Mathematics is a way of defining and solving problems by combining logic with insight, and by finding patterns and structure. At a most basic level, we use the abstract concept of "number" to understand what we observe, and we develop the method of "counting"; at a higher level, we use the language of "calculus" to understand motion, and we develop the methods of differentiation and integration. But mathematics is more than just computations with numbers and derivatives. Math is a way of thinking—an art that describes the abstract structure of logic, reason, and the scientific method.

The Undergraduate program in the Department of Mathematics is intended both for students interested in preparing for graduate study and research in pure mathematics, and for students interested in using mathematics to pose and solve problems in the sciences, engineering, social sciences, or other areas. Undergraduate mathematics majors and minors will study:

- The foundations of analysis, which begins with the study of functions and their derivatives and integrals
- The fundamentals of advanced algebra, which is based on axiomatic systems involving operations of addition and multiplication in general settings
- Additional subjects such as geometry, probability, and topology
- Applications of mathematics to science and/or engineering.

The graduate program is designed primarily to prepare students for research and teaching in mathematics. It is naturally centered around the research areas of the faculty, which include algebraic geometry, algebraic number theory, data-intensive computation, geometric analysis, harmonic analysis, mathematical physics, partial differential equations, stochastic partial differential equations, and topology. The program can be supplemented in applied directions by courses in theoretical physics, computer science, mechanics, probability, and statistics offered in other departments of the Krieger School of Arts and Sciences and in the Department of Applied Mathematics and Statistics in the Whiting School of Engineering.

Facilities

The Mathematics Department resides in Krieger Hall on the Keyser Quad of the Homewood Campus. Adjacent to Krieger Hall, The University's Milton S. Eisenhower Library has an unusually extensive collection of mathematics literature, including all the major research journals, almost all of which are also accessible electronically. The stacks are open to students. The department also has a useful reference library, the Philip Hartman Library. Graduate students share departmental offices, and study space can also be reserved in the university library. Graduate students may access the department's Linux and Windows servers, as well as computers in graduate student offices. The department also hosts numerous research seminars, special lectures, and conferences throughout the academic year.

Programs

The Department of Mathematics offers Bachelor's, Master's, and Doctoral degrees across a variety of programs. Undergraduates can elect to pursue a major or minor in Mathematics; the major has an Honors designation available, as well as a four-year BA/MA program. Graduate students can pursue doctoral work in the department. We do not have a terminal Master's program at this time.

- Mathematics, Bachelor of Arts (https://e-catalogue.jhu.edu/arts-sciences/full-time-residential-programs/degree-programs/mathematics/mathematics-bachelor-arts/)
- Mathematics, Minor (https://e-catalogue.jhu.edu/arts-sciences/full-time-residential-programs/degree-programs/mathematics/mathematics-minor/)
- Mathematics, Bachelor of Arts/Master of Arts (https://e-catalogue.jhu.edu/arts-sciences/full-time-residential-programs/degree-programs/mathematics/mathematics-bachelor-arts-master/)
- Mathematics, PhD (https://e-catalogue.jhu.edu/arts-sciences/full-time-residential-programs/degree-programs/mathematics/mathematics-phd/)

For current course information and registration go to https://sis.jhu.edu/classes/

Courses

AS.110.102. College Algebra. 3 Credits.
This introductory course will create a foundational understanding of topics in Algebra. An emphasis will be on applications to prepare students for future courses like Precalculus or Statistics. After a review of elementary algebra concepts, topics covered include: equations and inequalities, linear equations, exponents and polynomials, factoring, rational expressions and equations, relations and functions, radicals, linear and quadratic equations, higher-degree polynomials, exponential, logarithmic, and rational functions.
Area: Quantitative and Mathematical Sciences

AS.110.105. Precalculus. 4 Credits.
This course provides students with the background necessary for the study of calculus. It begins with a review of the coordinate plane, linear equations, and inequalities, and moves purposefully into the study of functions. Students will explore the nature of graphs and deepen their understanding of polynomial, rational, trigonometric, exponential, and logarithmic functions, and will be introduced to complex numbers, parametric equations, and the difference quotient.
Area: Quantitative and Mathematical Sciences

AS.110.106. Calculus I (Biology and Social Sciences). 4 Credits.
Differential and integral calculus. Includes analytic geometry, functions, limits, integrals and derivatives, introduction to differential equations, functions of several variables, linear systems, applications for systems of linear differential equations, probability distributions. Many applications to the biological and social sciences will be discussed.
Area: Quantitative and Mathematical Sciences

AS.110.107. Calculus II (For Biological and Social Science). 4 Credits.
Differential and integral Calculus. Includes analytic geometry, functions, limits, integrals and derivatives, introduction to differential equations, functions of several variables, linear systems, applications for systems of linear differential equations, probability distributions. Applications to the biological and social sciences will be discussed, and the courses are designed to meet the needs of students in these disciplines.
Recommended Course Background: Grade of C- or Better in AS.110.106 or AS.110.108, or a 5 on the AP AB exam.
Area: Quantitative and Mathematical Sciences

Mathematics
AS.110.108. Calculus I (Physical Sciences & Engineering). 4 Credits.
Differential and integral calculus. Includes analytic geometry, functions, limits, integrals and derivatives, polar coordinates, parametric equations, Taylor's theorem and applications, infinite sequences and series. Some applications to the physical sciences and engineering will be discussed, and the courses are designed to meet the needs of students in these disciplines.
Area: Quantitative and Mathematical Sciences

AS.110.109. Calculus II (For Physical Sciences and Engineering). 4 Credits.
Differential and integral calculus. Includes analytic geometry, functions, limits, integrals and derivatives, polar coordinates, parametric equations, Taylor's theorem and applications, infinite sequences and series. Some applications to the physical sciences and engineering will be discussed, and the courses are designed to meet the needs of students in these disciplines.
Recommended Course Background: Grade of C- or Better in AS.110.106 or AS.110.108, or a 5 on the AP BC exam.
Area: Quantitative and Mathematical Sciences

AS.110.113. Honors Single Variable Calculus. 4 Credits.
This is an honors alternative to the Calculus sequences AS.110.106-AS.110.107 or AS.110.108-AS.110.109 and meets the general requirement for both Calculus I and Calculus II (although the credit hours count for only one course). It is a more theoretical treatment of one variable differential and integral calculus and is based on our modern understanding of the real number system as explained by Cantor, Dedekind, and Weierstrass. Students who want to know the "why's and how's" of Calculus will find this course rewarding. Previous background in Calculus is not assumed. Students will learn differential Calculus (derivatives, differentiation, chain rule, optimization, related rates, etc), the theory of integration, the fundamental theorem(s) of Calculus, applications of integration, and Taylor series. Students should have a strong ability to learn mathematics quickly and on a higher level than that of the regular Calculus sequences.
Area: Quantitative and Mathematical Sciences

AS.110.201. Linear Algebra. 4 Credits.
Prerequisite(s): Grade of C- or better in AS.110.107 OR AS.110.109 OR AS.110.113 OR AS.110.202 OR AS.110.302, or a 5 on the AP BC exam.
Area: Quantitative and Mathematical Sciences

