MATHEMATICS

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General Information

Students who have special placement problems, or are unclear about their level, should make an appointment with a faculty member or the Chair.

Two help rooms, one in 404 Mathematics (on Columbia's campus) and one in 502 Milstein Center (on Barnard's campus), are available. Hours will be posted in the rooms and on https://math.barnard.edu/math-tutoring-schedules for students seeking individual help and counseling from Barnard tutors and Columbia teaching assistants. No appointments are necessary. Both Barnard and Columbia students are welcome. NOTE: Changes to tutoring schedules and remote tutoring can occur in response to COVID-19.

Courses for First-Year Students

The systematic study of Mathematics begins with one of the following alternative sequences:

Calculus I, II, III, IV	
MATH UN1101	CALCULUS I
MATH UN1102	CALCULUS II
MATH UN1201	CALCULUS III
MATH UN1202	CALCULUS IV
Honors Math A-B	
MATH UN1207	HONORS MATHEMATICS A
MATH UN1208	HONORS MATHEMATICS B

Credit is allowed for only one of the calculus sequences. The calculus sequence is a standard course in differential and integral calculus. *Honors Mathematics A-B* is for exceptionally well-qualified students who have strong advanced placement scores. It covers second-year Calculus (MATH UN1201 CALCULUS III−MATH UN1202 CALCULUS IV) and MATH UN2010 LINEAR ALGEBRA, with an emphasis on theory.

Calculus II is NOT a prerequisite for *Calculus III*, so students who plan to take only one year of calculus may choose between I and II or I and III. The latter requires a B or better in Calculus I and is a recommended option for some majors.

MATH UN2000 INTRO TO HIGHER MATHEMATICS is a course that can be taken in their first or second year by students with an aptitude for mathematics who would like to practice writing and understanding mathematical proofs.

Placement in the Calculus Sequence

College Algebra and Analytical Geometry is a refresher course for students who intend to take Calculus but do not have adequate background for it.

Advanced Placement: Students who have passed the advanced placement test for Calculus AB with a grade of 4 or 5 or BC with a grade of 4 receive 3 points of credit. Those who passed Calculus BC with a grade of 5 will receive 4 points of credit or 6 points on placing into Calculus III or Honors Math A and completing with a grade of C or better.

Calculus I, II, III: Students who have not previously studied calculus should begin with Calculus I. Students with 4 or higher on the Calculus AB or BC advanced placement test may start with Calculus II. Students with 5 on the Calculus BC test should start with Calculus III.

Honors Mathematics A: Students who have passed the Calculus BC advanced placement test with a grade of 5, and who have strong mathematical talent and motivation, should start with Honors Mathematics A. This is the most attractive course available to well-prepared, mathematically talented first-year students, whether or not they intend to be mathematics majors. Students who contemplate taking this course should consult with the instructor. If this is not possible ahead of time, they should register and attend the first class.

Chair: Daniela De Silva (Olin Professor of Mathematics)
Professors: Dave Bayer, Daniela De Silva (Olin Professor of Mathematics), Dusa McDuff (Joan Lyttle Birman '48 Chair of Mathematics)
Assistant Professor: Alisa Knizel
Term Associate Professor: Lindsay Piechnik
Professors Emeriti: Joan Birman, Walter Neumann

Links to other faculty of Columbia University offering courses in Mathematics:

Faculty by Rank: http://www.math.columbia.edu/people/faculty-by-rank/

Alphabetical Faculty Listing: http://www.math.columbia.edu/people/alphabetical-faculty-listing/

Requirements for the Major

The major programs in both Mathematics and Applied Mathematics are appropriate for students who plan to continue their training in graduate school. The major in Mathematical Sciences combines the elements of Mathematics, Computer Science and Statistics. It is designed to prepare students for employment in business, administration, and finance, and also give excellent background for someone planning graduate study in a social science field. Students who plan to obtain a teaching qualification in mathematics should plan their course of study carefully with an advisor, since courses that are too far from mathematics do not count towards certification.

For a major in Mathematics: 14 courses (a minimum of 35 credits) as follows:

- Four courses in calculus or Honors Mathematics A-B, including Advanced Placement Credit. A student who places out of Calc I/II with AP credits, will need to take a replacement course.
- Six courses in mathematics numbered at or above 2000.
- Four courses in any combination of mathematics and cognate courses.

