,1) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 425 or MCDB 427 or BIOLCHEM 415; basic programming skills desirable. Graduate standing and permission of instructor.*  
 This will be a computational laboratory course designed in parallel with MATH/STATS 547. Weekly hands-on problems will be presented on the algorithms presented in the course, the use of public sequence databases, the design of hidden Markov models. Concrete examples of homology, gene finding, structure analysis.
- 550 **MATH 550 / CMLXSYS 510.**  
**Introduction to Adaptive Systems.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 215, 255, or 285; MATH 217; and MATH 425, and permission of instructor. Working knowledge of calculus, probability, and matrix algebra.*  
 Centers on the construction and use of agent-based adaptive models. Course begins with classical differential equation and game theory approaches, and then focuses on the theory and application of particular models of adaptive systems such as models of neural systems, genetic algorithms, classifier systems, and cellular automata.

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- 563 **MATH 563.**  
**Advanced Mathematical Methods for the Biological Sciences.**  
 (3) : May not be repeated for credit.  
 (Excl). (BS).  
*Graduate standing.*  
 This course focuses on discovering the way in which spatial variation influences the motion, dispersion, and persistence of species. Specific topics may include  
 <ol type=i>  
 <LI>Models of Cell Motion: Diffusion, Convection, and Chemotaxis;  
 <LI>Transport Processes in Biology;  
 <LI>Biological Pattern Formation; and  
 <LI> Delay-differential Equations and Age-structured Models of Infectious Diseases.  
 </ol>
- 590 **MATH 590.**  
**Introduction to Topology.**  
 (3,3;3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 451. I.*  
 Topological and metric spaces, continuous functions, homeomorphism, compactness and connectedness, surface and manifolds, fundamental theorem of algebra and other topics.
- 602 **MATH 602.**  
**Real Analysis II.**  
 (3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 590 and 597.*  
 Introduction to functional analysis; metric spaces, completion, Banach spaces, Hilbert spaces,  $L^p$  spaces; linear functionals, dual spaces, Riesz representation theorems; principle of uniform boundedness, closed graph theorem, Hahn-Banach theorem, Baire category theorem, applications to classical analysis.
- 604 **MATH 604.**  
**Complex Analysis II.**  
 (3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 590 and 596.*  
 Selected topics such as potential theory, geometric function theory, analytic continuation, Riemann surfaces, uniformization and analytic varieties.
- 605 **MATH 605.**  
**Several Complex Variables.**  
 (3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 596 and 597. Graduate standing.*  
 Power series in several complex variables, domains of holomorphy, pseudo convexity, plurisubharmonic functions, the Levi problem. Domains with smooth boundary, tangential Cauchy-Riemann equations, the Lewy and Bochner extension theorems. The  $\bar{\partial}$ -operator and Hartog's Theorem, Dolbeault-Grothendieck lemma, theorems of Runge, Mittag-Leffler and Weierstrass. Analytic continuation, monodromy theorem, uniformization and Koebe's theorem, discontinuous groups.
- 609 **MATH 609.**  
**Topics in Analysis.**  
 (3,3) : May be repeated for credit.  
 (Excl). (BS).  
*MATH 451. Graduate standing.*  
 Selected topics in analysis. Content and prerequisites will vary from year to year.