AS.110.202. Calculus III. 4 Credits.
Calculus of functions of more than one variable: partial derivatives, and applications; multiple integrals, line and surface integrals; Green's Theorem, Stokes' Theorem, and Gauss' Divergence Theorem.
Prerequisite(s): Grade of C- or better in AS.110.107 OR AS.110.109 OR AS.110.113 OR AS.110.201 OR AS.110.212 OR AS.110.302, or a 5 on the AP BC exam.
Area: Quantitative and Mathematical Sciences

AS.110.211. Honors Multivariable Calculus. 4 Credits.
This course includes the material in AS.110.202 with some additional applications and theory. Recommended for mathematically able students majoring in physical science, engineering, or especially mathematics. AS.110.211-AS.110.212 used to be an integrated yearlong course, but now the two are independent courses and can be taken in either order.
Prerequisite(s): Grade of C- or better in (AS.110.201 or AS.110.212)
Area: Quantitative and Mathematical Sciences

AS.110.212. Honors Linear Algebra. 4 Credits.
This course includes the material in AS.110.201 with additional applications and theory, and is recommended only for mathematically able students majoring in physical science, engineering, or mathematics who are interested in a proof-based version of linear algebra. This course can serve as an Introduction to Proofs (IP) course. Prerequisites: Grade of B+ or better in 110.107 or 110.109 or 110.113, or a 5 on the AP BC exam.
Area: Quantitative and Mathematical Sciences

AS.110.225. Problem Solving Lab. 2 Credits.
This course is an introduction to mathematical reasoning and formalism in the context of mathematical problem solving, such as induction, invariants, inequalities and generating functions. This course does not satisfy any major requirement, and may be taken more than once for credit It is primarily used as training for the William Lowell Putnam Mathematics Competition.
Area: Quantitative and Mathematical Sciences

AS.110.275. Probability. 4 Credits.
This course follows the actuarial Exam P syllabus and learning objectives to prepare students to pass the SOA/CAS Probability Exam. Topics include axioms of probability, discrete and continuous random variables, conditional probability, Bayes' theorem, Chebyshov's Theorem, Central Limit Theorem, univariate and joint distributions and expectations, loss frequency, loss severity and other risk management concepts. Exam P learning objectives and learning outcomes are emphasized.
Recommended Course Background: Calculus II
Prerequisite(s): AS.110.107 OR AS.110.109
Area: Quantitative and Mathematical Sciences

AS.110.276. Introduction to Financial Mathematics. 4 Credits.
This course is designed to develop students' understanding of fundamental concepts of financial mathematics. The course will cover mathematical theory and applications including the time value of money, annuities and cash flows, bond pricing, loans, amortization, stock and portfolio pricing, immunization of portfolios, swaps and determinants of interest rates, asset matching and convexity. A basic knowledge of calculus and an introductory knowledge of probability is assumed.
Area: Quantitative and Mathematical Sciences

AS.110.301. Introduction to Proofs. 4 Credits.
This course will provide a practical introduction to mathematical proofs with the aim of developing fluency in the language of mathematics, which itself is often described as "the language of the universe." Along with a library of proof techniques, we shall tour propositional logic, set theory, cardinal arithmetic, and metric topology and explore "proof relevant" mathematics by interacting with a computer proof assistant. This course on the construction of mathematical proof will conclude with a deconstruction of mathematical proof, interrogating the extent to which proof serves as a means to discover universal truths and assessing the mechanisms by which the mathematical community achieves consensus regarding whether a claimed result has been proven.
Area: Quantitative and Mathematical Sciences
AS.110.302. Differential Equations and Applications. 4 Credits.
This is a course in ordinary differential equations (ODEs), equations involving an unknown function of one independent variable and some of its derivatives, and is primarily a course in the study of the structure of and techniques for solving ODEs as mathematical models. Specific topics include first and second ODEs of various types, systems of linear differential equations, autonomous systems, and the qualitative and quantitative analysis of nonlinear systems of first-order ODEs. Laplace transforms, series solutions and the basics of numerical solutions are included as extra topics. Prerequisites: Grade of C- or better in 110.107 or 110.109 or 110.113, or a 5 on the AP BC exam. Area: Quantitative and Mathematical Sciences
Prerequisite(s): Grade of C- or better in AS.110.107 or AS.110.109 or AS.110.113 or AS.110.201 or AS.110.202 or AS.110.211 or AS.110.212, or a 5 on the AP BC exam.
Area: Quantitative and Mathematical Sciences

AS.110.303. The Mathematics of Politics, Democracy, and Social Choice. 4 Credits.
This course is designed for students of all backgrounds to provide a mathematical introduction to social choice theory, weighted voting systems, apportionment methods, and gerrymandering. The search for ideal ways to make certain kinds of political decisions, a lot of wasted effort could be averted if mathematics could determine that finding such an ideal was actually possible in the first place. The course will analyze data from recent US elections as well as provide historical context to modern discussions in politics, culminating in a mathematical analysis of the US Electoral College. Case studies, future implications, and comparisons to other governing bodies outside the US will be used to apply the theory of the course. Students will use Microsoft Excel to analyze data sets. There are no mathematical prerequisites for this course.
Area: Quantitative and Mathematical Sciences
Writing Intensive

AS.110.304. Elementary Number Theory. 4 Credits.
The student is provided with many historical examples of topics, each of which serves as an illustration of and provides a background for many years of current research in number theory. Primes and prime factorization, congruences, Euler's function, quadratic reciprocity, primitive roots, solutions to polynomial congruences (Chevalley's theorem), Diophantine equations including the Pythagorean and Pell equations, Gaussian integers, Dirichlet's theorem on primes.
Prerequisite(s): Grade of C- or better in (AS.110.201 OR AS.110.212) Area: Quantitative and Mathematical Sciences

AS.110.311. Methods of Complex Analysis. 4 Credits.
This course is an introduction to the theory of functions of one complex variable. Its emphasis is on techniques and applications, and it serves as a basis for more advanced courses. Functions of a complex variable and their derivatives; power series and Laurent expansions; Cauchy integral theorem and formula; calculus of residues and contour integrals; harmonic functions.
Prerequisite(s): Grade of C- or better in (AS.110.202 or AS.110.211) Area: Quantitative and Mathematical Sciences

AS.110.365. Mathematical Foundations of AI Bias. 4 Credits.
At the end of this course students should be able to understand various sources of algorithmic bias; understand what types of bias can or cannot be addressed in a given data set; be able to reason over when different algorithms can be applied to a data set, and how they can be interpreted; take the outcomes of a given algorithm and reason about the bias of the output. Recommended Course Background: Vector calc, linear algebra, a sufficiently advanced stats course, programming ability in R, matlab or python
Prerequisite(s): AS.110.201 OR AS.110.202 OR EN.553.310
Area: Quantitative and Mathematical Sciences

AS.110.375. Introduction to Mathematical Cryptography. 4 Credits.
An Introduction to Mathematical Cryptography is an introduction to modern cryptography with an emphasis on the mathematics behind the theory of public key cryptosystems and digital signature schemes. The course develops the mathematical tools needed for the construction and security analysis of diverse cryptosystems. Other topics central to mathematical cryptography covered are: classical cryptographic constructions, such as Diffie-Hellman key exchange, discrete logarithm-based cryptosystems, the RSA cryptosystem, and digital signatures. Fundamental mathematical tools for cryptography studied include: primality testing, factorization algorithms, probability theory, information theory, and collision algorithms. A survey of important recent cryptographic innovations, such as elliptic curves, elliptic curve and pairing-based cryptography are included as well. This course is an ideal introduction for mathematics and computer science students to the mathematical foundations of modern cryptography.
Area: Quantitative and Mathematical Sciences