The courses in mathematics must include:

MATH UN2010	LINEAR ALGEBRA (also satisfied by Honors Math A-B)
MATH GU4041	INTRO MODERN ALGEBRA I (I)
MATH GU4042	INTRO MODERN ALGEBRA II (II)
MATH GU4061	INTRO MODERN ANALYSIS I (I)
MATH GU4062	INTRO MODERN ANALYSIS II (II)

MATH UN3951	UNDERGRADUATE SEMINARS I (at least one term)
or MATH UN3952	UNDERGRADUATE SEMINARS II

* Note: It is strongly recommended that the sequences MATH GU4041 INTRO MODERN ALGEBRA I - MATH GU4062 INTRO MODERN ANALYSIS II and MATH GU4061 INTRO MODERN ANALYSIS I - MATH GU4062 INTRO MODERN ANALYSIS II be taken in separate years.

However, students who are not contemplating graduate study in mathematics may replace one or both of the two terms of MATH GU4061 INTRO MODERN ANALYSIS I - MATH GU4062 INTRO MODERN ANALYSIS II with one or two of the following courses:

- MATH UN2500 ANALYSIS AND OPTIMIZATION,
- MATH UN3007 COMPLEX VARIABLES,
- or MATH GU4032 FOURIER ANALYSIS

and may replace MATH GU4042 INTRO MODERN ALGEBRA II with

- MATH UN3020 NUMBER THEORY AND CRYPTOGRAPHY
- or MATH UN3025 MAKING, BREAKING CODES

In exceptional cases, the chair will approve the substitution of certain more advanced courses for those mentioned above.

For a major in Applied Mathematics: 14 courses (a minimum of 35 credits)

Four courses in calculus or Honors Mathematics A-B, including Advanced Placement Credit. A student that places out of Calc I/II with AP credits, will need to take a replacement course.

MATH UN2010	LINEAR ALGEBRA (also satisfied by Honors Math A-B)
MATH GU4061	INTRO MODERN ANALYSIS I
APMA E4901	SEM-PROBLEMS IN APPLIED MATH
APMA E4903	SEM-PROBLEMS IN APPLIED MATH
APMA E3900	UNDERGRAD RES IN APPLIED MATH (APMA E3900 may be replaced, with approval, by another technical elective for seniors that involves an undergraduate thesis or creative research report)

Additional electives, to be approved by the Applied Math Committee, e.g.:

MATH UN2500	ANALYSIS AND OPTIMIZATION
MATH UN3007	COMPLEX VARIABLES
or MATH GU4065	HONORS COMPLEX VARIABLES
or APMA E4204	FUNCTNS OF A COMPLEX VARIABLE
MATH UN3027	Ordinary Differential Equations
or MATH UN2030	ORDINARY DIFFERENTIAL EQUATIONS
MATH UN3028	PARTIAL DIFFERENTIAL EQUATIONS
or APMA E4200	PARTIAL DIFFERENTIAL EQUATIONS
MATH GU4032	FOURIER ANALYSIS
APMA E4300	COMPUT MATH:INTRO-NUMERCL METH
APMA E4101	APPL MATH III:DYNAMICAL SYSTMS
APMA E4150	APPLIED FUNCTIONAL ANALYSIS

For a major in Mathematical Sciences: 14 courses (a minimum of 38 credits):

6 from Mathematics, 5 from a combination of Statistics and Computer Science and 3 electives from a combination of Mathematics, Statistics, Computer Science.

Mathematics

Six required courses:	
MATH UN1101	CALCULUS I
MATH UN1102	CALCULUS II
MATH UN1201	CALCULUS III
MATH UN2010	LINEAR ALGEBRA (also satisfied by Honors Math A-B)
MATH UN2000	INTRO TO HIGHER MATHEMATICS
MATH UN2030	ORDINARY DIFFERENTIAL EQUATIONS
or MATH UN3027	Ordinary Differential Equations
Possible further courses selected from the following:	
MATH UN1202	CALCULUS IV
MATH UN2500	ANALYSIS AND OPTIMIZATION
MATH UN3020	NUMBER THEORY AND CRYPTOGRAPHY
MATH UN3025	MAKING, BREAKING CODES
Any 3 credit MATH course numbered 2000 or above	

Statistics

Select at least one of the following:	
STAT UN1101	INTRODUCTION TO STATISTICS
STAT UN1201	CALC-BASED INTRO TO STATISTICS
or equivalent	
Other courses from the Statistics list (eg, STAT UN2102, STAT UN2103, STAT UN2104, STAT UN3105, STAT UN3106)	

Computer Science

Select at least one of the following programming courses:	
COMS W1002	COMPUTING IN CONTEXT
COMS W1004	Introduction to Computer Science and Programming in Java (preferred)
COMS W1005	Introduction to Computer Science and Programming in MATLAB
COMS W1007	Honors Introduction to Computer Science
Possible further courses selected from the following:	
Other classes from the Computer Science Core	
COMS W3203	DISCRETE MATHEMATICS
COMS W3210	Scientific Computation
ENGI E1006	INTRO TO COMP FOR ENG/APP SCI

More generally, electives may be any course with a prerequisite of at least one semester of Calculus, Statistics or Computer Science with the prior approval of the Mathematics Chair.

