Handbook for
Mathematics Majors and Minors

2013 − 2014

Department of Mathematics Directory

Chairman
Harold Layton
221 Physics Building, (919) 660-2800, `layton@math.duke.edu`

Associate Chairman
Paul Aspinwall
244 Physics Building, (919) 660-2800, `psa@cgtp.duke.edu`

Director of Graduate Studies
William Pardon
219 Physics Building, (919) 660-2800, `wlp@math.duke.edu`

Director of Undergraduate Studies
Chad Schoen
191 Physics Building, (919) 660-2800, `dus@math.duke.edu`

Associate Director of Undergraduate Studies
Clark Bray
123 Physics Building, (919) 660-2800, `dus@math.duke.edu`

Supervisor of First-year Instruction
Clark Bray
123 Physics Building, (919) 660-2800, `sfi@math.duke.edu`

Staff Assistant for the Majors and Minors Program
Tyffany Kittrell
117B Physics Building, (919) 660-2835, `kittrell@math.duke.edu`

Mailing Address
Department of Mathematics
Duke University, Box 90320, Durham, NC 27708-0320

Department Phone Number
(919) 660-2800

Facsimile
(919) 660-2821

Electronic Mail
`dept@math.duke.edu`

Home Page URL
`http://www.math.duke.edu`

Handbook for Mathematics
Majors and Minors

This handbook is directed primarily to mathematics majors and minors; its purpose is to provide useful advice and information so that students can get the most out of their studies in mathematics. This handbook should also be a useful resource for potential majors and minors and for university personnel who advise students. The information and policies set forth here are intended to supplement material contained in the *Bulletin of Duke University 2013–2014: Undergraduate Instruction.* Much information about the Mathematics Department, including this handbook, can be found at the web site, `http://www.math.duke.edu`, especially under The Undergraduate Program.

The information in this handbook applies to the academic year 2013-2014 and is accurate and current, to the best of our knowledge, as of August 2013. Inasmuch as changes may be necessary from time to time, the information contained herein is not binding on Duke University or the Duke University Department of Mathematics, and should not be construed as constituting a contract between Duke University and any individual. The University reserves the right to change programs of study, academic requirements, personnel assignments, the announced University calendar, and other matters described in this handbook without prior notice, in accordance with established procedures.

Acknowledgments

<div align="right">

Chad Schoen
Director of Undergraduate Studies
Clark Bray
Associate Director of Undergraduate Studies
August 29, 2013

</div>

Contents

Courses and Course Selection

———

Course Numbering and Scheduling

The numbering scheme of upper level courses in the Department of Mathematics (which differs somewhat from that of other departments) is given below.

Numbers

<500	Undergraduate courses.
500–699	Graduate courses open to advanced undergraduates.
501, 502 531, 532	These courses are strongly recommended for students planning graduate study in mathematics.

The department intends to offer all of the courses listed in this handbook regularly, assuming sufficient demand and staff. The courses that are offered every year are usually offered according to the schedule below.

Fall and spring:	221(104), 216(107), 353(108), 401(121), 356(131), 230(135), 431(139)
Fall:	371(124), 281S(149S), 333(181), 487(187), 501(200), 531(203), 581(215)
Spring:	222(105), 375(126), 453(133), 342(136), 388(188), 502(201), 532(204), 421(206)
Fall or spring:	seminars from among 323S(123S), 305S(128S), 451S(132S), 361S(160S), 476S(196S), 490S(197S)

