**MATHEMATICS (MATH)**

**MATH 104 Calculus, Part I**
Brief review of High School calculus, applications of integrals, transcendental functions, methods of integration, infinite series, Taylor's theorem, and first order ordinary differential equations. Use of symbolic manipulation and graphics software in calculus.
One-term course offered either term
Prerequisites: None. Engineering students are encouraged to register for the 006 lecture and group 6 recitations.
Activity: Recitation
1.0 Course Unit
Notes: This is a Formal Reasoning course.

**MATH 110 Calculus for Wharton Students**
Differential calculus, integral calculus, series, differential equations and elements of multivariable calculus, with an emphasis on applications.
One-term course offered either term
Activity: Lecture
1.0 Course Unit

**MATH 114 Calculus, Part II**
Functions of several variables, vector-valued functions, partial derivatives and applications, double and triple integrals, conic sections, polar coordinates, vectors and vector calculus, first order ordinary differential equations. Applications to physical sciences. Use of symbolic manipulation and graphics software in calculus.
One-term course offered either term
Prerequisite: Math 104
Activity: Recitation
1.0 Course Unit
Notes: This is a Formal Reasoning course.

**MATH 115 Calculus, Part II with Probability and Matrices**
Functions of several variables, partial derivatives, multiple integrals, differential equations; introduction to linear algebra and matrices with applications to linear programming and Markov processes. Elements of probability and statistics. Applications to social and biological sciences. Use of symbolic manipulation and graphics software in calculus.
One-term course offered either term
Prerequisite: MATH 104
Activity: Recitation
1.0 Course Unit
Notes: This is a Formal Reasoning course.

**MATH 116 Honors Calculus**
Students who are interested in math or science might also want to consider a more challenging Honors version of Calculus II and III, Math 116 and Math 260 (the analogues of Math 114 and Math 240, respectively). These courses will cover essentially the same material as 114 and 240, but more in depth and involve discussion of the underlying theory as well as computations.
One-term course offered either term
Activity: Recitation
1.0 Course Unit
Notes: This is a Formal Reasoning course.

**MATH 122 Community Algebra Initiative**
Community Algebra Initiative
One-term course offered either term
Activity: Lecture
1.0 Course Unit

**MATH 123 Community Math Teaching Project**
This course allows Penn students to teach a series of hands-on activities to students in math classes at University City High School. The semester starts with an introduction to successful approaches for teaching math in urban high schools. The rest of the semester will be devoted to a series of weekly hands-on activities designed to teach fundamental aspects of geometry. The first class meeting of each week, Penn faculty teach Penn students the relevant mathematical background and techniques for a hands-on activity. During the second session of each week, Penn students will teach the hands-on activity to a small group of UCHS students. The Penn students will also have an opportunity to develop their own activity and to implement it with the UCHS students.
Course not offered every year
Activity: Lecture
1.0 Course Unit

**MATH 170 Ideas in Mathematics**
Topics from among the following: logic, sets, calculus, probability, history and philosophy of mathematics, game theory, geometry, and their relevance to contemporary science and society.
For BA Students: Natural Science and Math Sector
One-term course offered either term
Activity: Lecture
1.0 Course Unit
Notes: May also be counted toward the General Requirement in Natural Science Mathematics

**MATH 180 Analytical Methods in Economics, Law, and Medicine**
Elementary applications of decision analysis, game theory, probability and statistics to issues in accounting, contracting, finance, law, and medicine, amongst others.
Course not offered every year
Activity: Lecture
1.0 Course Unit

**MATH 202 Proving Things: Analysis**
This course focuses on the creative side of mathematics, with an emphasis on discovery, reasoning, proofs and effective communication, while at the same time studying real and complex numbers, sequences, series, continuity, differentiability and integrability. Small class sizes permit an informal, discussion-type atmosphere, and often the entire class works together on a given problem. Homework is intended to be thought-provoking, rather than skill-sharpening.
One-term course offered either term
Corequisites: Math 104, 114 or 240
Activity: Seminar
1.0 Course Unit

**MATH 203 Proving things: Algebra**
This course focuses on the creative side of mathematics, with an emphasis on discovery, reasoning, proofs and effective communication, while at the same time studying arithmetic, algebra, linear algebra, groups, rings and fields. Small class sizes permit an informal, discussion-type atmosphere, and often the entire class works together on a given problem. Homework is intended to be thought-provoking, rather than skill-sharpening.
One-term course offered either term
Corequisites: Math 104, 114 or 240
Activity: Lecture
1.0 Course Unit
MATH 210 Mathematics in the Age of Information
This course counts as a regular elective for both the Mathematics Major and Minor. This is a course about mathematical reasoning and the media. Embedded in many stories one finds in the media are mathematical questions as well as implicit mathematical models for how the world behaves. We will discuss ways to recognize such questions and models, and how to think about them from a mathematical perspective. A key part of the course will be about what constitutes a mathematical proof, and what passes for proof in various media contexts. The course will cover a variety of topics in logic, probability and statistics as well as how these subjects can be used and abused.
One-term course offered either term
Prerequisites: Math 114, Math 115 or equivalent
Activity: Lecture
1.0 Course Unit

MATH 240 Calculus, Part III
Linear algebra: vectors, matrices, systems of linear equations, vector spaces, subspaces, spans, bases, and dimension, eigenvalues, and eigenvectors, matrix exponentials. Ordinary differential equations: higher-order homogeneous and inhomogeneous ODEs and linear systems of ODEs, phase plane analysis, non-linear systems.
One-term course offered either term
Prerequisite: Math 114
Activity: Recitation
1.0 Course Unit