The Capstone Experience can be fulfilled by a significant thesis written under the supervision of faculty of any one of the three departments or by the Undergraduate Seminar in Mathematics.

NOTE: A student that places out of Calc I/II with AP credits, will need to take a replacement course.

For a major in Mathematics-Statistics: 14 courses (a minimum of 38 credits):

Mathematics

Select one of the following sequences:	

MATH UN1101	CALCULUS I
- MATH UN1102	and CALCULUS II
- MATH UN1201	and CALCULUS III
- MATH UN2010	and LINEAR ALGEBRA
- MATH UN2500	and ANALYSIS AND OPTIMIZATION
MATH UN1207	HONORS MATHEMATICS A
- MATH UN1208	and HONORS MATHEMATICS B
- MATH UN2500	and ANALYSIS AND OPTIMIZATION

Statistics

Statistics required courses

STAT UN1201	CALC-BASED INTRO TO STATISTICS
STAT GU4203	PROBABILITY THEORY
STAT GU4204	STATISTICAL INFERENCE
STAT GU4205	LINEAR REGRESSION MODELS

And select one of the following courses:

STAT GU4207	ELEMENTARY STOCHASTIC PROCESS
STAT GU4262	Stochastic Processes for Finance
STAT GU4264	STOCHASTC PROCSSES-APPLICTNS I
STAT GU4265	STOCHASTIC METHODS IN FINANCE

Computer Science

Select one of the following courses:

COMS W1004	Introduction to Computer Science and Programming in Java
COMS W1005	Introduction to Computer Science and Programming in MATLAB
COMS W1007	Honors Introduction to Computer Science
ENGI E1006	INTRO TO COMP FOR ENG/APP SCI

or an advanced Computer Science offering in programming

Electives

An approved selection of three advanced courses in mathematics, statistics, applied mathematics, industrial engineering and operations research, computer science, or approved mathematical methods courses in a quantitative discipline. At least one elective must be a Mathematics Department course numbered 3000 or above.

Students should plan to include a senior thesis or the Undergraduate Seminar in Mathematics in their program, in consultation with their advisors.

NOTE*:* Students must obtain approval from an adviser in each of the two departments before selecting electives.

NOTE: A student that places out of Calc I/II with AP credits, will need to take a replacement course.

For a major in Mathematics-Computer Science 15 courses (a minimum of 38 credits):

Mathematics

Four courses in calculus or Honors Mathematics A-B, including Advanced Placement Credit. A student that places out of Calc I/II with AP credits, will need to take a replacement course; and the 3 following courses:

MATH UN2010	LINEAR ALGEBRA (also satisfied by Honors Math A-B)
MATH GU4041	INTRO MODERN ALGEBRA I
MATH UN3951	UNDERGRADUATE SEMINARS I (at least one term)
or MATH UN3952	UNDERGRADUATE SEMINARS II

Computer Science

COMS W1004	Introduction to Computer Science and Programming in Java
COMS W3134	Data Structures in Java
COMS W3157	ADVANCED PROGRAMMING
COMS W3203	DISCRETE MATHEMATICS
COMS W3261	COMPUTER SCIENCE THEORY
CSEE W3827	FUNDAMENTALS OF COMPUTER SYSTS

Note A: AP Computer Science with a grade of 4 or 5 or similar experience is a prerequisite for COMS W1007.

Electives: Two additional electives from computer science or math should be included. At least one should be level 3000 or higher; the second should be level 2000 or higher. With adviser approval, appropriate electives from other departments can be considered, such as Statistics or Applied Math.