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- 612 **MATH 612.**  
**Lie Algebra and their Representatives.**  
 (3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 593 and 594; Graduate standing.*  
 Representation Theory of semisimple Lie algebras over the complex numbers. Weyl's Theorem, root systems, Harish Chandra's Theorem, Weyl's formulae and Kostant's Multiplicity Theorem. Lie groups, their Lie algebras and further examples of representations.
- 614 **MATH 614.**  
**Commutative Algebra.**  
 (3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 593. Graduate standing.*  
 Review of commutative rings and modules. Local rings and localization. Noetherian and Artinian rings. Integral independence. Valuation rings, Dedekind domains, completions, graded rings. Dimension theory.
- 615 **MATH 615.**  
**Commutative Algebra II.**  
 (3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 614 and Graduate standing.*  
 This is a continuation of MATH 614: structure of complete local rings, regular, Cohen-Macaulay, and Gorenstein rings, excellent rings, Henselian rings, etale maps, equations over local rings.
- 619 **MATH 619.**  
**Topics in Algebra.**  
 (3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 593. Graduate standing.*  
 Selected topics.
- 623 **MATH 623 / IOE 623.**  
**Computational Finance.**  
 (3,3) : May not be repeated for credit.  
 (Excl).  
*MATH 316 and MATH 425 or 525. Graduate standing.*  
 This is a course in computational methods in finance and financial modeling. Particular emphasis will be put on interest rate models and interest rate derivatives. Specific topics include Black-Scholes theory, no-arbitrage and complete markets theory, term structure models, Hull and White models, Heath-Jarrow-Morton models, the stochastic differential equations and martingale approach, multinomial tree and Monte Carlo methods, the partial differential equations approach, finite difference methods.
- 625 **MATH 625 / STATS 625.**  
**Probability and Random Processes I.**  
 (3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 597. Graduate standing.*  
 Axiomatics; measures and integration in abstract spaces. Fourier analysis, characteristic functions. Conditional expectation, Kolmogoroff extension theorem. Stochastic processes; Wiener-Levy, infinitely divisible, stable. Limit theorems, law of the iterated logarithm.
- 626 **MATH 626 / STATS 626.**  
**Probability and Random Processes II.**  
 (3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 625. Graduate standing.*  
 Selected topics from among: diffusion theory and partial differential equations; spectral analysis; stationary processes, and ergodic theory; information theory; martingales and gambling systems; theory of partial sums.

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- 627 **MATH 627 / BIOSTAT 680.**  
**Applications of Stochastic Processes I.**  
 (3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*Graduate standing; BIOSTAT 601, 650, 602 and MATH 450.*  
 Conditional distributions, probability generating functions, convolutions, discrete and continuous parameters, Markov chains, medical and health related applications.
- 631 **MATH 631.**  
**Introduction to Algebraic Geometry.**  
 (3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 594 and Graduate standing.*  
 Theory of algebraic varieties: affine and projective varieties, dimension of varieties and subvarieties, singular points, divisors, differentials, intersections. Schemes, cohomology, curves and surfaces, varieties over the complex numbers.
- 632 **MATH 632.**  
**Algebraic Geometry II.**  
 (3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 631. Graduate standing.*  
 Continuation of MATH 631.
- 635 **MATH 635.**  
**Differential Geometry.**  
 (3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 537 and Graduate standing.*  
 Second fundamental form, Hadamard manifolds, spaces of constant curvature, first and second variational formulas, Rauch comparison theorem, and other topics chosen by the instructor
- 636 **MATH 636.**  
**Topics in Differential Geometry.**  
 (3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 635. Graduate standing.*  
 Second fundamental form, Hadamard manifolds, spaces of constant curvature, first and second variational formulas, Rauch comparison theorem, and other topics chosen by the instructor.
- 637 **MATH 637.**  
**Lie Groups.**  
 (3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 635. Graduate standing.*  
 Solvable Lie groups, compact Lie groups, classifications of semi-simple Lie groups, representation theory, homogeneous spaces. More advanced topics in Lie group theory from an "interdisciplinary" point of view. Emphasis will be on some of the remarkable facts about compact Lie groups
- 638 **MATH 638.**  
**Introduction to Representation Theory.**  
 (3,3) : May be repeated for credit.  
 (Excl). (BS).  
*MATH 597. Graduate standing.*  
 A course on representation theory. Content varies by term and instructor.