MATH 241 Calculus, Part IV
Partial differential equations and their solutions, including solutions of the wave, heat and Laplace equations, and Sturm-Liouville problems. Introduction to Fourier series and Fourier transforms. Computation of solutions, modeling using PDE's, geometric intuition, and qualitative understanding of the evolution of systems according to the type of partial differential operator.
One-term course offered either term
Prerequisite: MATH 240
Activity: Recitation
1.0 Course Unit

MATH 260 Honors Calculus, Part II
This is an honors version of Math 240 which explores the same topics but with greater mathematical rigor.
Course not offered every year
Prerequisite: Math 114
Activity: Recitation
1.0 Course Unit

MATH 280 Entropy Math Evolution
The goal of this is to explore a new theory of evolution developed by L. Demetrius at MIT based on the second law of thermodynamics. The essential idea is that life exists because if increases overall entropy quicker than other process es. The course will include an introduction to thermodynamics as well as to the information theory definition of entropy. Eventually I want to apply this to other systems. For instance, I think the theory explains why political candidates who create chaos, tweet and require more bits of information to describe each day are favored by the second law. Demetrius makes a distinction between robust high entropy environments and precarious low entropy environments and is a very interesting in many different systems.
Course usually offered in fall term
Activity: Seminar
1.0 Course Unit

MATH 290 Undergraduate Mathematics Research Course
This is a project-oriented mathematics research course that teaches students to solve real-world problems by constructing and analyzing mathematical models. Typically the problems considered will come from mathematics, chemistry, biology, and materials science but sometimes they will also come from economics, finance, and social sciences. The research problems in the course vary from year to year.
Activity: Lecture
1.0 Course Unit

MATH 299 Undergraduate Research in Mathematics
Course usually offered in spring term
Activity: Lecture
1.0 Course Unit

MATH 312 Linear Algebra
Linear transformations, Gauss Jordan elimination, eigenvalues and eigenvectors, theory and applications. Mathematics majors are advised that MATH 312 cannot be taken to satisfy the major requirements.
Course not offered every year
Prerequisite: MATH 240
Activity: Lecture
1.0 Course Unit
Notes: Students who have already received credit for either Math 370, 371, 502 or 503 cannot receive further credit for Math 312 or Math 313/513. Students can receive credit for at most one of Math 312 and Math 313/513.

MATH 313 Computational Linear Algebra
Many important problems in a wide range of disciplines within computer science and throughout science are solved using techniques from linear algebra. This course will introduce students to some of the most widely used algorithms and illustrate how they are actually used. Some specific topics: the solution of systems of linear equations by Gaussian elimination, dimension of a linear space, inner product, cross product, change of basis, affine and rigid motions, eigenvalues and eigenvectors, diagonalization of both symmetric and non-symmetric matrices, quadratic polynomials, and least squares optimization. Applications will include the use of matrix computations to computer graphics, use of the discrete Fourier transform and related techniques in digital signal processing, the analysis of systems of linear differential equations, and singular value decompositions with application to a principal component analysis. The ideas and tools provided by this course will be useful to students who intend to tackle higher level courses in digital signal processing, computer vision, robotics, and computer graphics.
Also Offered As: MATH 513
Prerequisites: Math 240, and some programming experience.
Activity: Lecture
1.0 Course Unit
Notes: Students who have already received credit for either Math 370, 371, 502 or 503 cannot receive further credit for Math 312 or Math 313. Students can receive credit for at most one of Math 312 and Math 313.
MATH 314 Advanced Linear Algebra
Topics will include: Vector spaces, Basis and dimension, quotients; Linear maps and matrices; Determinants, Dual spaces and maps; Invariant subspaces, Canonical forms; Scalar products: Euclidean, unitary and symplectic spaces; Orthogonal and Unitary operators; Tensor products and polyninear maps; Symmetric and skew-symmetric tensors and exterior algebra.
Taught by: Staff.
Also Offered As: AMCS 514, MATH 514
Prerequisite: Math 240
Activity: Lecture
1.0 Course Unit
Notes: Math 314/514 covers Linear Algebra at the advanced level with a theoretical approach. Students can receive credit for at most one of Math 312 or Math 314.

MATH 320 Computer Methods in Mathematical Science I
Students will use symbolic manipulation software and write programs to solve problems in numerical quadrature, equation-solving, linear algebra and differential equations. Theoretical and computational aspects of the methods will be discussed along with error analysis and a critical comparison of methods.
Course usually offered in fall term
Prerequisites: MATH 240 or concurrent and ability to program a computer, or permission of instructor
Activity: Lecture
1.0 Course Unit

MATH 340 Discrete Mathematics I
Topics will be drawn from some subjects in combinatorial analysis with applications to many other branches of math and science: graphs and networks, generating functions, permutations, posets, asymptotics.
Course not offered every year
Also Offered As: LGIC 210
Prerequisites: MATH 114 or Math 115 or permission of the instructor.
Activity: Lecture
1.0 Course Unit

MATH 341 Discrete Mathematics II
Topics will be drawn from some subjects useful in the analysis of information and computation: logic, set theory, theory of computation, number theory, probability, and basic cryptography.
Also Offered As: LGIC 220
Prerequisites: Math 340/Logic 210 or permission of the instructor.
Activity: Lecture
1.0 Course Unit

MATH 350 Number Theory
Congruences, Diophantine equations, continued fractions, nonlinear congruences, and quadratic residues.
Course not offered every year
Activity: Lecture
1.0 Course Unit