CSOR W4231	ANALYSIS OF ALGORITHMS I
COMS W4241	Numerical Algorithms and Complexity
MATH UN3020	NUMBER THEORY AND CRYPTOGRAPHY
MATH BC2006	COMBINATORICS
MATH GU4061	INTRO MODERN ANALYSIS I
MATH UN2500	ANALYSIS AND OPTIMIZATION
MATH UN3007	COMPLEX VARIABLES
MATH UN3386	DIFFERENTIAL GEOMETRY
MATH GU4051	TOPOLOGY

Students seeking to pursue a Ph.D. program in either discipline are urged to take additional courses, in consultation with their advisers.

For a major in Economics and Mathematics, see the catalogue.

Requirement for the Minor in Mathematics

For a minor in Mathematics or Applied Mathematics: Six courses from any of the courses offered by the department except MATH UN1003 COLLEGE ALGEBRA-ANLYTC GEOMTRY, MATH UN1101 CALCULUS I / MATH UN1102 CALCULUS II. Some cognate courses are also acceptable with prior approval from the department chair.

Requirements for the Minor in Mathematical Sciences

The minor in Mathematical Sciences comprises 6 courses, at least two from Mathematics and one from each of Statistics and Computer Science. There should be a minimum of three courses in Statistics and Computer Science. Eligible courses are any listed in the Mathematical Sciences Major with the exception of Calculus I and II.

MATH UN1003 COLLEGE ALGEBRA-ANLYTC GEOMTRY. *3.00 points*.
Prerequisites: score of 550 on the mathematics portion of the SAT completed within the last year, or the appropriate grade on the General Studies Mathematics Placement Examination. For students who wish to study calculus but do not know analytic geometry. Algebra review, graphs and functions, polynomial functions, rational functions, conic sections, systems of equations in two variables, exponential and logarithmic functions, trigonometric functions and trigonometric identities, applications of trigonometry, sequences, series, and limits

MATH UN1101 CALCULUS I. *3.00 points*.
Prerequisites: (see Courses for First-Year Students). Functions, limits, derivatives, introduction to integrals, or an understanding of pre-calculus will be assumed. (SC)

MATH UN1102 CALCULUS II. *3.00 points*.
Prerequisites: MATH UN1101 or the equivalent.
Prerequisites: MATH UN1101 or the equivalent. Methods of integration, applications of the integral, Taylors theorem, infinite series. (SC)

MATH UN1201 CALCULUS III. *3.00 points*.
Prerequisites: MATH UN1101 or the equivalent
Prerequisites: MATH UN1101 or the equivalent Vectors in dimensions 2 and 3, complex numbers and the complex exponential function with applications to differential equations, Cramers rule, vector-valued functions of one variable, scalar-valued functions of several variables, partial derivatives, gradients, surfaces, optimization, the method of Lagrange multipliers. (SC)

MATH UN1202 CALCULUS IV. *3.00 points*.
Prerequisites: MATH UN1102 and MATH UN1201 or the equivalent
Prerequisites: MATH UN1102 and MATH UN1201 or the equivalent Multiple integrals, Taylor's formula in several variables, line and surface integrals, calculus of vector fields, Fourier series. (SC)

MATH UN1207 HONORS MATHEMATICS A. *4.00 points*.
Prerequisites: (see Courses for First-Year Students). The second term of this course may not be taken without the first. Multivariable calculus and linear algebra from a rigorous point of view. Recommended for mathematics majors. Fulfills the linear algebra requirement for the major. (SC)

MATH UN1208 HONORS MATHEMATICS B. *4.00 points*.
Prerequisites: (see Courses for First-Year Students).
Prerequisites: (see Courses for First-Year Students). The second term of this course may not be taken without the first. Multivariable calculus and linear algebra from a rigorous point of view. Recommended for mathematics majors. Fulfills the linear algebra requirement for the major. (SC)

MATH UN2000 INTRO TO HIGHER MATHEMATICS. *3.00 points*.
Introduction to understanding and writing mathematical proofs. Emphasis on precise thinking and the presentation of mathematical results, both in oral and in written form. Intended for students who are considering majoring in mathematics but wish additional training. CC/GS: Partial Fulfillment of Science Requirement. BC: Fulfillment of General Education Requirement: Quantitative and Deductive Reasoning (QUA)

MATH BC2001 PERSPECTIVES IN MATHEMATICS. *1.00 point*.
Prerequisites: some calculus or the instructor's permission. Intended as an enrichment to the mathematics curriculum of the first years, this course introduces a variety of mathematical topics (such as three dimensional geometry, probability, number theory) that are often not discussed until later, and explains some current applications of mathematics in the sciences, technology and economics

MATH BC2006 COMBINATORICS. *3.00 points*.