Rapid Reference Course List

221(104)	Linear Algebra and Applications	541(216)	Applied Stochastic Processes (C-L: see Statistical Science 621(253))
222(105)	Vector Calculus		
230(135)	Probability (C-L: Statistical Science 230(104))	545(219)	Introduction to Stochastic Calculus
		551(211)	Applied Partial Differential Equations and Complex Variables
281S(149S)	Problem Solving Seminar		
305S(128S)	Number Theory	553(233)	Asymptotic and Perturbation Methods
323S(123S)	Geometry	555(231)	Ordinary Differential Equations
333(181)	Complex Analysis	557(232)	Intro. to Partial Differential Equations
340	Advanced Introduction to Probability (C-L: Statistical Science 231)	561(224)	Scientific Computing
		563(225)	Scientific Computing II
342(136)	Statistics (C-L: Statistical Science 250(114))	565(221)	Numerical Analysis (C-L: see Computer Science 520(250), Statistical Science 612(250))
353(108)	Ordinary and Partial Differential Equations		
		573S(214S)	Modeling of Biological Systems (C-L: Comp. Bio. and Bioinformatics 573S)
356(131)	Elementary Differential Equations		
361S(160S)	Mathematical Numerical Analysis	575(228)	Mathematical Fluid Dynamics
371(124)	Combinatorics	577(229)	Mathematical Modeling
375(126)	Introduction to Linear Programming and Game Theory	581(215)	Mathematical Finance (C-L: Economics 673(225))
388(188)	Logic and Its Applications (C-L: Computer Science 288(148), Philosophy 350(150))	582	Financial Derivatives
		590-01(298)	Special Readings
		601(251)	Groups, Rings, and Fields
391(191)	Independent Study	602(252)	An Introduction to Commutative Algebra and Algebraic Geometry
392	Independent Study (2nd sem.)		
393(192)	Research Independent Study	603(253)	Representation Theory (C-L: Physics 603(293))
394	Research Independent Study (2nd sem.)		
401(121)	Introduction to Abstract Algebra	605(274)	Number Theory
411(205)	Topology	607(250)	Computation in Algebra and Geometry
412	Topology with Applications (C-L: Computer Science 434)	611(261)	Algebraic Topology I
		612(262)	Algebraic Topology II
421(206)	Differential Geometry	619(264)	Computational Topology (C-L: Comp. Sci. 636)
431(139)	Advanced Calculus I		
451S(132S)	Nonlinear Ordinary Differential Equations	621(267)	Differential Geometry
		625(272)	Riemann Surfaces
453(133)	Introduction to Partial Differential Equations	627(273)	Algebraic Geometry
		631(241)	Real Analysis
465	Introduction to High Dimensional Data Analysis (C-L: Computer Science 445)	633(245)	Complex Analysis
		635(242)	Functional Analysis
472(150)	Topics in Mathematics from a Historical Perspective	641(287)	Probability (C-L: Statistical Science 811(207))
476S(196S)	Seminar in Mathematical Modeling	651(281)	Hyperbolic PDE's
477S	Math Modeling with writing	653(282)	Elliptic PDE's
481S(151S)	Advanced Problem Solving	660	Intro. to Numerical PDE's
487(187)	Introduction to Mathematical Logic	661(226)	Numerical Solution of Hyperbolic Partial Differential Equations
490S(197S)	Seminar in Mathematics		
491(193)	Independent Study	663(227)	Numerical Solution of Elliptic and Parabolic Partial Differential Equations
492	Independent Study (2nd sem.)		
493(194)	Research Independent Study	690-00(277)	Topics in Algebraic Geometry
494	Research Independent Study (2nd sem.)	690-10(263)	Topics in Topology
499S(199S)	Honors Seminar	690-05	Topics in Number Theory
501(200)	Introduction to Algebraic Structures I	690-20(268)	Topics in Differential Geometry
502(201)	Introduction to Algebraic Structures II	690-30(278)	Topics in Complex Analysis
527(236)	General Relativity (C-L: see Physics 622(292))	690-32	Topics in Analysis
		690-40(288)	Topics in Probability Theory (C-L: Statistical Science 690-40(297))
531(203)	Basic Analysis I		
532(204)	Basic Analysis II	690-50(283)	Topics in Partial Differential Equations

Requirements for the Mathematics Major

The Department of Mathematics offers both the Bachelor of Arts (A.B.) degree and the Bachelor of Science (B.S.) degree. Students who plan to attend graduate school in mathematics or the sciences should consider working toward the B.S. degree.

The specific requirements for the A.B. and B.S. degrees are listed below.

Bachelor of Arts Degree (A.B.)

Prerequisites: Mathematics 21(31) or 111L(31L) or an equivalent course; Mathematics 22(32) or 112L(32L) or 122(32) or 122L(41L) or an equivalent course; Mathematics 212(103) or 222(105) and Mathematics 221(104)[1] or equivalent courses[2]. (Many upper level mathematics courses assume programming experience at the level of Computer Science 94(4). Students without computer experience are encouraged to take Computer Science 101(6).)