MATH 360 Advanced Calculus
Syllabus for MATH 360-361: a study of the foundations of the differential and integral calculus, including the real numbers and elementary topology, continuous and differentiable functions, uniform convergence of series of functions, and inverse and implicit function theorems.
MATH 508-509 is a masters level version of this course.
One-term course offered either term
Prerequisite: MATH 240
Activity: Lecture
1.0 Course Unit

MATH 361 Advanced Calculus
Continuation of MATH 360.
One-term course offered either term
Prerequisite: MATH 360
Activity: Lecture
1.0 Course Unit

MATH 370 Algebra
Syllabus for MATH 370-371: an introduction to the basic concepts of modern algebra. Linear algebra, eigenvalues and eigenvectors of matrices, groups, rings and fields. MATH 502-503 is a masters level version of this course.
One-term course offered either term
Prerequisites: MATH 240 and Math 314, or permission of the instructor.
Activity: Lecture
1.0 Course Unit
Notes: Students who have already received credit for either Math 370, 371, 502 or 503 cannot receive further credit for Math 312 or Math 313/513. Students can receive credit for at most one of Math 312 and Math 313/513.

MATH 371 Algebra
Continuation of MATH 370.
One-term course offered either term
Prerequisites: MATH 240, Math 314 and Math 370, or permission of the instructor.
Activity: Lecture
1.0 Course Unit
Notes: Students who have already received credit for either Math 370, 371, 502 or 503 cannot receive further credit for Math 312 or Math 313/513. Students can receive credit for at most one of Math 312 and Math 313/513.

MATH 410 Complex Analysis
Complex numbers, DeMoivre's theorem, complex valued functions of a complex variable, the derivative, analytic functions, the Cauchy-Riemann equations, complex integration, Cauchy's integral theorem, residues, computation of definite integrals by residues, and elementary conformal mapping.
One-term course offered either term
Also Offered As: AMCS 510
Prerequisite: MATH 240 or permission of instructor
Activity: Lecture
1.0 Course Unit

MATH 420 Ordinary Differential Equations
After a rapid review of the basic techniques for solving equations, the course will discuss one or more of the following topics: stability of linear and nonlinear systems, boundary value problems and orthogonal functions, numerical techniques, Laplace transform methods.
One-term course offered either term
Also Offered As: AMCS 520
Prerequisite: MATH 240 permission of instructor
Activity: Lecture
1.0 Course Unit
MATH 425 Partial Differential Equations
Method of separation of variables will be applied to solve the wave, heat, and Laplace equations. In addition, one or more of the following topics will be covered: qualitative properties of solutions of various equations (characteristics, maximum principles, uniqueness theorems), Laplace and Fourier transform methods, and approximation techniques.
Course usually offered in fall term
Also Offered As: AMCS 525
Prerequisites: MATH 240 or permission of instructor. Knowledge of PHYS 150-151 will be helpful.
Activity: Lecture
1.0 Course Unit

MATH 432 Game Theory.
A mathematical approach to game theory, with an emphasis on examples of actual games. Topics will include mathematical models of games, combinatorial games, two person (zero sum and general sum) games, non-cooperating games and equilibria.
One-term course offered either term
Prerequisites: Math 240.
Activity: Lecture
1.0 Course Unit

MATH 460 Topology
Point set topology: metric spaces and topological spaces, compactness, connectedness, continuity, extension theorems, separation axioms, quotient spaces, topologies on function spaces, Tychonoff theorem. Fundamental groups and covering spaces, and related topics.
Course not offered every year
Also Offered As: MATH 500
Prerequisites: MATH 240 and 241
Activity: Lecture
1.0 Course Unit

MATH 465 Differential Geometry
Differential geometry of curves in the plane and in 3-space; n gauge theories. Surfaces in 3-space; The geometry of the Gauss map; ons. The language of Intrinsic geometry of surfaces; Geodesics; Moving frames; of vector bundles, The Gauss-Bonnet Theorem; Assorted additional topics.
Course not offered every year
Also Offered As: MATH 501
Prerequisites: MATH 361 or Permission of the instructor.
Activity: Lecture
1.0 Course Unit

MATH 480 Topics in Modern Math
Mathematics 480 will open with a review of the basics of real analysis (brief or extended background required). The review will include: introduction of the real numbers through Dedekind cuts, continuity of real-valued functions on the real line; Cantor nested-interval principle, basic results for continuous functions, Maximum and Intermediate Value theorems, Heine-Borel Theorem, Uniform Continuity on closed intervals; metric spaces, convergence of sequences, Cauchy sequences, completeness, more general uniform continuity and intermediate value theorems; general topology, separation, compactness, product spaces, Tychonoff's Theorem. Special topics in analysis: Weierstrass Polynomial Approximation Theorem, Bernstein polynomials and simultaneous approxfunctions and derivatives, topics from divergent series, summation methods; r measure theory, the Lebesgue integral, Lp spaces, Holder, Minkowski, and and Cauchy-Schwarz inequalities; basics of Functional Analysis, normed spaces, Banach spaces and Hilbert space, with examples (Lp spaces, continuous-functions spaces), Banach spaces and spectral theory, groups and Fourier transforms, Tauberian theorems; approximation theory, again, through the prism of functional analysis; extension of the polynomial approximation theorem (Stone-Weierstrass theorem), Muntz approximation theorem (by polynomials with preassigned powers), compact operators, the Spectral theorem, Stone's theorem (representation of the additive group of real numbers); Peter-Weyl theory (representations of compact groups). A selection from these topics as time and class preparation allow.
Course not offered every year
Prerequisites: A year of analysis at the 300 level or above (for example, Mathematics 360-361,508-509); a semester of linear algebra at the 300 level or above (for example, Mathematics 370).
Activity: Lecture
1.0 Course Unit