MATH UN2010 LINEAR ALGEBRA. *3.00 points*.
Matrices, vector spaces, linear transformations, eigenvalues and eigenvectors, canonical forms, applications. (SC)

MATH UN2020 Honors Linear Algebra. *3 points*.
Not offered during 2023-2024 academic year.

Prerequisites: MATH UN1201. A more extensive treatment of the material in MATH UN2010, with increased emphasis on proof. Not to be taken in addition to MATH UN2010 or MATH UN1207-MATH UN1208.

MATH UN2030 ORDINARY DIFFERENTIAL EQUATIONS. *3.00 points*.
Prerequisites: MATH UN1102 and MATH UN1201 or the equivalent.
Prerequisites: MATH UN1102 and MATH UN1201 or the equivalent. Special differential equations of order one. Linear differential equations with constant and variable coefficients. Systems of such equations. Transform and series solution techniques. Emphasis on applications

MATH UN2500 ANALYSIS AND OPTIMIZATION. *3.00 points*.
Prerequisites: MATH UN1102 and MATH UN1201 or the equivalent and MATH UN2010.
Prerequisites: MATH UN1102 and MATH UN1201 or the equivalent and MATH UN2010. Mathematical methods for economics. Quadratic forms, Hessian, implicit functions. Convex sets, convex functions. Optimization, constrained optimization, Kuhn-Tucker conditions. Elements of the calculus of variations and optimal control. (SC)

MATH UN3007 COMPLEX VARIABLES. *3.00 points*.
Prerequisites: MATH UN1202 An elementary course in functions of a complex variable.
Prerequisites: MATH UN1202 An elementary course in functions of a complex variable. Fundamental properties of the complex numbers, differentiability, Cauchy-Riemann equations. Cauchy integral theorem. Taylor and Laurent series, poles, and essential singularities. Residue theorem and conformal mapping.(SC)

MATH UN3020 NUMBER THEORY AND CRYPTOGRAPHY. *3.00 points*.
Prerequisites: one year of calculus.
Prerequisites: one year of calculus. Prerequisite: One year of Calculus. Congruences. Primitive roots. Quadratic residues. Contemporary applications

MATH UN3025 MAKING, BREAKING CODES. *3.00 points*.
Prerequisites: (MATH UN1101 and MATH UN1102 and MATH UN1201) and and MATH UN2010.
Prerequisites: (MATH UN1101 and MATH UN1102 and MATH UN1201) and and MATH UN2010. A concrete introduction to abstract algebra. Topics in abstract algebra used in cryptography and coding theory

MATH UN3027 Ordinary Differential Equations. *3 points*.
Prerequisites: MATH UN1102 and MATH UN1201 or the equivalent. Corequisites: MATH UN2010
Equations of order one; systems of linear equations. Second-order equations. Series solutions at regular and singular points. Boundary value problems. Selected applications.

MATH UN3028 PARTIAL DIFFERENTIAL EQUATIONS. *3.00 points*.
Prerequisites: MATH UN3027 and MATH UN2010 or the equivalent
Prerequisites: (MATH UN2010 and MATH UN2030) or the equivalent introduction to partial differential equations. First-order equations. Linear second-order equations; separation of variables, solution by series expansions. Boundary value problems

MATH UN3050 DISCRETE TIME MODELS IN FINANC. *3.00 points*.
Prerequisites: (MATH UN1102 and MATH UN1201) or (MATH UN1101 and MATH UN1102 and MATH UN1201) and MATH UN2010 Recommended: MATH UN3027 (or MATH UN2030 and SIEO W3600).
Prerequisites: (MATH UN1102 and MATH UN1201) or (MATH UN1101 and MATH UN1102 and MATH UN1201) and MATH UN2010 Recommended: MATH UN3027 (or MATH UN2030 and SIEO W3600). Elementary discrete time methods for pricing financial instruments, such as options. Notions of arbitrage, risk-neutral valuation, hedging, term-structure of interest rates

MATH UN3386 DIFFERENTIAL GEOMETRY. *3.00 points.*
Prerequisites: MATH UN1202 or the equivalent.
Local and global differential geometry of submanifolds of Euclidiean 3-space. Frenet formulas for curves. Various types of curvatures for curves and surfaces and their relations. The Gauss-Bonnet theorem.