AS.110.401. Introduction to Abstract Algebra. 4 Credits.
An introduction to the basic notions of modern abstract algebra and can serve as as Introduction to Proofs (IP) course. This course is an introduction to group theory, with an emphasis on concrete examples, and especially on geometric symmetry groups. The course will introduce basic notions (groups, subgroups, homomorphisms, quotients) and prove foundational results (Lagrange's theorem, Cauchy's theorem, orbit-counting techniques, the classification of finite abelian groups). Examples to be discussed include permutation groups, dihedral groups, matrix groups, and finite rotation groups, culminating in the classification of the wallpaper groups. Prerequisites: Grade of C- or better in 110.201 or 110.212 Area: Quantitative and Mathematical Sciences.
Prerequisite(s): Grade of C- or better in (AS.110.201 or AS.110.212) Area: Quantitative and Mathematical Sciences

AS.110.405. Real Analysis I. 4 Credits.
This course is designed to give a firm grounding in the basic tools of analysis. It is recommended as preparation (but may not be a prerequisite) for other advanced analysis courses and may be taken as an Introduction to Proofs (IP) course. Topics include the formal properties of real and complex number systems, topology of metric spaces, limits, continuity, infinite sequences and series, differentiation, Riemann-Stieltjes integration. Prerequisites: Grade of C- or better in 110.201 or 110.212 and 110.202 or 110.211
Prerequisite(s): Grade of C- or better in (AS.110.201 OR AS.110.212) AND (AS.110.202 OR AS.110.211) Area: Quantitative and Mathematical Sciences
AS.110.406. Real Analysis II. 4 Credits.
This course continues AS.110.405 with an emphasis on the fundamental
notions of modern analysis. Sequences and series of functions,
Fourier series, equicontinuity and the Arzela-Ascoli theorem, the Stone-
Weierstrass theorem, functions of several variables, the inverse and
implicit function theorems, introduction to the Lebesgue integral.
Area: Quantitative and Mathematical Sciences

AS.110.407. Honors Complex Analysis. 4 Credits.
This course is an introduction to the theory of functions of one complex variable
for honors students. Its emphasis is on techniques and applications,
and can serve as an Introduction to Proofs (IP) course. Topics will
include functions of a complex variable and their derivatives; power
series and Laurent expansions; Cauchy integral theorem and formula;
calculus of residues and contour integrals; harmonic functions, as well as
applications to number theory and harmonic analysis.Area: Quantitative
and Mathematical Sciences. This is not an Introduction to Proofs course
(IP) and may not be taken as a first proof-based mathematics course
except at the discretion of the instructor. This course satisfies a core
requirement of the mathematics major as a second analysis course, and
is a core requirement for honors in the major.
Prerequisite(s): AS.110.405 OR AS.110.415
Area: Quantitative and Mathematical Sciences

AS.110.411. Honors Algebra I. 4 Credits.
An introduction to the basic notions of modern algebra for students
with some prior acquaintance with abstract mathematics. Elements of
group theory: groups, subgroups, normal subgroups, quotient groups,
and homomorphisms. Generators and relations, free groups, products,
abelian groups, finite groups. Groups acting on sets, the Sylow theorems.
Definition and examples of rings and ideals.
Prerequisite(s): Grade of C- or better in AS.110.202 OR AS.110.304
OR AS.110.113 OR AS.110.405 OR AS.110.415 OR AS.110.407 OR
AS.110.413 OR AS.110.421
Area: Quantitative and Mathematical Sciences

AS.110.412. Honors Algebra II. 4 Credits.
This is a continuation of 110.411 Honors Algebra I. Topics studies
include principal ideal domains, structure of finitely generated modules
over them. Introduction to field theory. Linear algebra over a field. Field
extensions, constructible polygons, non-trisectability. Splitting field of a
polynomial, algebraic closure of a field. Galois theory: correspondence
between subgroups and subfields. Solvability of polynomial equations by
radicals. Prerequisites: Grade of C- or better in 110.201 or 110.212 OR
110.202 or 110.211 and 110.302 Area: Quantitative and Mathematical Sciences
Prerequisite(s): Grade of C- or better in (AS.110.201 OR AS.110.212) AND
(AS.110.202 or AS.110.211) AND 110.302
Area: Quantitative and Mathematical Sciences

AS.110.416. Honors Analysis II. 4 Credits.
Lebesgue integration and differentiation. Elementary Hilbert and Banach
space theory. Baire category theorem. Continuation of AS.110.415,
introduction to real analysis.
Prerequisite(s): Grade of C- or better in AS.110.415
Area: Quantitative and Mathematical Sciences

AS.110.417. Partial Differential Equations. 4 Credits.
Characteristics. Classification of second order equations, well-posed
problems. Separation of variables and expansions of solutions. The
wave equation: Cauchy problem, Poisson's solution, energy inequalities,
domains of influence and dependence. Laplace's equation: Poisson's
formula, maximum principles, Green's functions, potential theory Dirichlet
and Neumann problems, eigenvalue problems. The heat equation:
fundamental solutions, maximum principles. Recommended Course
Background: AS.110.405 or AS.110.415
Area: Quantitative and Mathematical Sciences

AS.110.421. Dynamical Systems. 4 Credits.
This is a course in the modern theory of Dynamical Systems. Topic
include both discrete (iterated maps) and continuous (differential
equations) dynamical systems and focuses on the qualitative structure
of the system in developing properties of solutions. Topics include
contractions, interval and planar maps, linear and nonlinear ODE systems
including bifurcation theory, recurrence, transitivity and mixing, phase
volume preservation as well as chaos theory, fractional dimension and
topological entropy. May be taken as an Introduction to Proofs (IP)
course. Prerequisites: Grade of C- or better in 110.201 or 110.212 OR
110.202 or 110.211 and 110.302 Area: Quantitative and Mathematical Sciences
Prerequisite(s): Grade of C- or better in (AS.110.201 OR AS.110.212) AND
(AS.110.202 or AS.110.211) AND 110.302
Area: Quantitative and Mathematical Sciences

AS.110.433. Introduction to Harmonic Analysis and Its Applications. 4
Credits.
The course is an introduction to methods in harmonic analysis, in
particular Fourier series, Fourier integrals, and wavelets. These methods
will be introduced rigorously, together with their motivations and
applications to the analysis of basic partial differential equations and
integral kernels, signal processing, inverse problems, and statistical/
machine learning.
Prerequisite(s): (AS.110.201 OR AS.110.212 OR EN.550.291 OR
EN.553.291) AND (AS.110.202 OR AS.110.211) AND (AS.110.405 OR
AS.110.415)
Area: Quantitative and Mathematical Sciences
AS.110.435. Introduction to Algebraic Geometry. 4 Credits.
Algebraic geometry studies zeros of polynomials in several variables and is based on the use of abstract algebraic techniques, mainly from commutative algebra, for solving geometric problems about these sets of zeros. The fundamental objects of study are algebraic varieties which are the geometric manifestations of solutions of systems of polynomial equations. Algebraic geometry occupies a central place in modern mathematics and has multiple conceptual connections with diverse fields such as complex analysis, topology and number theory. This course aims to provide to an undergraduate student majoring in mathematics the fundamental background to approach the study of algebraic geometry by providing the needed abstract knowledge also complemented by several examples and applications.
Area: Quantitative and Mathematical Sciences