Major Requirements: Seven courses in mathematics numbered 230 or above including Mathematics 401(121) or 501(200) and Mathematics 431(139) or 531(203).

Bachelor of Science Degree (B.S.)

Prerequisites: Mathematics 21(31) or 111L(31L) or an equivalent course; Mathematics 22(32) or 112L(32L) or 122(32) or 122L(41L) or an equivalent course; Mathematics 212(103) or 222(105) and Mathematics 221(104)[1] or equivalent courses[2]. (Many upper level mathematics courses assume programming experience at the level of Computer Science 94(4). Students without computer experience are encouraged to take Computer Science 101(6).)

Major Requirements: Eight courses in mathematics numbered 230 or above including: Mathematics 401(121) or 501(200); Mathematics 431(139) or 531(203); and one of Mathematics 333(181), 342(136), 411(205), 421(206), 502(201), 532(204), 541(216), 581(215). There is also a Physics requirement. It may be met by receiving Advanced Placement credit for Physics 25(61) and 26(62); or by completing Physics 141L(53L) and 142L(54L), Physics 151L(61L) and 152L(62L), or Physics 161L(41L) and 162L(42L); or by completing a program of Physics courses approved by the director of undergraduate studies[3].

Requirements for the Mathematics Minor

Prerequisites: Mathematics 212(103) or 222(105) or the equivalent.
Minor requirements: Five courses in mathematics numbered above 212, other than 222(105)[4], to include at least one course (or its equivalent) from: Mathematics 230(135), 333(181), 340, 361S(160S), 401(121), 411(205), 412, 421(206), 431(139), 451S(132S), 487(187), or any Mathematics course at the 500 or 600 level.

---

[1] A student who has already taken 216(107) and is interested in the major should consult with the Director of Undergraduate Studies.

[2] Math 222(105) is recommended for math majors; see **Math 222(105)** link at http://www.math.duke.edu

[3] A student may combine first and second semester courses from different pairs (e.g., Physics 161L(41L) and Physics 152L(62L)).

[4] For students who entered before the academic year 2009-10, Math 222(105) can count as one of the five courses for the minor.

Comments on Specific Courses

Math 216(107) – This course is <u>not recommended for mathematics majors</u>. Mathematics majors should instead take Math 221(104) (Linear Algebra and Applications), a prerequisite for the Mathematics major; and then Math 356(131) for a first course in differential equations, rather than Math 216(107) and Math 353(108).

Math 391(191), 393(192), 491(193), 493(194) – For more information on these courses, see the "Independent Study" section in this Handbook.

Course Descriptions

Given below are catalog descriptions of the mathematics courses numbered 220 and above that are most often taken by undergraduates. These descriptions are taken directly from the *Undergraduate Bulletin*. Please note that all courses listed below satisfy the **M**, **QID** and **QS** requirements for *Curriculum 2000*. In addition, Mathematics 431(139) (Advanced Calculus), Mathematics 531(203) (Basic Analysis I) and Mathematics 476S(196S) (Seminar in Mathematical Modeling) satisfy the **W** (writing) requirement. All seminars satisfy the **R** (research) requirement; these are: 89S(49S), 323S(123S), 305S(128S), 451S(132S), 281S(149S), 481S(151S), 361S(160S), 476S(196S), 490S(197S), 499S(199S).