MATH UN3901 SUPERVISED READINGS I. *1.00-3.00 points.*
Prerequisites: The written permission of the faculty member who agrees to act as sponsor (sponsorship limited to full-time instructors on the staff list), as well as the permission of the Director of Undergraduate Studies. The written permission must be deposited with the Director of Undergraduate Studies before registration is completed. Guided reading and study in mathematics. A student who wishes to undertake individual study under this program must present a specific project to a member of the staff and secure his or her willingness to act as sponsor. Written reports and periodic conferences with the instructor. Supervising Readings do NOT count towards major requirements, with the exception of an advanced written approval by the DUS

MATH UN3902 SUPERVISED READINGS II. *1.00-3.00 points.*
Prerequisites: The written permission of the faculty member who agrees to act as sponsor (sponsorship limited to full-time instructors on the staff list), as well as the permission of the Director of Undergraduate Studies. The written permission must be deposited with the Director of Undergraduate Studies before registration is completed. Guided reading and study in mathematics. A student who wishes to undertake individual study under this program must present a specific project to a member of the staff and secure his or her willingness to act as sponsor. Written reports and periodic conferences with the instructor. Supervising Readings do NOT count towards major requirements, with the exception of an advanced written approval by the DUS

MATH UN3951 UNDERGRADUATE SEMINARS I. *3.00 points.*
Prerequisites: Two years of calculus, at least one year of additional mathematics courses, and the director of undergraduate studies' permission.
Prerequisites: Two years of calculus, at least one year of additional mathematics courses, and the director of undergraduate studies permission. The subject matter is announced at the start of registration and is different in each section. Each student prepares talks to be given to the seminar, under the supervision of a faculty member or senior teaching fellow

MATH UN3952 UNDERGRADUATE SEMINARS II. *3.00 points.*
Prerequisites: two years of calculus, at least one year of additional mathematics courses, and the director of undergraduate studies' permission.
Prerequisites: two years of calculus, at least one year of additional mathematics courses, and the director of undergraduate studies' permission. The subject matter is announced at the start of registration and is different in each section. Each student prepares talks to be given to the seminar, under the supervision of a faculty member or senior teaching fellow. Prerequisite: two years of calculus, at least one year of additional mathematics courses, and the director of undergraduate studies' permission

MATH UN3997 SUPERVISED INDIVIDUAL RESEARCH. *1.00-4.00 points.*
Prerequisites: the written permission of the faculty member who agrees to act as a supervisor, and the director of undergraduate studies permission. For specially selected mathematics majors, the opportunity to write a senior thesis on a problem in contemporary mathematics under the supervision of a faculty member

MATH UN3998 SUPERVISED INDIVIDUAL RESEARCH. *3.00 points.*
Prerequisites: The written permission of the faculty member who agrees to act as a supervisor, and the permission of the Director of Undergraduate Studies. For specially selected mathematics majors, the opportunity to write a senior thesis on a problem in contemporary mathematics under the supervision of a faculty member.

MATH GU4007 ANALYTIC NUMBER THEORY. *3.00 points.*
Prerequisites: MATH UN3007
Prerequisites: MATH UN3007 A one semeser course covering the theory of modular forms, zeta functions, L -functions, and the Riemann hypothesis. Particular topics covered include the Riemann zeta function, the prime number theorem, Dirichlet characters, Dirichlet L-functions, Siegel zeros, prime number theorem for arithmetic progressions, SL (2, Z) and subgroups, quotients of the upper half-plane and cusps, modular forms, Fourier expansions of modular forms, Hecke operators, L-functions of modular forms

MATH GU4032 FOURIER ANALYSIS. *3.00 points.*
Prerequisites: three terms of calculus and linear algebra or four terms of calculus.
Prerequisites: three terms of calculus and linear algebra or four terms of calculus. Prerequisite: three terms of calculus and linear algebra or four terms of calculus. Fourier series and integrals, discrete analogues, inversion and Poisson summation formulae, convolution. Heisenberg uncertainty principle. Stress on the application of Fourier analysis to a wide range of disciplines

MATH GU4041 INTRO MODERN ALGEBRA I. *3.00 points.*
Prerequisites: MATH UN1102 and MATH UN1202 and MATH UN2010 or the equivalent
Prerequisites: MATH UN1102 and MATH UN1202 and MATH UN2010 or the equivalent. The second term of this course may not be taken without the first. Groups, homomorphisms, normal subgroups, the isomorphism theorems, symmetric groups, group actions, the Sylow theorems, finitely generated abelian groups