AS.110.439. Introduction To Differential Geometry. 4 Credits.
Theory of curves and surfaces in Euclidean space: Frenet equations, fundamental forms, curvatures of a surface, theorems of Gauss and Mainardi-Codazzi, curves on a surface; introduction to tensor analysis and Riemannian geometry; theorema egregium; elementary global theorems.
Prerequisite(s): Grade of C- or better in (AS.110.201 OR AS.110.212) AND (AS.110.202 OR AS.110.211)
Area: Quantitative and Mathematical Sciences

AS.110.441. Calculus on Manifolds. 4 Credits.
This course provides the tools for classical three-dimensional physics and mechanics. This course extends these techniques to the general locally Euclidean spaces (manifolds) needed for an understanding of such things as Maxwell's equations or optimization in higher dimensional contexts, e.g., in economics. The course will cover the theory of differential forms and integration. Specific topics include Maxwell's equations in terms of 4D Lorentz geometry, vector (in particular, tangent) bundles, an introduction to de Rham theory, and Sard's theorem on the density of regular values of smooth functions. The course is intended to be useful to mathematics students interested in analysis, differential geometry, and topology, as well as to students in physics and economics.
Area: Quantitative and Mathematical Sciences

AS.110.443. Fourier Analysis. 4 Credits.
Prerequisite(s): Grade of C- or better in (AS.110.201 OR AS.110.212) AND (AS.110.202 OR AS.110.211)
Area: Quantitative and Mathematical Sciences

AS.110.445. Mathematical and Computational Foundations of Data Science. 4 Credits.
We will cover several topics in the mathematical and computational foundations of Data Science. The emphasis is on fundamental mathematical ideas (basic functional analysis, reproducing kernel Hilbert spaces, concentration inequalities, uniform central limit theorems), basic statistical modeling techniques (e.g. linear regression, parametric and non-parametric methods), basic machine learning techniques for unsupervised (e.g. clustering, manifold learning), supervised (classification, regression), and semi-supervised learning, and corresponding computational aspects (linear algebra, basic linear and nonlinear optimization to attack the problems above). Applications will include statistical signal processing, imaging, inverse problems, graph processing, and problems at the intersection of statistics/machine learning and physical/dynamical systems (e.g. model reduction for stochastic dynamical systems).
Area: Quantitative and Mathematical Sciences

AS.110.503. Undergraduate Research in Mathematics. 1 - 4 Credits.
Prerequisite(s): You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration & Online Forms.

AS.110.586. Independent Study. 1 - 4 Credits.
Prerequisite(s): You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration & Online Forms.

AS.110.587. DRP Independent Study. 1 Credit.
Directed Reading Program (DRP) Independent Study.
Prerequisite(s): You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration & Online Forms.
Area: Quantitative and Mathematical Sciences

AS.110.599. Independent Study. 1 - 3 Credits.
Area: Quantitative and Mathematical Sciences

AS.110.601. Algebra I.
The first of a two semester algebra sequence to provide the student with the foundations for Number Theory, Algebraic Geometry, Representation Theory, and other areas. Topics include refined elements of group theory, commutative algebra, Noetherian rings, local rings, modules, and rudiments of category theory, homological algebra, field theory, Galois theory, and non-commutative algebras.
Area: Quantitative and Mathematical Sciences

AS.110.602. Algebra II.
The second of a two semester algebra sequence to provide the student with the foundations for Number Theory, Algebraic Geometry, Representation Theory, and other areas. Topics include refined elements of group theory, commutative algebra, Noetherian rings, local rings, modules, and rudiments of category theory, homological algebra, field theory, Galois theory, and non-commutative algebras.
Area: Quantitative and Mathematical Sciences

AS.110.605. Real Analysis.
This course covers the theory of the Lebesgue theory of integration in d-dimensional Euclidean space, and offers a brief introduction to the theory of Hilbert spaces. Topics include the Lebesgue measure on Euclidean space, the Lebesgue integral, classical convergence results for the Lebesgue integral, Fubini's theorem, the spaces of $L^1$ and $L^2$ functions.
Area: Quantitative and Mathematical Sciences
AS.110.607. Complex Variables.
Analytic functions of one complex variable. Topics include Cauchy integral theorems, residue theory, conformal mapping, harmonic functions, riemann mapping theorem, normal families. Other topics may include Mittag-Leffler theorem, Weierstrass factorization theorem, elliptic functions, Picard theorem, and Nevanlinna theory.

AS.110.608. Riemann Surfaces.
Abstract Riemann surfaces. Examples: algebraic curves, elliptic curves and functions on them. Holomorphic and meromorphic functions and differential forms, divisors and the Mittag-Leffler problem. The analytic genus. Bezout's theorem and applications. Introduction to sheaf theory, with applications to constructing linear series of meromorphic functions. Serre duality, the existence of meromorphic functions on Riemann surfaces, the equality of the topological and analytic genera, the equivalence of algebraic curves and compact Riemann surfaces, the Riemann-Roch theorem. Period matrices and the Abel-Jacobi mapping, Jacobi inversion, the Torelli theorem. Uniformization (time permitting).

AS.110.615. Algebraic Topology I.
Singular homology theory, cohomology and products, category theory and homological algebra, Künneth and universal coefficient theorems, Poincaré and Alexander duality theorems, Lefschetz fixed-point theorem, covering spaces and fundamental groups. Prerequisites: the equivalent of one semester in both Abstract Algebra and Real Analysis (specifically, point set topology).

AS.110.616. Algebraic Topology II.
Higher homotopy groups, CW complexes, cellular homology and cohomology, spectral sequences and comparison theorems, graded homological algebra, fibrations, Serre and Eilenberg-Moore spectral sequence, Eilenberg-MacLane spaces, Steenrod algebra, spectra. Category theory and some applications. Prerequisites: the equivalent of one year of Abstract Algebra.

AS.110.617. Number Theory I.
Elements of advanced algebra and number theory. Possible topics for the year-long sequence include local and global fields, Galois cohomology, semisimple algebras, class field theory, elliptic curves, modular and automorphic forms, integral representations of L-functions, adele geometry and function fields, fundamental notions in arithmetic geometry (including Arakelov and diophantine geometry).

AS.110.618. Number Theory II.
Topics in advanced algebra and number theory. Possible topics for the year-long sequence include local and global fields, Galois cohomology, semisimple algebras, class field theory, elliptic curves, modular and automorphic forms, integral representations of L-functions, adele geometry and function fields, fundamental notions in arithmetic geometry (including Arakelov and diophantine geometry).

Lie groups and Lie algebras, classification of complex semi-simple Lie algebras, compact forms, representations and Weyl formulas, symmetric Riemannian spaces.

AS.110.631. Partial Differential Equations I.
This course is the first in the sequence about the general theory of PDEs. The beginning of the course will describe several important results of functional analysis which are instrumental for the study of PDEs: Hahn-Banach theorem, Uniform boundedness and closed graph theorems, reflexive spaces and weak topologies, elements of semi-group theory. Then we will describe the basic theory of Sobolev spaces and the standard existence theory for (initial) boundary value problems of elliptic/parabolic type. Finally, the rest of the course will be devoted to finer properties of solutions of elliptic equations such as maximum principles, Harnack principles and regularity.