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- 650 **MATH 650.**  
**Fourier Analysis.**  
 (3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 596 and 602. Graduate standing.*  
 General properties of orthogonal systems. Convergence criteria for Fourier series. The Fourier integral, Fourier transform and Plancherel theorem. Wiener's Tauberian theorem. Elements of harmonic analysis. Applications.
- 651 **MATH 651.**  
**Topics in Applied Mathematics I.**  
 (3,3) : May be elected twice for credit.  
 (Excl). (BS).  
*MATH 451, 555 and one other 500-level course in analysis or differential equations. Graduate standing.*  
 Topics such as celestial mechanics, continuum mechanics, control theory, general relativity, nonlinear waves, optimization, statistical mechanics.
- 654 **MATH 654.**  
**Introduction to Fluid Dynamics.**  
 (3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 450; MATH 555 or 596; and MATH 454 or 556. Graduate standing.*  
 Characteristics, heat, wave and Laplace's equation, energy methods, maximum principles, distribution theory.
- 655 **MATH 655.**  
**Topics in Fluid Dynamics.**  
 (3,3) : May be repeated for credit.  
 (Excl). (BS).  
*MATH 555, 556, 557, 558; Graduate standing.*  
 A course on topics in fluid dynamics. Content varies by term and instructor.
- 656 **MATH 656.**  
**Partial and Differential Equations I.**  
 (3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 558, 596 and 597, and Graduate standing.*  
 In this introductory course, we shall study the basic concepts in the field, including: characteristics and initial-value problems, the wave equation, energy integrals, and their applications, uniqueness theorems, Sobolev spaces, theory of distributions, and applications, elliptic equations, parabolic equations, and an introduction to nonlinear hyperbolic equations.
- 657 **MATH 657.**  
**Nonlinear Partial Differential Equations.**  
 (3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 656.*  
 A survey of ideas and methods arising in the study of nonlinear partial differential equations, nonlinear variational problems, bifurcation theory, nonlinear semigroups, shock waves, dispersive equations.
- 658 **MATH 658.**  
**Ordinary Differential Equations.**  
 (3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*A course in differential equations (e.g., MATH 404 or 558). Graduate standing.*  
 This course will discuss certain aspects of the modern theory of ordinary differential equations and dynamical systems, with emphasis on applications to mechanics and nonlinear control theory. Topics will include the qualitative theory of ODE's on manifolds, nonlinear stability theory, Lagrangian and Hamiltonian mechanics, mechanical systems with constraints including nonholonomic systems and the Dirac theory of constraints, reduction and symmetries, integrable systems, mechanical systems with forces, and some key ideas in the control of nonlinear mechanical systems and optimal control. The geometric underpinning of many of these concepts will be discussed.

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- 660 **MATH 660 / IOE 610.**  
**Linear Programming II.**  
 (3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 561. Graduate standing. CAEN lab access fee required for non-Engineering students.*  
 Primal-dual algorithm. Resolution of degeneracy, upper bounding. Variants of simplex method. Geometry of the simplex method, application of adjacent vertex methods in non-linear programs, fractional linear programming. Decomposition principle, generalized linear programs. Linear programming under uncertainty. Ranking algorithms, fixed charge problem. Integer programming. Combinatorial problems.
- 663 **MATH 663 / IOE 611.**  
**Nonlinear Programming.**  
 (3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 561. Graduate standing. CAEN lab access fee required for non-Engineering students.*  
 Modeling, theorems of alternatives, convex sets, convex and generalized convex functions, convex inequality systems, necessary and sufficient optimality conditions, duality theory, algorithms for quadratic programming, linear complementary problems, and fixed point computing. Methods of direct search, Newton and Quasi-Newton, gradient projection, feasible direction, reduced gradient; solution methods for nonlinear equations.
- 664 **MATH 664.**  
**Combinatorial Theory I.**  
 (3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 512. Graduate standing.*  
 An introduction to the techniques of enumeration. Basic material for first half of this course is found in Stanley's Enumerative Combinatorics, Vol. I. The second half consists of topics such as ordinary and exponential generating functions, Sieve methods, partitions and q-series, Pólya Theory and other optional topics as time permits.
- 665 **MATH 665.**  
**Combinatorial Theory II.**  
 (3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 664 and Graduate standing.*  
 A course on combinatorial theory. Content varies by term and instructor.
- 669 **MATH 669.**  
**Topics in Combinatorial Theory.**  
 (3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 565, 566, or 664, and Graduate standing.*  
 Selected topics from the foundations of combinatorics, including the analysis of general partially ordered sets, combinatorial designs in loops and structures in abstract systems, enumeration under group action, combinatorial aspects of finite simple groups.
- 671 **MATH 671.**  
**Analysis of Numerical Methods I.**  
 (3,3) : May be repeated for credit.  
 (Excl). (BS).  
*MATH 571, 572, and Graduate standing.*  
 This is a course on special topics in numerical analysis and scientific computing. Subjects of current research interest are included. Recent topics have been: Finite difference methods for hyperbolic problems, Multigrid methods for elliptic boundary value problems.