MATH GU4042 INTRO MODERN ALGEBRA II. *3.00 points.*
Prerequisites: MATH UN1102 and MATH UN1202 and MATH UN2010 or the equivalent.
Prerequisites: MATH UN1102 and MATH UN1202 and MATH UN2010 or the equivalent. The second term of this course may not be taken without the first. Rings, homomorphisms, ideals, integral and Euclidean domains, the division algorithm, principal ideal and unique factorization domains, fields, algebraic and transcendental extensions, splitting fields, finite fields, Galois theory

MATH GU4043 ALGEBRAIC NUMBER THEORY. *3.00 points.*
Prerequisites: MATH GU4041 and MATH GU4042 or the equivalent
Prerequisites: MATH GU4041 and MATH GU4042 or the equivalent
Algebraic number fields, unique factorization of ideals in the ring of algebraic integers in the field into prime ideals. Dirichlet unit theorem, finiteness of the class number, ramification. If time permits, p-adic numbers and Dedekind zeta function

MATH GU4044 REPRESENTATNS OF FINITE GROUPS. *3.00 points.*
Prerequisites: MATH UN2010 and MATH GU4041 or the equivalent.
Prerequisites: MATH UN2010 and MATH GU4041 or the equivalent. Finite groups acting on finite sets and finite dimensional vector spaces. Group characters. Relations with subgroups and factor groups. Arithmetic properties of character values. Applications to the theory of finite groups: Frobenius groups, Hall subgroups and solvable groups. Characters of the symmetric groups. Spherical functions on finite groups

MATH GU4045 ALGEBRAIC CURVES. *3.00 points*.
Prerequisites: (MATH GU4041 and MATH GU4042) and MATH UN3007
Prerequisites: (MATH GU4041 and MATH GU4042) and MATH UN3007
Plane curves, affine and projective varieties, singularities, normalization, Riemann surfaces, divisors, linear systems, Riemann-Roch theorem

MATH W4046 Introduction to Category Theory. *3 points*.
CC/GS: Partial Fulfillment of Science Requirement
Not offered during 2023-2024 academic year.

Prerequisites: *MATH W4041*.
Categories, functors, natural transformations, adjoint functors, limits and colimits, introduction to higher categories and diagrammatic methods in algebra.

MATH GU4051 TOPOLOGY. *3.00 points*.
Prerequisites: (MATH UN1202 and MATH UN2010) and rudiments of group theory (e.g., MATH GU4041). MATH UN1208 or MATH GU4061 is recommended, but not required.
Prerequisites: (MATH UN1202 and MATH UN2010) and rudiments of group theory (e.g. MATH GU4041). MATH UN1208 or MATH GU4061 is recommended, but not required. Metric spaces, continuity, compactness, quotient spaces. The fundamental group of topological space. Examples from knot theory and surfaces. Covering spaces

MATH GU4052 INTRODUCTION TO KNOT THEORY. *3.00 points*.
CC/GS: Partial Fulfillment of Science Requirement

Prerequisites: MATH GU4051 Topology and / or MATH GU4061 Introduction To Modern Analysis I (or equivalents). Recommended (can be taken concurrently): MATH UN2010 linear algebra, or equivalent.
Prerequisites: MATH GU4051 Topology and / or MATH GU4061 Introduction To Modern Analysis I (or equivalents). Recommended (can be taken concurrently): MATH UN2010 linear algebra, or equivalent. The study of algebraic and geometric properties of knots in R#3, including but not limited to knot projections and Reidemeisters theorem, Seifert surfaces, braids, tangles, knot polynomials, fundamental group of knot complements. Depending on time and student interest, we will discuss more advanced topics like knot concordance, relationship to 3-manifold topology, other algebraic knot invariants

MATH GU4053 INTRO TO ALGEBRAIC TOPOLOGY. *3.00 points*.
Prerequisites: MATH UN2010 and MATH GU4041 and MATH GU4051
Prerequisites: MATH UN2010 and MATH GU4041 and MATH GU4051
The study of topological spaces from algebraic properties, including the essentials of homology and the fundamental group. The Brouwer fixed point theorem. The homology of surfaces. Covering spaces

MATH GU4061 INTRO MODERN ANALYSIS I. *3.00 points*.
Prerequisites: MATH UN1202 or the equivalent, and MATH UN2010. The second term of this course may not be taken without the first.
Prerequisites: MATH UN1202 or the equivalent, and MATH UN2010. The second term of this course may not be taken without the first. Real numbers, metric spaces, elements of general topology, sequences and series, continuity, differentiation, integration, uniform convergence, Ascoli-Arzela theorem, Stone-Weierstrass theorem