AS.110.632. Partial Differential Equations II.
An introductory graduate course in partial differential equations. Classical topics include first order equations and characteristics, the Cauchy-Kowalevski theorem, Laplace’s equation, heat equation, wave equation, fundamental solutions, weak solutions, Sobolev spaces, maximum principles. The second term focuses on special topics such as second order elliptic theory.

AS.110.633. Harmonic Analysis.
Fourier multipliers, oscillatory integrals, restriction theorems, Fourier integral operators, pseudodifferential operators, eigenfunctions. Undergrads need instructor’s permission. Area: Quantitative and Mathematical Sciences

AS.110.637. Functional Analysis.
This class will explore basic aspects of functional analysis, focusing mostly on normed vector spaces. This will include the Hahn-Banach and open mapping theorems, a discussion of strong and weak topologies, the theory of compact operators, and spaces of integrable functions and Sobolev spaces, with applications to the study of some partial differential equations. Prerequisite: Real Analysis

AS.110.643. Algebraic Geometry I.
Introduction to affine varieties and projective varieties. Hilbert’s theorems about polynomials in several variables with their connections to geometry. Abstract algebraic varieties and projective geometry. Dimension of varieties and smooth varieties. Sheaf theory and some notions of cohomology. Applications of sheaves to geometry; e.g., theory of divisors, rudiments of scheme theory for the understanding of the Riemann-Roch theorem for curves and surfaces. Other topics may include Jacobian varieties, resolution of singularities, birational geometry on surfaces, schemes, connections with complex analytic geometry and topology?

AS.110.644. Algebraic Geometry II.
Introduction to affine varieties and projective varieties. Hilbert’s theorems about polynomials in several variables with their connections to geometry. Abstract algebraic varieties and projective geometry. Dimension of varieties and smooth varieties. Sheaf theory and some notions of cohomology. Applications of sheaves to geometry; e.g., theory of divisors, rudiments of scheme theory for the understanding of the Riemann-Roch theorem for curves and surfaces. Other topics may include Jacobian varieties, resolution of singularities, birational geometry on surfaces, schemes, connections with complex analytic geometry and topology.
Introducing the computer proof assistant Agda. Amenability to computer formalization, which this course will illustrate by a common proposition. One advantage of this foundation system is its thought of as revealing fundamental differences between two proofs of types might have interesting higher homotopical structure, which can now be interpreted as a path between two points in a space. In particular, those spaces. A proof that two terms in a common type are equal is constructing a term in the type that encodes its statement. In Homotopy system for constructive mathematics, in which a theorem is proven by Voevodsky’s univalence axiom. Dependent type theory is a formal Homotopy type theory (HoTT) is a new proposed foundation system AS.110.721.

AS.110.722. Topics in Homotopy Theory.
The course will focus on recent developments in homotopy theory, such as Galois theory for $E_n$ ($n \geq 2$) ring-spectra, and on connections with number theory; in particular, work of Bhatt, Hesselholt, Lurie, Scholze and others on topological Hochschild homology and its applications to geometry over the p-adic complex numbers.
Area: Quantitative and Mathematical Sciences

AS.110.726. Topics in Analysis.
The topics covered will involve the theory of calculus of Functors applied to Geometric problems like Embedding theory. Other related areas will be covered depending on the interest of the audience.
Area: Quantitative and Mathematical Sciences

AS.110.727. Topics in Algebraic Topology.

AS.110.731. Topics in Geometric Analysis.

AS.110.733. Topics In Alg Num Theory.

AS.110.737. Topics Algebraic Geometry.

AS.110.739. Topics in Analytic Number Theory.
The course will be on functional analysis (applied to number theory) and Connes-Meyer’s spectral interpretation of zeroes of Hecke L functions. Topics will include: adeles, ideles, bornologies, spectral theory, condensed/liquid modules à la Scholze-Clausen, Pontryagin duality and almost-periodic functions, Tate’s thesis, Connes-Meyer’s spectral interpretation. Relations with category theory, quantum mechanics, Bost-Connes systems and non-commutative geometry will be evoked. This course will be designed to be appealing for students from analysis or from algebra.

AS.110.741. Topics in Partial Differential Equations.

AS.110.742. Topics In Partial Differential Equations.
In this course we will be discussing some dispersive evolution equations, primarily the nonlinear Schrodinger equation. Topics will include well-posedness theory, conservation laws, and scattering. The course will be accessible to students who have not taken graduate partial differential equations or functional analysis.

AS.110.745. Introduction to Curvature Flows.

AS.110.749. Topics in Differential Geometry.
In this class, we will study Aaron Naber and Jeff Cheeger’s recent result on proving codimension four conjecture. We plan to talk about some early results of the structure on manifolds with lower Ricci bound by Cheeger and Colding. We will prove quantitative splitting theorem, convergence theorem, and the result that almost volume cone implies almost metric cone. Then we will discuss regularity of Einstein manifolds and the codimension four conjecture. Area: Quantitative and Mathematical Sciences

AS.110.750. Topics in Geometric Analysis.

AS.110.755. Topics in Representation Theory.
Area: Quantitative and Mathematical Sciences

AS.110.756. Topics in Algebra.
This will be a course in commutative algebra. Topics may include: Noetherian rings and modules, the Nullstellensatz, Hilbert basis theorem, localization, integrality, Noether normalization, primary decomposition, DVRs, Dedekind domains, dimension theory, smoothness and regularity, and homological methods.
Area: Quantitative and Mathematical Sciences
AS.110.757. Topics in Stochastic Dynamical Systems.
The course will present an introduction to stochastic dynamical systems and some applications in model reduction and data assimilation. The main focus will be on stability and ergodicity of stochastic dynamical systems, including stochastic differential equations driven by white and fractional noise, and their numerical approximations. We will then discuss model reduction, focusing on Mori-Zwanzig formalism and approximation of the generalized Langevin equation, and methods on the parametric inference of related stochastic systems. Data assimilation and stochastic control will also be briefly introduced.
Area: Quantitative and Mathematical Sciences

AS.110.771. Mathematics GTA Teaching Seminar.
The goals of this seminar center on the preparedness for graduate students in mathematics to engage in classroom instructions for undergraduates at Johns Hopkins University. This seminar augments the teaching orientation provided to graduate students by the CER and Mathematics Department by addressing (1) teaching-techniques: student-centered inclusive teaching strategies, facilitating small group work, incorporating student ideas and student thinking into active hole class discussions, and choosing appropriate mathematical tasks, (2) opportunities for practice teaching in classrooms before their first assignment to TA for a course in scaffolded micro-teaching experiences and (3) preparing for the practice of and documentation of a reflective teaching practice necessary for success in their careers as mathematicians and educators.
Area: Quantitative and Mathematical Sciences

Presentations of current research papers by faculty, graduate students and invited guest speakers. For graduate students only.
Area: Quantitative and Mathematical Sciences

AS.110.793. Seminar in Topology.
For graduate students only. Presentations of current research papers by faculty, graduate students and invited guest speakers.
Area: Quantitative and Mathematical Sciences

AS.110.794. Seminar in Category Theory.
Presentations of current research papers by faculty, graduate students and invited guest speakers. For graduate students only.
Area: Quantitative and Mathematical Sciences

AS.110.795. Data Science Seminar.
Presentations of current research papers by faculty, graduate students and invited guest speakers. For graduate students only.
Area: Quantitative and Mathematical Sciences

AS.110.798. Seminar in Number Theory.
Presentations of current research papers by faculty, graduate students and invited guest speakers. For graduate students only.