221(104). Linear Algebra and Applications. QS Systems of linear equations and elementary row operations, Euclidean n-space and subspaces, linear transformations and matrix representations, Gram-Schmidt orthogonalization process, determinants, eigenvectors and eigenvalues; applications. Not open to students who have taken Mathematics 216(107). Prerequisite: Mathematics 22(32), 112L(32L), 122(32), or 122L(41L). Instructor: Staff. One course.
222(105). Vector Calculus. QS Partial differentiation, multiple integrals, and topics in differential and integral vector calculus, including Green's theorem, Stokes's theorem, and Gauss's theorem for students with a background in linear algebra. Not open to students who have taken Mathematics 202(102) or 212(103). Prerequisite: Mathematics 221(104). Instructor: Staff. One course.
230(135). Probability. QS Probability models, random variables with discrete and continuous distributions. Independence, joint distributions, conditional distributions. Expectations, functions of random variables, central limit theorem. Prerequisite: Mathematics 202(102), 212(103), or 222(105). Not open to students who have taken Mathematics 340. Instructor: Staff. One course. C-L: Statistical Science 230(104)
281S(149S). Problem Solving Seminar. QS Techniques for attacking and solving challenging mathematics problems and writing mathematical proofs. Course may be repeated. Consent of instructor required. Instructor: Staff. Half course.
305S(128S). Number Theory. QS, R Divisibility properties of integers, prime numbers, congruences, quadratic reciprocity, number-theoretic functions, simple continued fractions, rational approximations; contributions of Fermat, Euler, and Gauss. Prerequisite: Mathematics 22(32), 112L(32L), 122(32), or 122L(41L), or consent of instructor. Individual research paper required. Instructor: Staff. One course.
323S(123S). Geometry. QS, R Euclidean geometry, inverse and projective geometries, topology (Möbius strips, Klein bottle, projective space), and non-Euclidean geometries in two and three dimensions; contributions of Euclid, Gauss, Lobachevsky, Bolyai, Riemann, and Hilbert. Research project and paper required. Prerequisite: Mathematics 22(32), 112L(32L), 122(32), or 122L(41L), or consent of instructor. Instructor: Staff. One course.

333(181). Complex Analysis. QS Complex numbers, analytic functions, complex integration, Taylor and Laurent series, theory of residues, argument and maximum principles, conformal mapping. Prerequisite: Mathematics 212(103) and 221(104) or consent of instructor. Instructor: Staff. One course.

340. Advanced Introduction to Probability. QS Advanced introduction to basic, non-measure theoretic probability covering topics in more depth and with more rigor than MATH 230. Topics include random variables with discrete and continuous distributions. Independence, joint distributions, conditional distributions, generating functions, Bayes' formula, and Markov chains. Rigorous arguments are presented for the law of large numbers, central limit theorem, and Poisson limit theorems. Prerequisite: Mathematics 202, 212, or 222. Not open to those who have taken Mathematics 230 or Statistics 230. Instructor: Staff. One course. C-L: Statistical Science 231

342(136). Statistics. QS An introduction to the concepts, theory, and application of statistical inference, including the structure of statistical problems, probability modeling, data analysis and statistical computing, and linear regression. Inference from the viewpoint of Bayesian statistics, with some discussion of sampling theory methods and comparative inference. Applications to problems in various fields. Prerequisite: Mathematics 221(104) or equivalent and Mathematics 230(135)/Statistical Science 230(104) or Mathematics 340 or equivalent. Instructor: Staff. One course. C-L: see Statistical Science 250(114)

353(108). Ordinary and Partial Differential Equations. QS First and second order ordinary differential equations with applications, Laplace transforms, series solutions and qualitative behavior, Fourier series, partial differential equations, boundary value problems, Sturm-Liouville theory. Intended primarily for engineering and science students. Prerequisite: Mathematics 216(107). Not open to students who have had Mathematics 356(131). Instructor: Staff. One course.

356(131). Elementary Differential Equations. QS First and second order differential equations with applications; linear systems of differential equations; Fourier series and applications to partial differential equations. Additional topics may include stability, nonlinear systems, bifurcations, or numerical methods. Not open to students who have had Mathematics 216(107) or Mathematics 353(108). Prerequisites: Mathematics 221(104) and one of 202(102), 212(103), or 222(105). Instructor: Staff. One course.

361S(160S). Mathematical Numerical Analysis. QS, R Development of numerical techniques for accurate, efficient solution of problems in science, engineering, and mathematics through the use of computers. Linear systems, nonlinear equations, optimization, numerical integration, differential equations, simulation of dynamical systems, error analysis. Research project and paper required. Not open to students who have had Computer Science 220(150) or 520(250). Prerequisites: Mathematics 212(103) and 221(104) and basic knowledge of a programming language (at the level of Computer Science 101(6)), or consent of instructor. Instructor: Staff. One course.