MATH 499 Supervised Study
Study under the direction of a faculty member. Intended for a limited number of mathematics majors.
One-term course offered either term
Prerequisite: Permission of major adviser
Activity: Independent Study
1.0 Course Unit

Notes: Hours and credit to be arranged

MATH 500 Geometry-Topology, Differential Geometry
Point set topology: metric spaces and topological spaces, compactness, connectedness, continuity, extension theorems, separation axioms, quotient spaces, topologies on function spaces, Tychonoff theorem. Fundamental groups and covering spaces, and related topics.
Course not offered every year
Also Offered As: MATH 460
Prerequisites: Math 240 and 241.
Activity: Lecture
1.0 Course Unit
MATH 501 Geometry-Topology, Differential Geometry
The course moves from a study of extrinsic geometry (curves and surfaces in n-space) to the intrinsic geometry of manifolds. After a review of vector calculus and a section on tensor algebra, we study manifolds and their intrinsic geometry, including metrics, connections, geodesics, and the Riemann curvature tensor. Topics include Eulerian curvature and Euler's theorems, the Gauss map and first/second fundamental forms, the Theorema Egregium, minimal surfaces in n-space; other topics as time permits.
Course not offered every year
Also Offered As: MATH 465
Prerequisites: Math 240, Math 312 (or 370), and Math 361 (or 508); or Math 500; or with the permission of the instructor.
Activity: Lecture
1.0 Course Unit

MATH 502 Abstract Algebra
An introduction to groups, rings, fields and other abstract algebraic systems, elementary Galois Theory, and linear algebra – a more theoretical course than Math 370.
Course usually offered in fall term
Prerequisites: Math 240 or Math 260; and Math 314/514 or permission of the instructor
Activity: Lecture
1.0 Course Unit
Notes: Students who have already received credit for either Math 370, 371, 502 or 503 cannot receive further credit for Math 312 or Math 313/513. Students can receive credit for at most one of Math 312 and Math 313/513.

MATH 503 Abstract Algebra
Continuation of Math 502.
Course usually offered in spring term
Prerequisites: Math 502 or with the permission of the instructor.
Activity: Lecture
1.0 Course Unit
Notes: Students who have already received credit for either Math 370, 371, 502 or 503 cannot receive further credit for Math 312 or Math 313/513. Students can receive credit for at most one of Math 312 and Math 313/513.

MATH 504 Graduate Proseminar in Mathematics
This course focuses on problems from Algebra (especially linear algebra and multilinear algebra) and Analysis (especially multivariable calculus through vector fields, multiple integrals and Stokes theorem). The material is presented through student solving of problems. In addition there will be a selection of advanced topics which will be accessible via this material.
Course usually offered in fall term
Activity: Lecture
1.0 Course Unit

MATH 505 Graduate Proseminar in Mathematics
This course focuses on problems from Algebra (especially linear algebra and multilinear algebra) and Analysis (especially multivariable calculus through vector fields, multiple integrals and Stokes theorem). The material is presented through student solving of problems. In addition there will be a selection of advanced topics which will be accessible via this material.
Course usually offered in spring term
Activity: Lecture
1.0 Course Unit

MATH 506 Advanced Analysis
Construction of real numbers, the topology of the real line and the foundations of single variable calculus. Notions of convergence for sequences of functions. Basic approximation theorems for continuous functions and rigorous treatment of elementary transcendental functions. The course is intended to teach students how to read and construct rigorous formal proofs. A more theoretical course than Math 360.
Course usually offered in fall term
Prerequisites: Math 240 and 241. Math 200 and 201 also recommended.
Activity: Lecture
1.0 Course Unit

MATH 507 Advanced Analysis
Continuation of Math 506. The Arzela-Ascoli theorem. Introduction to the topology of metric spaces with an emphasis on higher dimensional Euclidean spaces. The contraction mapping principle. Inverse and implicit function theorems. Rigorous treatment of higher dimensional differential calculus. Introduction to Fourier analysis and asymptotic methods. The course usually offered in spring term
Prerequisites: Math 506 or with the permission of the instructor. Linear algebra is also helpful.
Activity: Lecture
1.0 Course Unit

MATH 508 Advanced Analysis
Construction of real numbers, the topology of the real line and the foundations of single variable calculus. Notions of convergence for sequences of functions. Basic approximation theorems for continuous functions and rigorous treatment of elementary transcendental functions. The course is intended to teach students how to read and construct rigorous formal proofs. A more theoretical course than Math 360.
Course usually offered in fall term
Prerequisites: Math 240 and 241. Math 200 and 201 also recommended.
Activity: Lecture
1.0 Course Unit

MATH 509 Advanced Analysis
Continuation of Math 508. The Arzela-Ascoli theorem. Introduction to the topology of metric spaces with an emphasis on higher dimensional Euclidean spaces. The contraction mapping principle. Inverse and implicit function theorems. Rigorous treatment of higher dimensional differential calculus. Introduction to Fourier analysis and asymptotic methods. The course usually offered in spring term
Prerequisites: Math 506 or with the permission of the instructor. Linear algebra is also helpful.
Activity: Lecture
1.0 Course Unit

MATH 510 Advanced Analysis
Continuation of Math 509. The Arzela-Ascoli theorem. Introduction to the topology of metric spaces with an emphasis on higher dimensional Euclidean spaces. The contraction mapping principle. Inverse and implicit function theorems. Rigorous treatment of higher dimensional differential calculus. Introduction to Fourier analysis and asymptotic methods. The course usually offered in spring term
Prerequisites: Math 506 or with the permission of the instructor. Linear algebra is also helpful.
Activity: Lecture
1.0 Course Unit