AS.110.799. Seminar in Algebraic Geometry.
For graduate students only. Presentations of current research papers by faculty, graduate students and invited guest speakers.

AS.110.800. Independent Study-Graduates.
Area: Quantitative and Mathematical Sciences

AS.110.801. Thesis Research.

AS.110.802. Graduate Student Research.
Graduate level research on a topic chosen by the professor and student.
Writing Intensive

Cross Listed Courses
Applied Mathematics & Statistics
EN.553.738. High-Dimensional Approximation, Probability, and Statistical Learning. 3 Credits.
The course covers fundamental mathematical ideas for certain approximation and statistical learning problems in high dimensions. We start with basic approximation theory in low-dimensions, in particular linear and nonlinear approximation by Fourier and wavelets in classical smoothness spaces, and discuss applications in imaging, inverse problems and PDE’s. We then introduce notions of complexity of function spaces, which will be important in statistical learning. We then move to basic problems in statistical learning, such as regression and density estimation. The interplay between randomness and approximation theory is introduced, as well as fundamental tools such as concentration inequalities, basic random matrix theory, and various estimators constructed in detail, in particular multi scale estimators. At all times we consider the geometric aspects and interpretations, and will discuss concentration of measure phenomena, embedding of metric spaces, optimal transportation distances, and their applications to problems in machine learning such as manifold learning and dictionary learning for signal processing.

Applied and Computational Mathematics
EN.625.603. Statistical Methods and Data Analysis. 3 Credits.
This course introduces statistical methods that are widely used in modern applications. A balance is struck between the presentation of the mathematical foundations of concepts in probability and statistics and their appropriate use in a variety of practical contexts. Foundational topics of probability, such as probability rules, related inequalities, random variables, probability distributions, moments, and jointly distributed random variables, are followed by foundations of statistical inference, including estimation approaches and properties, hypothesis testing, and model building. Data analysis ranging from descriptive statistics to the implementation of common procedures for estimation, hypothesis testing, and model building is the focus after the foundational methodology has been covered. Software, for example R-Studio, will be leveraged to illustrate concepts through simulation and to serve as a platform for data analysis. Prerequisite(s): Multivariate calculus.
EN.625.616. Optimization in Finance. 3 Credits.
Optimization models play an increasingly important role in financial decisions. This course introduces the student to financial optimization models and methods. We will specifically discuss linear, integer, quadratic, and general nonlinear programming. If time permits, we will also cover dynamic and stochastic programming. The main theoretical features of these optimization methods will be studied as well as a variety of algorithms used in practice. Prerequisite(s): Multivariate calculus and linear algebra. Course Note(s): Due to overlap in subject matter in EN.625.615 and EN.625.616, students may not receive credit towards the MS or post-master’s certificate for both EN.625.615 and EN.625.616.
EN.625.633. Monte Carlo Methods. 3 Credits.
This course is an introduction to fundamental tools in designing, conducting, and interpreting Monte Carlo simulations. Emphasis is on generic principles that are widely applicable in simulation, as opposed to detailed discussion of specific applications and/or software packages. At the completion of this course, it is expected that students will have the insight and understanding to critically evaluate or use many state-of-the-art methods in simulation. Topics covered include random number generation, simulation of Brownian motion and stochastic differential equations, output analysis for Monte Carlo simulations, variance reduction, Markov chain Monte Carlo, simulation-based estimation for dynamical (state-space) models, and, time permitting, sensitivity analysis and simulation-based optimization. Course Note(s): This course serves as a complement to the 700-level course EN.625.744 Modeling, Simulation, and Monte Carlo. EN.625.633 Monte Carlo Methods and EN.625.744 emphasize different topics, and EN.625.744 is taught at a slightly more advanced level. EN.625.633 includes topics not covered in EN.625.744 such as simulation of Brownian motion and stochastic differential equations, general output analysis for Monte Carlo simulations, and general variance reduction. EN.625.744 includes greater emphasis on generic modeling issues (bias-variance tradeoff, etc.), simulation-based optimization of real-world processes, and optimal input selection.
Prerequisite(s): Linear algebra and a graduate-level statistics course such as EN.625.603 Statistical Methods and Data Analysis.

EN.625.641. Mathematics of Finance. 3 Credits.
This course offers a rigorous treatment of the subject of investment as a scientific discipline. Mathematics is employed as the main tool to convey the principles of investment science and their use to make investment calculations for good decision making. Topics covered in the course include the basic theory of interest and its applications to fixed-income securities, cash flow analysis and capital budgeting, mean-variance portfolio theory and the associated capital asset pricing model, utility function theory and risk analysis, derivative securities and basic option theory, and portfolio evaluation.
Prerequisite(s): Multivariate calculus and a course in probability and statistics (such as EN.625.603 Statistical Methods and Data Analysis).

EN.625.642. Mathematics of Risk, Options, and Financial Derivatives. 3 Credits.
The concept of options stems from the inherent human desire and need to reduce risks. This course starts with a rigorous mathematical treatment of options pricing, and related areas by developing a powerful mathematical tool known as Ito calculus. We introduce and use the well-known field of stochastic differential equations to develop various techniques as needed, as well as discuss the theory of martingales. The mathematics will be applied to the arbitrage pricing of financial derivatives, which is the main topic of the course. We treat the Black-Scholes theory in detail and use it to understand how to price various options and other quantitative financial instruments. Topics covered in the course include options strategies, binomial pricing, Weiner processes and Ito's lemma, the Black-Scholes-Merton Model, futures options and Black's Model, option Greeks, numerical procedures for pricing options, the volatility smile, the value at risk, exotic options, martingales and risk measures. Course Note(s): This class is distinguished from EN.625.641 Mathematics of Finance: Investment Science (formerly 625.439) and EN.625.714 Introductory Stochastic Differential Equations with Applications, as follows: EN.625.641 Mathematics of Finance: Investment Science gives a broader and more general treatment of financial mathematics, and EN.625.714 Introductory Stochastic Differential Equations with Applications provides a deeper (more advanced) mathematical understanding of stochastic differential equations, with applications in both finance and non-finance areas.
Prerequisite(s): Multivariate calculus, linear algebra and matrix theory (e.g., EN.625.609 Matrix Theory), and a graduate-level course in probability and statistics (such as EN.625.603 Statistical Methods and Data Analysis).

EN.625.695. Time Series Analysis. 3 Credits.
This course will be a rigorous and extensive introduction to modern methods of time series analysis and dynamic modeling. Topics to be covered include elementary time series models, trend and seasonality, stationary processes, Hilbert space techniques, the spectral distribution function, autoregressive/ integrated/moving average (ARIMA) processes, fitting ARIMA models, forecasting, spectral analysis, the periodogram, spectral estimation techniques, multivariate time series, linear systems and optimal control, state-space models, and Kalman filtering and prediction. Additional topics may be covered if time permits. Some applications will be provided to illustrate the usefulness of the techniques. Course Note(s): This course is also offered in the Department of Applied Mathematics and Statistics (Homewood campus) as EN.553.639.
Prerequisite(s): Graduate course in probability and statistics (such as EN.625.603 Statistical Methods and Data Analysis) and familiarity with matrix theory and linear algebra.