371(124). Combinatorics. QS Permutations and combinations, generating functions, recurrence relations; topics in enumeration theory, including the Principle of Inclusion-Exclusion and Polya Theory; topics in graph theory, including trees, circuits, and matrix representations; applications. Prerequisite: Mathematics 22(32), 112L(32L), 122(32), or 122L(41L) or consent of instructor. Instructor: Staff. One course.

375(126). Introduction to Linear Programming and Game Theory. QS Fundamental properties of linear programs; linear inequalities and convex sets; primal simplex method, duality; integer programming; two-person and matrix games. Prerequisite: Mathematics 221(104) or equivalence. Instructor: Staff. One course.

388(188). Logic and Its Applications. QS Topics in proof theory, model theory, and recursion theory; applications to computer science, formal linguistics, mathematics, and philosophy. Usually taught jointly by faculty members from the departments of computer science, math-

ematics, and philosophy. Prerequisite: a course in logic or consent of instructor. Instructor: Staff. One course. C-L: Computer Science 288(148), Philosophy 350(150)

391(191). Independent Study. Directed reading in a field of special interest under the supervision of a faculty member, resulting in a substantive paper or written report containing significant analysis and interpretation of a previously approved topic. Consent of instructor and director of undergraduate studies required. Instructor: Staff. One course.

392. Independent Study. Same as Mathematics 391(191), but for a second semester. Consent of instructor and director of undergraduate studies required. Instructor: Staff. One course.

393(192). Research Independent Study. R Individual research in a field of special interest under the supervision of a faculty member, the central goal of which is a substantive paper or written report containing significant analysis and interpretation of a previously approved topic. Consent of instructor and director of undergraduate studies required. Instructor: Staff. One course.

394. Research Independent Study. Same as Mathematics 393(192), but for a second semester. Consent of instructor and director of undergraduate studies required. Instructor: Staff. One course.

401(121). Introduction to Abstract Algebra. QS Groups, rings, and fields. Students intending to take a year of abstract algebra should take Mathematics 501(200) and 502(201). Not open to students who have had Mathematics 501(200). Prerequisite: Mathematics 221(104). Instructor: Staff. One course.

411(205). Topology. QS Elementary topology, surfaces, covering spaces, Euler characteristic, fundamental group, homology theory, exact sequences. Prerequisite: Mathematics 221(104). Instructor: Staff. One course.

412. Topology with Applications. QS Introduction to topology from a computational view-point, with a focus on applications. Themes include: basic notions of point-set topology, persistent homology, finding multi-scale topological structure in point cloud data. Algorithmic considerations emphasized. Prerequisite: Mathematics 221(104) or equivalent. Instructor: Staff. One course. C-L: Computer Science 434

421(206). Differential Geometry. QS Geometry of curves and surfaces, the Serret-Frenet frame of a space curve, Gauss curvature, Cadazzi-Mainardi equations, the Gauss-Bonnet formula. Prerequisite: Mathematics 221(104). Instructor: Staff. One course.

431(139). Advanced Calculus I. QS, W Algebraic and topological structure of the real number system; rigorous development of one-variable calculus including continuous, differentiable, and Riemann integrable functions and the Fundamental Theorem of Calculus; uniform convergence of a sequence of functions; contributions of Newton, Leibniz, Cauchy, Riemann, and Weierstrass. Not open to students who have had Mathematics 531(203). Prerequisite: Mathematics 202(102),212(103) or 222(105). Instructor: Staff. One course.

451S(132S). Nonlinear Ordinary Differential Equations. QS, R Theory and applications of systems of nonlinear ordinary differential equations. Topics may include qualitative behavior, numerical experiments, oscillations, bifurcations, deterministic chaos, fractal dimension of attracting sets, delay differential equations, and applications to the biological and physical sciences. Research project and paper required. Prerequisite: Mathematics 216(107) or 356(131) or consent of instructor. Instructor: Staff. One course.