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- 675 **MATH 675.**  
**Analytic Theory of Numbers.**  
 (3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 575 and 596. Graduate standing.*  
 Theory of the Riemann zeta-function and the L-functions, distribution of primes, Dirichlet's theorem on primes in a progression, quadratic forms, transcendental numbers.
- 676 **MATH 676.**  
**Theory of Algebraic Numbers.**  
 (3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 575 and 594. Graduate standing.*  
 Arithmetic of algebraic extensions, the basis theorems for units, valuation and ideal theory.
- 677 **MATH 677.**  
**Diophantine Problems.**  
 (3,3) : May be repeated for credit.  
 (Excl). (BS).  
*MATH 575. Graduate standing.*  
 Topics in diophantine approximation, diophantine equations and transcendence.
- 678 **MATH 678.**  
**Modular Forms.**  
 (3,3) : May be repeated for credit.  
 (Excl). (BS).  
*MATH 575 and 596. Graduate standing.*  
 A basic introduction to modular functions, modular forms, modular groups. Hecke operators, Selberg trace formula. Applications to theory of partitions, quadratic forms, class field theory and elliptic curves.
- 679 **MATH 679.**  
**Arithmetic of Elliptic Curves.**  
 (3,3) : May be repeated for credit.  
 (Excl). (BS).  
*MATH 594. Graduate standing.*  
 Topics in the theory of elliptic curves.
- 681 **MATH 681.**  
**Mathematical Logic.**  
 (3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*Mathematical maturity appropriate for a 600-level MATH course. Graduate standing.*  
 Syntax and semantics of first-order logic. Formal deductive systems. Soundness and completeness theorems. Compactness principle and applications. Decision problems for formal theories. Additional topics may include non-standard models and logical systems other than classical first-order logic.
- 682 **MATH 682.**  
**Set Theory.**  
 (3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 681.*  
 Axiomatic development of set theory including cardinal and ordinal numbers. Constructible sets and the consistency of the axiom of choice and the generalized continuum hypothesis. Forcing and the independence of choice and the continuum hypothesis. Additional topics may include combinatorial set theory, descriptive set theory, or further independence results.

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- 683 **MATH 683.**  
**Model Theory.**  
 (3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 681.*  
 Connections between classes of mathematical structures and the sentences (in first-order logic) describing them. Definable sets within structures; definable classes of structures. Methods for producing structures with prescribed properties. Categorical and complete theories. Methods for analyzing the first-order properties of structures. Introduction to some concepts of classification theory.
- 694 **MATH 694.**  
**Differential Topology II.**  
 (3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 537 and 591 and Graduate standing.*  
 Transversality, embedding theorems, vector bundles and selected topics from the theories of cobordism, surgery, and characteristic classes.
- 695 **MATH 695.**  
**Algebraic Topology I.**  
 (3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 591 and Graduate standing.*  
 Cohomology Theory, the Universal Coefficient Theorems, Kunneth Theorems (product spaces and their homology and cohomology), fiber bundles, higher homotopy groups, Hurewicz' Theorem, Poincaré and Alexander duality.
- 696 **MATH 696.**  
**Algebraic Topology II.**  
 (3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 695.*  
 Further topics in algebraic topology typically taken from: obstruction theory, cohomology operations, homotopy theory, spectral sequences and computations, cohomology of groups, characteristic classes.
- 697 **MATH 697.**  
**Topics in Topology.**  
 (2-3,2-3) : May not be repeated for credit.  
 (Excl). (BS).  
*Graduate standing.*  
 An intermediate level topics course.
- 700 **MATH 700.**  
**Directed Reading and Research.**  
 (1-3,1-3) : May be elected up to three times for credit.  
 (Excl). (INDEPENDENT).  
*Consent of instructor required (Prerequisites enforced at registration). Graduate standing. Permission of instructor required.*  
 Designed for individual students who have an interest in a specific topic (usually that has stemmed from a previous course). An individual instructor must agree to direct such a reading, and the requirements are specified when approval is granted.
- 702 **MATH 702.**  
**Functional Analysis II.**  
 (3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 602; and MATH 701 is sometimes required.*  
 Further topics in Functional Analysis.