MATH GU4062 INTRO MODERN ANALYSIS II. *3.00 points*.
Prerequisites: MATH UN1202 or the equivalent, and MATH UN2010. The second term of this course may not be taken without the first.
The second term of this course may not be taken without the first. Power series, analytic functions, Implicit function theorem, Fubini theorem, change of variables formula, Lebesgue measure and integration, function spaces

MATH GU4065 HONORS COMPLEX VARIABLES. *3.00 points*.
Prerequisites: (MATH UN1207 and MATH UN1208) or MATH GU4061
Prerequisites: (MATH UN1207 and MATH UN1208) or MATH GU4061
A theoretical introduction to analytic functions. Holomorphic functions, harmonic functions, power series, Cauchy-Riemann equations, Cauchy's integral formula, poles, Laurent series, residue theorem. Other topics as time permits: elliptic functions, the gamma and zeta function, the Riemann mapping theorem, Riemann surfaces, Nevanlinna theory

MATH GU4071 Introduction to the Mathematics of Finance. *3 points*.
CC/GS: Partial Fulfillment of Science Requirement

Prerequisites: MATH UN1202 and MATH UN3027 and STAT W4150 and SEIO W4150, or their equivalents.
The mathematics of finance, principally the problem of pricing of derivative securities, developed using only calculus and basic probability. Topics include mathematical models for financial instruments, Brownian motion, normal and lognormal distributions, the Blackû Scholes formula, and binomial models.

MATH GU4081 INTRO-DIFFERENTIABLE MANIFOLDS. *3.00 points*.
Prerequisites: (MATH GU4051 or MATH GU4061) and MATH UN2010
Prerequisites: (MATH GU4051 or MATH GU4061) and MATH UN2010
Concept of a differentiable manifold. Tangent spaces and vector fields. The inverse function theorem. Transversality and Sards theorem. Intersection theory. Orientations. Poincare-Hopf theorem. Differential forms and Stokes theorem

MATH GU4155 PROBABILITY THEORY. *3.00 points*.
Prerequisites: MATH GU4061 or MATH UN3007
Prerequisites: MATH GU4061 or MATH UN3007 A rigorous introduction to the concepts and methods of mathematical probability starting with basic notions and making use of combinatorial and analytic techniques. Generating functions. Convergence in probability and in distribution. Discrete probability spaces, recurrence and transience of random walks. Infinite models, proof of the law of large numbers and the central limit theorem. Markov chains

MATH GU4392 INTRO TO QUANTUM MECHANICS II. *3.00 points*.
Continuation of GU4391. This course will focus on quantum mechanics, paying attention to both the underlying mathematical structures as well as their physical motivations and consequences. It is meant to be accessible to students with no previous formal training in quantum theory. The role of symmetry, groups and representations will be stressed.

SIEO W3600 INTRO PROBABILITY/STATISTICS. *4.00 points*.

SIEO W4150 INTRO-PROBABILITY # STATISTICS. *3.00 points*.

Cross-Listed Courses
Computer Science
COMS S3251 Computational Linear Algebra. *3 points*.
Not offered during 2023-2024 academic year.

Prerequisites: two terms of calculus.
Computational linear algebra, solution of linear systems, sparse linear systems, least squares, eigenvalue problems, and numerical solution of other multivariate problems as time permits.

COMS W4203 Graph Theory. *3 points*.
Lect: 3.

Prerequisites: (COMS W3203)
General introduction to graph theory. Isomorphism testing, algebraic specification, symmetries, spanning trees, traversability, planarity, drawings on higher-order surfaces, colorings, extremal graphs, random graphs, graphical measurement, directed graphs, Burnside-Polya counting, voltage graph theory.

COMS W3203 DISCRETE MATHEMATICS. *4.00 points*.
Lect: 3.

Prerequisites: Any introductory course in computer programming.
Logic and formal proofs, sequences and summation, mathematical induction, binomial coefficients, elements of finite probability, recurrence relations, equivalence relations and partial orderings, and topics in graph theory (including isomorphism, traversability, planarity, and colorings)

Industrial Engineering and Operations Research
CSOR E4010 GRAPH THEORY: COMBINATL VIEW. *3.00 points*.
Lect: 3.**Not offered during 2023-2024 academic year.**

Prerequisites: Linear Algebra, or instructor's permission.
An introductory course in graph theory with emphasis on its combinatorial aspects. Basic definitions, and some fundamental topics in graph theory and its applications. Topics include trees and forests graph coloring, connectivity, matching theory and others