EN.625.714. Introductory Stochastic Differential Equations with Applications. 3 Credits.
The goal of this course is to give basic knowledge of stochastic differential equations useful for scientific and engineering modeling, guided by some problems in applications. The course treats basic theory of stochastic differential equations, including weak and strong approximation, efficient numerical methods and error estimates, the relation between stochastic differential equations and partial differential equations, Monte Carlo simulations with applications in financial mathematics, population growth models, parameter estimation, and filtering and optimal control problems. Prerequisite(s): Multivariate calculus and a graduate course in probability and statistics, as well as exposure to ordinary differential equations.
Chemical & Biomolecular Engineering
EN.540.468. Introduction to Nonlinear Dynamics and Chaos. 3 Credits.
An introduction to the phenomenology of nonlinear dynamic behavior with emphasis on models of actual physical, chemical, and biological systems, involving an interdisciplinary approach to ideas from mathematics, computing, and modeling. The common features of the development of chaotic behavior in both mathematical models and experimental studies are stressed, and the use of modern data-mining tools to analyze dynamic data will be explored. Knowledge of Linear Algebra and Ordinary Differential Equations is a prerequisite (at an undergraduate level); Some computing experience is desirable. Emphasis will be placed on the geometric/visual computer-aided description and understanding of dynamics and chaos.
Prerequisite(s): ((AS.110.201 OR AS.110.212) AND (AS.110.302 OR AS.110.306)) OR EN.553.291; Students may receive credit for only one of EN.553.473 OR EN.553.673 OR EN.540.468 OR EN.540.668.
Area: Engineering, Quantitative and Mathematical Sciences

EN.540.668. Introduction to Nonlinear Dynamics and Chaos. 3 Credits.
An introduction to the phenomenology of nonlinear dynamic behavior with emphasis on models of actual physical, chemical, and biological systems, involving an interdisciplinary approach to ideas from mathematics, computing, and modeling. The common features of the development of chaotic behavior in both mathematical models and experimental studies are stressed, and the use of modern data-mining tools to analyze dynamic data will be explored. Knowledge of Linear Algebra and Ordinary Differential Equations is a prerequisite (at an undergraduate level); Some computing experience is desirable. Emphasis will be placed on the geometric/visual computer-aided description and understanding of dynamics and chaos.
Prerequisite(s): ((AS.110.201 OR AS.110.212) AND (S.110.302 OR AS.110.306)) OR EN.553.291[C]; Students may receive credit for only one of EN.553.473 OR EN.553.673 OR EN.540.468 OR EN.540.668.
Area: Engineering, Quantitative and Mathematical Sciences

Computer Science
EN.601.442. Modern Cryptography. 3 Credits.
Modern Cryptography includes seemingly paradoxical notions such as communicating privately without a shared secret, proving things without leaking knowledge, and computing on encrypted data. In this challenging but rewarding course we will start from the basics of private and public key cryptography and go all the way up to advanced notions such as zero-knowledge proofs, functional encryption and program obfuscation. The class will focus on rigorous proofs and require mathematical maturity.
[Analysis]
Prerequisite(s): Students may receive credit for only one of EN.601.442, EN.601.442, EN.601.642, (EN.601.230 OR EN.601.231) AND (EN.553.310 OR EN.553.311 OR EN.553.420 OR EN.553.421)
Area: Engineering, Quantitative and Mathematical Sciences

EN.601.642. Modern Cryptography. 3 Credits.
Same material as 601.442, for graduate students. Modern Cryptography includes seemingly paradoxical notions such as communicating privately without a shared secret, proving things without leaking knowledge, and computing on encrypted data. In this challenging but rewarding course we will start from the basics of private and public key cryptography and go all the way up to advanced notions such as zero-knowledge proofs, functional encryption and program obfuscation. The class will focus on rigorous proofs and require mathematical maturity. [Analysis] Required course background: Probability & Automata/Computation Theory
Prerequisite(s): Students may receive credit for only one of EN.601.442 OR EN.601.642.
Area: Engineering, Quantitative and Mathematical Sciences

Financial Mathematics
EN.555.642. Investment Science. 3 Credits.
This is the key introductory course for the financial mathematics program and introduces the major topics of investment finance. The investment universe, its context of markets, and the flow of global capital are introduced. Details of equities, interest, bonds, commodities, forwards, futures, and derivatives are introduced to varying degree. The concepts of deterministic cash flow stream, valuation, term structure theories, risk, and single- and multi-period random cash flows are presented. Here the neoclassical theory of finance is introduced including the topics of efficient markets, the risk-return twins leading to the mean variance Capital Asset Pricing Model (CAPM), the efficient frontier, the intermittent models, and Arbitrage Pricing Theory (APT). Some introductory models of asset dynamics (including the binomial model), basic options theory, and elements of hedging are also included in this course. Course Note(s): This course is the same as EN.553.642 offered by through the full-time Applied Mathematics & Statistics department for the residence Master of Science in Engineering in Financial Mathematics.

EN.555.644. Introduction to Financial Derivatives. 3 Credits.
This is the first of a two-course sequence devoted to the mathematical modeling of securities and the markets in which they are created and exchanged. The basic cash, hybrid, and derivative instruments are reviewed and set in a rigorous mathematical context. This includes equities, bonds, options, forwards, futures, and swaps, as well as their dealer, over-the-counter, and exchange environment. Models of the term structure of interest rates, spot rates and, the forward rate curve are treated; derived from cash instruments (e.g., bonds and interest rates like LIBOR) as well as from derivatives (such as Eurodollar futures and swaps). Principles of static, discrete, continuous and dynamic probabilistic models for derivative analysis (including the Weiner process, Ito’s Lemma, and an introduction to risk-neutral valuation) are applied to develop the binomial tree approach to option valuation, the Black-Scholes-Merton differential equation, and the Black-Scholes formulas for option pricing. Course Note(s): This course is the same as EN.553.644 offered by through the full-time Applied Mathematics & Statistics department for the residence Master of Science in Engineering in Financial Mathematics.