MATH 511 Advanced Analysis
Continuation of Math 509. The Arzela-Ascoli theorem. Introduction to the topology of metric spaces with an emphasis on higher dimensional Euclidean spaces. The contraction mapping principle. Inverse and implicit function theorems. Rigorous treatment of higher dimensional differential calculus. Introduction to Fourier analysis and asymptotic methods. The course usually offered in spring term
Prerequisites: Math 506 or with the permission of the instructor. Linear algebra is also helpful.
Activity: Lecture
1.0 Course Unit

MATH 512 Advanced Linear Algebra
Topics will include: Vector spaces, Basis and dimension, quotients; Linear maps and matrices; Determinants, Dual spaces and maps; Invariant subspaces, Cononical forms; Scalar products: Euclidean, unitary and symplectic spaces; Orthogonal and unitary operators; Tensor products and multilinear maps; Symmetric and skew-symmetric tensors and exterior algebra.
Prerequisites: Math 114 or 115.
Activity: Lecture
1.0 Course Unit
Notes: Math 512 covers Linear Algebra at the advanced level with a theoretical approach. Students can receive credit for at most one of Math 312 and Math 512.

MATH 513 Computational Linear Algebra
A number of important and interesting problems in a wide range of disciplines within computer science are solved by recourse to techniques from linear algebra. The goal of this course will be to introduce students to some of the most important and widely used algorithms in matrix computation and to illustrate how they are actually used in various settings. Motivating applications will include: the solution of systems of linear equations, applications matrix computations to modeling geometric transformations in graphics, applications of the Discrete Fourier Transform and related techniques in digital signal processing, the solution of linear least squares optimization problems and the analysis of systems of linear differential equations. The course will cover the theoretical underpinnings of these problems and the numerical algorithms that are used to perform important matrix computations such as Gaussian Elimination, LU Decomposition and Singular Value Decomposition.
Also Offered As: MATH 313
Activity: Lecture
1.0 Course Unit
MATH 514 Advanced Linear Algebra
Topics will include: Vector spaces, Basis and dimension, quotients; Linear maps and matrices; Determinants, Dual spaces and maps; Invariant subspaces, Canonical forms; Scalar products; Euclidean, unitary and symplectic spaces; Orthogonal and Unitary operators; Tensor products and polylinear maps; Symmetric and skew-symmetric tensors and exterior algebra.
Also Offered As: AMCS 514, MATH 314
Prerequisite: Math 114 or Math 115
Activity: Lecture
1.0 Course Unit

MATH 520 Selections from Algebra
Informal introduction to such subjects as homological algebra, number theory, and algebraic geometry.
Course not offered every year
Corequisite: Math 502 or permission of the instructor
Activity: Lecture
1.0 Course Unit

MATH 530 Mathematics of Finance
This course presents the basic mathematical tools to model financial markets and to make calculations about financial products, especially financial derivatives. Mathematical topics covered: stochastic processes, partial differential equations and their relationship. No background in finance is assumed.
Course not offered every year
Prerequisites: Math 240, Stat 430
Activity: Lecture
1.0 Course Unit

MATH 546 Advanced Probability
The required background is (1) enough math background to understand proof techniques in real analysis (closed sets, uniform coverage, fourier series, etc.) and (2) some exposure to probability theory at an intuitive level (a course at the level of Ross's probability text or some exposure to probability in a statistics class). After a summary of the necessary results from measure theory, we will learn the probabist's lexicon (random variables, independence, etc.). We will then develop the necessary techniques (Borel Cantelli lemmas, estimates on sums of independent random variables and truncation techniques) to prove the classical laws of large numbers. Next come Fourier techniques and the Central Limit Theorem, followed by combinatorial techniques and the study of random walks.
Course usually offered in fall term
Activity: Lecture
1.0 Course Unit

MATH 547 Stochastic Processes
Course not offered every year
Also Offered As: MATH 649, STAT 931
Prerequisites: Math 546/Stat 930 the equivalent.
Activity: Lecture
1.0 Course Unit

MATH 560 Selections from Geometry and Topology
Informal introduction to such subjects as homology and homotopy theory, classical differential geometry, dynamical systems, and knot theory.
Course not offered every year
Corequisite: Math 500 or permission of the instructor
Activity: Lecture
1.0 Course Unit

MATH 561 Selections from Geometry and Topology
Informal introduction to such subjects as homology and homotopy theory, classical differential geometry, dynamical systems, and knot theory.
Course not offered every year
Corequisite: Math 500 or permission of the instructor
Activity: Lecture
1.0 Course Unit

MATH 570 Introduction to Logic and Computability
Course not offered every year
Also Offered As: LGIC 310, PHIL 410
Prerequisite: Math 371 or Math 503
Activity: Lecture
1.0 Course Unit

MATH 571 Introduction to Logic and Computability
Continuation of Math 570.
Course not offered every year
Also Offered As: LGIC 320
Prerequisites: Math 570 or with the permission of the instructor.
Activity: Seminar
1.0 Course Unit

MATH 580 Combinatorial Analysis and Graph Theory
Generating functions, enumeration methods, Polya's theorem, combinatorial designs, discrete probability, extremal graphs, graph algorithms and spectral graph theory, combinatorial and computational geometry.
Course not offered every year
Prerequisite: Permission of the instructor
Activity: Lecture
1.0 Course Unit