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- 703 **MATH 703.**  
**Topics in Complex Function Theory I.**  
(3,3) : May be repeated for credit.  
(Excl). (BS).  
*MATH 604. Graduate standing.*  
Selected advanced topics in function theory. Content will vary from year to year.
- 704 **MATH 704.**  
**Topics in Complex Function Theory II.**  
(3,3) : May be repeated for credit.  
(Excl). (BS).  
*MATH 703. Graduate standing.*  
Selected advanced topics in function theory. Content will vary from year to year.
- 709 **MATH 709.**  
**Topics in Modern Analysis I.**  
(3,3) : May not be repeated for credit.  
(Excl). (BS).  
*MATH 597. Graduate standing.*  
Selected advanced topics in analysis.
- 710 **MATH 710.**  
**Topics in Modern Analysis II.**  
(3,3) : May not be repeated for credit.  
(Excl). (BS).  
*MATH 597. Graduate standing.*  
Selected advanced topics in analysis.
- 711 **MATH 711.**  
**Advanced Algebra.**  
(3,3) : May not be repeated for credit.  
(Excl). (BS).  
*MATH 594 or 612 and Graduate standing.*  
Topics of current research interest, such as groups, rings, lattices, etc., including a thorough study of one such topic.
- 715 **MATH 715.**  
**Advanced Topics in Algebra.**  
(3,3) : May be repeated for credit.  
(Excl). (BS).  
*MATH 594 and 612. Graduate standing.*  
A course on advanced topics in algebra. Content varies by term and instructor.
- 725 **MATH 725 / STATS 725.**  
**Topics in Advanced Probability I.**  
(3,3) : May not be repeated for credit.  
(Excl). (BS).  
*MATH 626. Graduate standing.*  
A course on advanced topics in probability. Content varies by term and instructor.
- 731 **MATH 731.**  
**Topics in Algebraic Geometry.**  
(3,3) : May not be repeated for credit.  
(Excl). (BS).  
*Graduate standing.*  
Selected topics in algebraic geometry.

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- 732 **MATH 732.**  
**Topics in Algebraic Geometry II.**  
 (3,3) : May not be repeated for credit.  
 (Excl). (BS).  
*MATH 631 or 731.*  
 Selected topics in algebraic geometry.
- 775 **MATH 775.**  
**Topics in Analytic Number Theory.**  
 (3,3) : May be repeated for credit.  
 (Excl). (BS).  
*MATH 675.*  
 Selected topics in analytic number theory.
- 776 **MATH 776.**  
**Topics in Algebraic Number Theory.**  
 (3,3) : May be repeated for credit.  
 (Excl). (BS).  
*MATH 676. Graduate standing.*  
 Selected topics in algebraic number theory.
- 777 **MATH 777.**  
**Topics in Diophantine Problems.**  
 (3,3) : May be repeated for credit.  
 (Excl). (BS).  
*MATH 677, and graduate standing.*  
 A course on topics in diophantine problems. Content varies by term and instructor.
- 781 **MATH 781.**  
**Topics in Mathematical Logic.**  
 (3,3) : May be repeated for credit.  
 (Excl). (BS).  
*Graduate standing.*  
 Advanced topics in mathematical logic. Content will vary from year to year.
- 821 **MATH 821.**  
**Actuarial Math.**  
 (1,1) : May not be repeated for credit.  
 (Excl).
- 990 **MATH 990.**  
**Dissertation/Precandidate.**  
 (1-8,1-4) : May be repeated for credit.  
 (Excl). (INDEPENDENT).  
*Election for dissertation work by doctoral student not yet admitted as a Candidate. Graduate standing. This course has a grading basis of "S" or "U."*  
 Election for dissertation work by doctoral student not yet admitted as a Candidate.
- 993 **MATH 993.**  
**Graduate Student Instructor Training Program.**  
 (1,1) : May not be repeated for credit.  
 (Excl).  
*Graduate standing and appointment as GSI in Mathematics Department. This course has a grading basis of "S" or "U."*  
 A seminar for all beginning graduate student instructors, consisting of a two day orientation before the term starts and periodic workshops/meetings during the Fall Term. Beginning graduate student instructors are required to register for this class.

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995 **MATH 995.****Dissertation/Candidate.**

(8,4) : May be repeated for credit.

(Excl). (INDEPENDENT).

*Graduate School authorization for admission as a doctoral Candidate (Prerequisites enforced at registration). This course has a grading basis of "S" or "U."*

Graduate School authorization for admission as a doctoral Candidate. N.B. The defense of the dissertation (the final oral examination) must be held under a full term Candidacy enrollment period.