EN.555.645. Interest Rate and Credit Derivatives. 3 Credits.
This is the second of a two-course sequence devoted to the mathematical modeling of securities and the markets in which they are created and exchanged. Focus turns to interest rate derivatives and the credit markets. The martingale approach to risk-neutral valuation is covered, followed by interest rate derivatives and models of the short rate process (including Heath, Jarrow & Morton and the Libor Market Model); analysis of bonds with embedded options and other interest rate derivatives (e.g., caps, floors, swaptions). Credit risk and credit derivatives, including copula models of time to default, credit default swaps, and a brief introduction to collateralized debt obligations will be covered. A major component of this course is computational methods. This includes data and time series analysis (e.g., estimation of volatilities), developing binomial and trinomial lattices and derivative analysis schemes, and numerical approaches to solving the partial differential equations of derivatives. Course Note(s): This course is the same as EN.553.645 offered through the full-time Applied Mathematics & Statistics department for the residence Master of Science in Engineering in Financial Mathematics.
Prerequisite(s): EN.555.644 Introduction to Financial Derivatives
EN.555.646. Financial Risk Management and Measurement. 3 Credits. This course applies advanced mathematical techniques to the measurement, analysis, and management of risk. The focus is on financial risk. Sources of risk for financial instruments (e.g., market risk, interest rate risk, credit risk) are analyzed; models for these risk factors are studied and the limitation, shortcomings, and compensatory techniques are addressed. Throughout the course, the environment for risk is considered, be it regulatory or social (e.g., Basel capital accords). A major component of the course are the Value at Risk (VaR) and Conditional VaR measures for market risk in trading operations, including approaches for calculating and aggregating VaR, testing VaR, VaR-driven capital for market risk, and limitations of the VaR-based approach. Asset Liability Management (ALM), where liquidity risk as well as market risk can affect the balance sheet, is analyzed. Here, models for interest rate, spread, and volatility risks are applied to quantify this exposure. Another major component of the course is credit risk. Sources of credit risk, how measured risk is used to manage exposure, credit derivatives, techniques for measuring default exposure for a single facility (including discriminant analysis and Merton-based simulation), portfolio risk aggregation approaches (including covariance, actuarial, Merton-based simulation, macro-economic default model, and the macro-economic cashflow model - for structured and project finance). Finally, there is a brief introduction to concepts and tools that remain valid for large and extreme price moves, including the theory of copulas and their empirical testing and calibration. Course Note(s): This course is the same as EN.553.646 offered through the full-time Applied Mathematics & Statistics department for the residence Master of Science in Engineering in Financial Mathematics.

EN.555.647. Quantitative Portfolio Theory & Performance Analysis. 3 Credits. This course focuses on modern quantitative portfolio theory, models, and analysis. Topics include intertemporal approaches to modeling and optimizing asset selection and asset allocation; benchmarks (indexes), performance assessment (including Sharpe, Treynor, and Jenson ratios) and performance attribution; immunization theorems; alpha-beta separation in management, performance measurement, and attribution; Replicating Benchmark Index (RBI) strategies using cash securities/derivatives; Liability-Driven Investment (LDI); and the taxonomy and techniques of strategies for traditional management (Passive, Quasi-Passive [Indexing] Semi-Active [Immunization & Dedicated] Active [Scenario, Relative Value, Total Return and Optimization]). In addition, risk management and hedging techniques are also addressed. Course Note(s): This course is the same as EN.553.647 offered through the full-time Applied Mathematics & Statistics department for the residence Master of Science in Engineering in Financial Mathematics.

EN.555.648. Financial Engineering and Structured Products. 3 Credits. This course focuses on structured securities and the structuring of aggregates of financial instruments into engineered solutions of problems in capital finance. Topics include the fundamentals of creating asset-backed and structured securities—including mortgage-backed securities (MBS), stripped securities, collateralized mortgage obligations (CMOs), and other asset-backed collateralized debt obligations (CDOs)—structuring and allocating cash-flows as well as enhancing credit; equity hybrids and convertible instruments; asset swaps, credit derivatives, and total return swaps; assessment of structure-risk interest rate-risk and credit-risk as well as strategies for hedging these exposures; managing portfolios of structured securities; and relative value analysis (including OAS and scenario analysis). Course Note(s): This course is the same as EN.553.648 offered through the full-time Applied Mathematics & Statistics department for the residence Master of Science in Engineering in Financial Mathematics.

First Year Seminars
AS.001.141. FYS: The Art of Mathematics. 3 Credits. Mathematics is so much more than simply the language of science, or a set of techniques for solving quantitative-based problems. In fact, it is not a science at all, but an art, a construct of the imagination that not only provides structure to the reality of the world, but also gives form to anything and everything we can possibly imagine. Many of its fundamental principles and methods of employment are shared by artists of all types, from musicians to painters, sculptors, and poets. In this First-Year Seminar, we will explore these principles and methods shared by mathematicians and artists, like the notions of abstraction, metaphor, and pattern, the aesthetic quality both mathematicians and artists give to their work, the geometry of representation and visualization, the imagination as a tool of discovery and structure, and the use of mathematics in art, as well as the use of art in mathematics. Along the way, we will talk to artists and mathematicians, and hopefully visit the studios and galleries of each.

Area: Quantitative and Mathematical Sciences

AS.001.184. FYS: The Mathematics of Politics, Democracy, and Social Choice. 3 Credits. This First-Year Seminar is designed for students of all backgrounds to provide a mathematical introduction to social choice theory, weighted voting systems, apportionment methods, and gerrymandering. In the search for ideal ways to make certain kinds of political decisions, a lot of wasted effort could be averted if mathematics could determine that finding such an ideal were actually possible in the first place. The seminar will analyze data from recent US elections as well as provide historical context to modern discussions in politics, culminating in a mathematical analysis of the US Electoral College. Case studies, future implications, and comparisons to other governing bodies outside the US will be used to apply the theory of the course. Students will use Microsoft Excel to analyze data sets. There are no mathematical prerequisites for this course.

Area: Quantitative and Mathematical Sciences

Mathematics
AS.110.433. Introduction to Harmonic Analysis and Its Applications. 4 Credits. The course is an introduction to methods in harmonic analysis, in particular Fourier series, Fourier integrals, and wavelets. These methods will be introduced rigorously, together with their motivations and applications to the analysis of basic partial differential equations and integral kernels, signal processing, inverse problems, and statistical/machine learning. Prerequisite(s): (AS.110.201 OR AS.110.212 OR EN.550.291 OR EN.553.291) AND (AS.110.202 OR AS.110.211) AND (AS.110.405 OR AS.110.415)

Area: Quantitative and Mathematical Sciences
AS.110.445. **Mathematical and Computational Foundations of Data Science. 4 Credits.**

We will cover several topics in the mathematical and computational foundations of Data Science. The emphasis is on fundamental mathematical ideas (basic functional analysis, reproducing kernel Hilbert spaces, concentration inequalities, uniform central limit theorems), basic statistical modeling techniques (e.g. linear regression, parametric and non-parametric methods), basic machine learning techniques for unsupervised (e.g. clustering, manifold learning), supervised (classification, regression), and semi-supervised learning, and corresponding computational aspects (linear algebra, basic linear and nonlinear optimization to attack the problems above). Applications will include statistical signal processing, imaging, inverse problems, graph processing, and problems at the intersection of statistics/machine learning and physical/dynamical systems (e.g. model reduction for stochastic dynamical systems).

Area: Quantitative and Mathematical Sciences

AS.110.653. **Stochastic Differential Equations: An Introduction With Applications.**

This course is an introduction to stochastic differential equations and applications. Basic topics to be reviewed include Ito and Stratonovich integrals, Ito formula, SDEs and their integration. The course will focus on diffusion processes and diffusion theory, with topics include Markov properties, generator, Kolmogrov’s equations (Fokker-Planck equation), Feynman-Kac formula, the martingale problem, Girsanov theorem, stability and ergodicity. The course will briefly introduce applications, with topics include statistical inference of SDEs, filtering and control.

Area: Quantitative and Mathematical Sciences

AS.110.795. **Data Science Seminar.**

Presentations of current research papers by faculty, graduate students and invited guest speakers. For graduate students only.

Area: Quantitative and Mathematical Sciences

For current faculty and contact information go to http://www.mathematics.jhu.edu/people/