MATH 581 Combinatorial Analysis and Graph Theory
Continuation of Math 580.
Course not offered every year
Prerequisites: Math 580 or with the permission of the instructor.
Activity: Lecture
1.0 Course Unit
MATH 584 The Mathematics of Medical Imaging and Measurement
The last several decades have seen major revolutions in both medical and non-medical and imaging technologies. Underlying all of these advances are sophisticated mathematical tools to model the measurement process and reconstruct images. This course begins with an introduction of the mathematical models and then proceeds to discuss the integral transforms that underlie these models: the Fourier transform, the Radon transform and the Laplace transform. We discuss how each of these transforms is inverted, both in theory and in practice. Along the way we study interpolation, sampling, approximation theory, filtering and noise analysis. This course assumes a thorough knowledge of linear algebra and a knowledge of analysis at the undergraduate level (Math 314 and Math 360 and Math 361, or Math 508 and Math 509).
Taught by: Staff.
Course not offered every year
Also Offered As: AMCS 584, BE 584
Prerequisites: Math 314 and Math 360 and 361, or Math 508 and 509 or with permission of the instructor.
Activity: Lecture
1.0 Course Unit

MATH 586 Topics in Mathematical Biology.
This course will cover various mathematical models and tools that are used to study modern biological problems. The specific emphasis will vary from year to year, but typically will include an introduction to stochastic processes and computational methods that arise in evolutionary biology and population genetics. No prior knowledge of biology is needed to take this course, but a strong background in probability and familiarity with algorithms and combinatorics will be assumed.
Also Offered As: BIOL 586
Prerequisites: Math 430 or equivalent is required. Math 241 and 340 are recommended.
Activity: Lecture
1.0 Course Unit

MATH 594 Mathematical Methods of Physics
Introduction to mathematics used in physics and engineering, with the goal of developing facility in classical techniques. Vector spaces, linear algebra, computation of eigenvalues and eigenvectors, boundary value problems, spectral theory of second order equations, asymptotic expansions, partial differential equations, differential operators and Green's functions, orthogonal functions, generating functions, contour integration, Fourier and Laplace transforms and an introduction to representation theory of SU(2) and SO(3). The course will draw on examples in continuum mechanics, electrostatics and transport problems.
Course not offered every year
Also Offered As: PHYS 500
Prerequisites: Math 241 or Permission of Instructor. Physics 151 would be helpful for undergraduates.
Activity: Lecture
1.0 Course Unit

MATH 599 Independent Study
One-term course offered either term
Activity: Independent Study
1.0 Course Unit

MATH 600 Topology and Geometric Analysis
Course usually offered in fall term
Prerequisites: Math 500 and 501 or with the permission of the instructor.
Activity: Lecture
1.0 Course Unit

MATH 601 Topology and Geometric Analysis
Covering spaces and fundamental groups, van Kampen's theorem and classification of surfaces. Basics of homology and cohomology, singular and cellular; isomorphism with de Rham cohomology. Brouwer fixed point theorem, CW complexes, cup and cap products, Poincare duality, Lefschetz and universal coefficient theorems, Alexander duality, Lefschetz fixed point theorem.
Course usually offered in spring term
Prerequisites: Math 600 or with the permission of the instructor.
Activity: Lecture
1.0 Course Unit

MATH 602 Algebra
Course usually offered in fall term
Prerequisites: Math 370 and 371 or Math 502 and 503
Activity: Lecture
1.0 Course Unit

MATH 603 Algebra
Continuation of Math 602.
Course usually offered in spring term
Prerequisites: Math 602 or with the permission of the instructor.
Activity: Lecture
1.0 Course Unit

MATH 604 First Year Seminar in Mathematics
This is a seminar for first year Mathematics graduate student, supervised by faculty. Students give talks on topics from all areas of mathematics at a level appropriate for first year graduate students. Attendance and preparation will be expected by all participants, and learning how to present mathematics effectively is an important part of the seminar.
Course usually offered in fall term
Prerequisites: Open to first year Mathematics graduate students. Others need permission of the instructor.
Activity: Seminar
1.0 Course Unit
MATH 608 Analysis
Complex analysis: analyticity, Cauchy theory, meromorphic functions, isolated singularities, analytic continuation, Runge’s theorem, d-bar equation, Mittag-Leffler theorem, harmonic and sub-harmonic functions, Riemann mapping theorem, Fourier transform from the analytic perspective. Introduction to real analysis: Weierstrass approximation, Lebesgue measure in Euclidean spaces, Borel measures and convergence theorems, $C_0$ and the Riesz-Markov theorem, $L_p$-spaces, Fubini Theorem. One-term course offered either term
Also Offered As: AMCS 608
Prerequisites: Math 508 and 509
Activity: Lecture
1.0 Course Unit

MATH 609 Analysis
Real analysis: general measure theory, outer measures and Caratheodory construction, Hausdorff measures, Radon-Nikodym theorem, Fubini’s theorem, Hilbert space and $L^2$-theory of the Fourier transform. Functional analysis: normed linear spaces, convexity, the Hahn-Banach theorem, duality for Banach spaces, weak convergence, bounded linear operators, Baire category theorem, uniform boundedness principle, open mapping theorem, closed graph theorem, compact operators, Fredholm theory, interpolation theorems, $L_p$-theory for the Fourier transform. One-term course offered either term
Also Offered As: AMCS 609
Prerequisites: Math 608 or permission of the instructor.
Activity: Lecture
1.0 Course Unit

MATH 610 Functional Analysis
Also Offered As: AMCS 610
Prerequisites: Math 608 or 609, some elementary complex analysis is essential.
Activity: Lecture
1.0 Course Unit