453(133). Introduction to Partial Differential Equations. QS Heat, wave, and potential equations: scientific context, derivation, techniques of solution, and qualitative properties. Topics to include Fourier series and transforms, eigenvalue problems, maximum principles, Green's functions, and characteristics. Intended primarily for mathematics majors and those with similar backgrounds. Prerequisite: Mathematics 353(108) or 356(131) or consent of instructor. Instructor: Staff. One course.

465. Introduction to High Dimensional Data Analysis. QS Geometry of high dimensional data sets. Linear dimension reduction, principal component analysis, kernel methods.

Nonlinear dimension reduction, manifold models. Graphs. Random walks on graphs, diffusions, page rank. Clustering, classification and regression in high-dimensions. Sparsity. Computational aspects, randomized algorithms. Prerequisite: MATH 221. Instructor: Staff. One course. C-L: Computer Science 445

472(150). Topics in Mathematics from a Historical Perspective. QS Content of course determined by instructor. Prerequisite: Mathematics 431(139) or 531(203) or consent of instructor. Instructor: Staff. One course.

476S(196S). Seminar in Mathematical Modeling. QS, R Introduction to techniques used in the construction, analysis, and evaluation of mathematical models. Individual modeling projects in biology, chemistry, economics, engineering, medicine, or physics. This course is similar to Math 477S but there is less of a focus on scientific writing. Prerequisite: Mathematics 353(108) or 356(131) or consent of instructor. Instructor: Staff. One course.

477S. Seminar in Mathematical Modeling with a focus on writing. QS, R, W Introduction to techniques used in the construction, analysis, and evaluation of mathematical models. Individual modeling projects in biology, chemistry, economics, engineering, medicine, or physics. Considerable attention is given to writing in an interdisciplinary context. Prerequisite: Mathematics 353(108) or 356(131) or consent of instructor. Instructor: Staff. One course. *(Pending approval)*

481S(151S). Advanced Problem Solving. QS Challenging problem sets focused on Putnam Mathematics Competitions. May be repeated. Consent of instructor required. Instructor: Staff. Half course.

487(187). Introduction to Mathematical Logic. QS Propositional calculus; predicate calculus. Gödel completeness theorem, applications of number theory, incompleteness theorem, additional topics in proof theory or computability; contributions of Aristotle, Boole, Frege, Hilbert, and Gödel. Prerequisite: Mathematics 212(103) and 221(104) or Philosophy 250(103). Instructor: Staff. One course.

490S(197S). Seminar in Mathematics. QS, R Intended primarily for juniors and seniors majoring in mathematics. Required research project culminating in written report. Prerequisite: Mathematics 212(103) and 221(104). Instructor: Staff. One course.

491(193). Independent Study. Same as Mathematics 391(191), but for seniors. Consent of instructor and director of undergraduate studies required. Instructor: Staff. One course.

492. Independent Study. Same as Mathematics 491(193), but for a second semester. Consent of instructor and director of undergraduate studies required. Instructor: Staff. One course.

493(194). Research Independent Study. R Same as Mathematics 393(192), but for seniors. Consent of instructor and director of undergraduate studies required. Instructor: Staff. One course.

494. Research Independent Study. Same as Mathematics 493(194), but for a second semester. Consent of instructor and director of undergraduate studies required. Instructor: Staff. One course.

499S(199S). Honors Seminar. QS, R Topics vary. Consent of instructor and director of undergraduate studies required. Instructor: Staff. One course. For Seniors and Graduates

501(200). Introduction to Algebraic Structures I. QS Groups: symmetry, normal subgroups, quotient groups, group actions. Rings: homomorphisms, ideals, principal ideal domains, the Euclidean algorithm, unique factorization. Not open to students who have had Mathematics 401(121). Prerequisite: Mathematics 221(104) or equivalent. Instructor: Staff. One course.

502(201). Introduction to Algebraic Structures II. QS Fields and field extensions, modules over rings, further topics in groups, rings, fields, and their applications. Prerequisite: Mathematics 501(200), or 401(121) and consent of instructor. Instructor: Staff. One course.

527(236). General Relativity. NS One course. C-L: see Physics 622(292)

531(203). Basic Analysis I. QS, W Topology of Rn, continuous functions, uniform convergence, compactness, infinite series, theory of differentiation, and integration. Not open to

students who have had Mathematics 431(139). Prerequisite: Mathematics 221(104). Instructor: Staff. One course.