MATH 612 Selections from Algebra
Informal introduction to such subjects as homological algebra, number theory, and algebraic geometry. Course not offered every year
Corequisites: MATH 600 and 602
Activity: Lecture
1.0 Course Unit

MATH 618 Algebraic Topology, Part I
Homotopy groups, Hurewicz theorem, Whitehead theorem, spectral sequences. Classification of vector bundles and fiber bundles. Characteristic classes and obstruction theory. Course usually offered in fall term
Prerequisite: Math 600/601 or with the permission of the instructor
Activity: Lecture
1.0 Course Unit
MATH 625 Algebraic Geometry
Continuation of Math 624.
Course not offered every year
Prerequisites: Math 624 or with the permission of the instructor.
Activity: Lecture
1.0 Course Unit

MATH 626 Commutative Algebra
Topics in commutative algebra taken from the literature. Material will vary from year to year depending upon the instructor's interests.
Course not offered every year
Prerequisites: Math 602 and 603
Activity: Lecture
1.0 Course Unit

MATH 628 Homological Algebra
Complexes and exact sequences, homology, categories, derived functors (especially Ext and Tor). Homology and cohomology arising from complexes in algebra and geometry, e.g. simplicial and singular theories, Cech cohomology, de Rham cohomology, group cohomology, Hochschild cohomology. Projective resolutions, cohomological dimension, derived categories, spectral sequences. Other topics may include: Lie algebra cohomology, Galois and etale cohomology, cyclic cohomology, l-adic cohomology. Algebraic deformation theory, quantum groups, Brauer groups, descent theory.
Course not offered every year
Prerequisites: Math 602 and 603
Activity: Lecture
1.0 Course Unit

MATH 629 Homological Algebra
Continuation of Math 628.
Course not offered every year
Prerequisites: Math 628 or with the permission of the instructor.
Activity: Lecture
1.0 Course Unit

MATH 634 Arithmetic Geometry
Arithmetic Geometry
Activity: Lecture
1.0 Course Unit

MATH 642 Topics in Partial Differential Equations
Problems in differential geometry, as well as those in physics and engineering, inevitable involve partial derivatives. This course will be an introduction to these problems and techniques. We will use P.D.E. as a tool. Some of the applications will be small, some large. The proof of the Hodge Theorem will be a small application. Discussion of the Yamabe problem and ricci flow (used to prove the Poincare Conjecture) will be larger.
Prerequisites: Math 608, 609. This course will not presume courses in Partial Differential Equations or Differential Geometry. Background will be covered in the course.
Activity: Lecture
1.0 Course Unit

MATH 644 Partial Differential Equations
Subject matter varies from year to year. Some topics are: the classical theory of the wave and Laplace equations, general hyperbolic and elliptic equations, theory of equations with constant coefficients, pseudo-differential operators, and non-linear problems. Sobolev spaces and the theory of distributions will be developed as needed.
Course not offered every year
Prerequisites: Math 608 and 609 or permission of the instructor
Activity: Lecture
1.0 Course Unit

MATH 645 Partial Differential Equations
Subject matter varies from year to year. Some topics are: the classical theory of the wave and Laplace equations, general hyperbolic and elliptic equations, theory of equations with constant coefficients, pseudo-differential operators, and nonlinear problems. Sobolev spaces and the theory of distributions will be developed as needed.
Course not offered every year
Prerequisites: Math 608 and 609 or permission of the instructor
Activity: Lecture
1.0 Course Unit

MATH 649 Stochastic Processes
Conditional expectations, martingales, Markov chains, Brownian motion, diffusions.
Course not offered every year
Also Offered As: MATH 547, STAT 931
Prerequisite: Math 648
Activity: Lecture
1.0 Course Unit

MATH 652 Operator Theory
Subject matter may include spectral theory of operators in Hilbert space, C*-algebras, von Neumann algebras.
Course not offered every year
Activity: Lecture
1.0 Course Unit

MATH 654 Lie Groups
Connection of Lie groups with Lie algebras, Lie subgroups, exponential map. Algebraic Lie groups, compact and complex Lie groups, solvable and nilpotent groups. Other topics may include relations with symplectic geometry, the orbit method, moment map, symplectic reduction, geometric quantization, Poisson-Lie and quantum groups.
Course not offered every year
Prerequisites: Math 600 and 601, Math 602 and 603
Activity: Lecture
1.0 Course Unit

MATH 655 Lie Groups
Continuation of Math 654.
Course not offered every year
Prerequisites: Math 654 or with the permission of the instructor.
Activity: Lecture
1.0 Course Unit

MATH 656 Representation of Continuous Groups
Possible topics: harmonic analysis on locally compact abelian groups; almost periodic functions; direct integral decomposition theory. Types I, II and III: induced representations, representation theory of semisimple groups.
Course not offered every year
Activity: Lecture
1.0 Course Unit
MATH 657 Representation of Continuous Groups
Possible topics: harmonic analysis on locally compact abelian groups; almost periodic functions; direct integral decomposition theory, Types I, II and III: induced representations, representation theory of semisimple groups.
Course not offered every year
Activity: Lecture
1.0 Course Unit

MATH 660 Differential Geometry
Riemannian metrics and connections, geodesics, completeness, Hopf-Rinow theorem, sectional curvature, Ricci curvature, scalar curvature, Jacobi fields, second fundamental form and Gauss equations, manifolds of constant curvature, first and second variation formulas, Bonnet-Myers theorem, comparison theorems, Morse index theorem, Hadamard theorem, Preissmann theorem, and further topics such as sphere theorems, critical points of distance functions, the soul theorem, Gromov-Hausdorff convergence.
Course not offered every year
Prerequisites: Math 600 and 601, Math 602 and 603
Activity: Lecture
1.0 Course Unit

MATH 661 Differential Geometry
Continuation of Math 660.
Course not offered every year
Prerequisites: Math 660 or with the permission of the instructor.
Activity: Lecture
1.0 Course Unit

MATH 671 Topics in Logic
Discusses advanced topics in logic.
Course not offered every year
Also Offered As: PHIL 412
Prerequisites: Math 570 and 571
Activity: Seminar
1.0 Course Unit

MATH 694 Mathematical Foundations of Theoretical Physics
Selected topics in mathematical physics, such as mathematical methods of classical mechanics, electrodynamics, relativity, quantum mechanics and quantum field theory.
Course not offered every year
Activity: Lecture
1.0 Course Unit

MATH 695 Mathematical Foundations of Theoretical Physics
Selected topics in mathematical physics, such as mathematical methods of classical mechanics, electrodynamics, relativity, quantum mechanics and quantum field theory.
Course not offered every year
Activity: Lecture
1.0 Course Unit

MATH 702 Topics in Algebra
Topics from the literature. The specific subjects will vary from year to year.
Course not offered every year
Activity: Lecture
1.0 Course Unit

MATH 703 Topics in Algebra
Topics from the literature. The specific subjects will vary from year to year.
Course not offered every year
Activity: Lecture
1.0 Course Unit

MATH 704 Topics in Algebra
Topics from the literature. The specific subjects will vary from year to year.
Course not offered every year
Activity: Lecture
1.0 Course Unit

MATH 720 Advanced Number Theory
Ramification theory, adeles and ideles, Tate's thesis, group cohomology and Galois cohomology, class field theory in terms of ideles and cohomology, Lubin-Tate formal groups, Artin and Swan conductors, central simple algebras over local and global fields, general Hasse principles. Other topics may include the following: zero-dimensional Arakelov theory, Tate duality, introduction to arithmetic of elliptic curves, local and global epsilon factors in functional equations, $p$-adic L-functions and Iwasawa theory, modular forms and functions and modular curves.
Course not offered every year
Prerequisites: Math 620 and 621
Activity: Lecture
1.0 Course Unit

MATH 721 Advanced Number Theory
Continuation of Math 720.
Course not offered every year
Prerequisites: Math 720 or with the permission of the instructor.
Activity: Lecture
1.0 Course Unit

MATH 724 Topics in Algebraic Geometry
Topics from the literature. The specific subjects will vary from year to year.
Course not offered every year
Prerequisites: Either Math 622 and 623 or Math 624 and 625
Activity: Lecture
1.0 Course Unit

MATH 727 Topics in Algebraic Geometry
Topics from the literature. The specific subjects will vary from year to year.
Course not offered every year
Prerequisites: Either Math 622 and 623 or Math 624 and 625
Activity: Lecture
1.0 Course Unit

MATH 730 Topics in Algebraic and Differential Topology
Topics from the literature. The specific subjects will vary from year to year.
Course not offered every year
Prerequisites: Math 618 and 619
Activity: Lecture
1.0 Course Unit

MATH 731 Topics in Algebraic and Differential Topology
Topics from the literature. The specific subjects will vary from year to year.
Course not offered every year
Prerequisites: Math 618 and 619
Activity: Lecture
1.0 Course Unit

MATH 748 Topics in Classical Analysis
Harmonic analysis in Euclidean space, Riemann surfaces, Discontinuous groups and harmonic analysis in hyperbolic space, Pseudodifferential operators and index theorems, Variational methods in non-linear PDE, Hyperbolic equations and conservation laws, Probability and stochastic processes, Geometric measure theory, Applications of analysis to problems in differential geometry. The specific subjects will vary from year to year.
Course not offered every year
Prerequisites: Math 608 and Math 609 and permission from the instructor
Activity: Lecture
1.0 Course Unit

MATH 752 Topics in Operator theory
Topics from the literature. The specific subjects will vary from year to year.
Course not offered every year
Activity: Lecture
1.0 Course Unit
MATH 753 Topics in Operator Theory
Topics from the literature. The specific subjects will vary from year to year.
Course not offered every year
Activity: Lecture
1.0 Course Unit

MATH 760 Topics in Differential Geometry
Topics from the literature. The specific subjects will vary from year to year.
Course not offered every year
Prerequisites: Math 660 and 661
Activity: Lecture
1.0 Course Unit

MATH 761 Topics in Differential Geometry
Topics from the literature. The specific subjects will vary from year to year.
Course not offered every year
Prerequisites: Math 660 and 661
Activity: Lecture
1.0 Course Unit

MATH 820 Algebra Seminar
Seminar on current and recent literature in algebra.
Course not offered every year
Activity: Seminar
1.0 Course Unit

MATH 830 Geometry-Topology Seminar
Seminar on current and recent literature in geometry-topology
Course not offered every year
Activity: Seminar
1.0 Course Unit

MATH 831 Geometry-Topology Seminar
Seminar on current and recent literature in geometry-topology
Course not offered every year
Activity: Seminar
1.0 Course Unit

MATH 871 Logic Seminar
Seminar on current and recent literature in logic.
Course not offered every year
Activity: Seminar
1.0 Course Unit

MATH 878 Probability and Algorithm Seminar
Seminar on current and recent literature in probability and algorithm.
Taught by: Staff.
Activity: Seminar
1.0 Course Unit

MATH 881 Combinatorics Seminar
Seminar on current and recent literature in combinatorics.
Course not offered every year
Activity: Seminar
1.0 Course Unit