532(204). Basic Analysis II. QS Differential and integral calculus in Rn. Inverse and implicit function theorems. Further topics in multivariable analysis. Prerequisite: Mathematics 221(104); Mathematics 531(203), or 431(139) and consent of instructor. Instructor: Staff. One course.

541(216). Applied Stochastic Processes. QS An introduction to stochastic processes without measure theory. Topics selected from: Markov chains in discrete and continuous time, queuing theory, branching processes, martingales, Brownian motion, stochastic calculus. Prerequisite: Mathematics 230(135) or 340 or equivalent. Instructor: Staff. One course. C-L: Statistical Science 621(253)

545(219). Introduction to Stochastic Calculus. QS Introduction to the theory of stochastic differential equations oriented towards topics useful in applications. Brownian motion, stochastic integrals, and diffusions as solutions of stochastic differential equations. Functionals of diffusions and their connection with partial differential equations. Ito's formula, Girsanov's theorem, Feynman-Kac formula, Martingale representation theoerm. Additional topics have included one dimensional boundary behavior, stochastic averaging, stochastic numerical methods. Prerequisites: Undergraduate background in real analysis (Mathematics 431(139)) and probability (Mathematics 230(135) or 340). Instructor: Staff. One course.

551(211). Applied Partial Differential Equations and Complex Variables. QS Initial and boundary value problems for the heat and wave equations in one and several dimensions. Fourier series and integrals, eigenvalue problems. Laplace transforms, solutions via contour integration, and elementary complex variables. Solutions via Green's functions. Intended for applied math students and students in science and engineering. Prerequisite: Mathematics 216(107) and 353(108) or the equivalent. Instructor: Staff. One course.

553(233). Asymptotic and Perturbation Methods. QS Asymptotic solution of linear and nonlinear ordinary and partial differential equations. Asymptotic evaluation of integrals. Singular perturbation. Boundary layer theory. Multiple scale analysis. Prerequisite: Mathematics 353(108) or equivalent. Instructor: Staff. One course.

555(231). Ordinary Differential Equations. QS Existence and uniqueness theorems for nonlinear systems, well-posedness, two-point boundary value problems, phase plane diagrams, stability, dynamical systems, and strange attractors. Prerequisite: Mathematics 221(104), 216(107) or 356(131), and 531(203) or 431(139). Instructor: Staff. One course.

557(232). Introduction to Partial Differential Equations. QS Fundamental solutions of linear partial differential equations, hyperbolic equations, characteristics, Cauchy-Kowalevski theorem, propagation of singularities. Prerequisite: Mathematics 532(204) or equivalent. Instructor: Staff. One course.

561(224). Scientific Computing. QS Structured scientific programming in C/C++ and FORTRAN. Floating point arithmetic and interactive graphics for data visualization. Numerical linear algebra, direct and iterative methods for solving linear systems, matrix factorizations, least squares problems and eigenvalue problems. Iterative methods for nonlinear equations and nonlinear systems, Newton's method. Prerequisite: Mathematics 212(103) and 221(104). Instructor: Staff. One course.

563(225). Scientific Computing II. QS Approximation theory: Fourier series, orthogonal polynomials, interpolating polynomials and splines. Numerical differentiation and integration. Numerical methods for ordinary differential equations: finite difference methods for initial and boundary value problems, and stability analysis. Introduction to finite element methods. Prerequisite: Mathematics 561(224) and familiarity with ODEs at the level of Mathematics 216(107) or 356(131). Instructor: Staff. One course.

565(221). Numerical Analysis. QS, R One course. C-L: see Computer Science 520(250); also C-L: Statistical Science 612(250)

573S(214S). Modeling of Biological Systems. QS, R Research seminar on mathematical methods for modeling biological systems. Exact content based on research interests of students. Review methods of differential equations and probability. Discuss use of mathematical techniques in development of models in biology. Student presentations and class discussions on individual research projects. Presentation of a substantial individual modeling project to be agreed upon during the first weeks of the course. May serve as capstone course for MBS certificate. Not open to students who have had MBS 495S(200S). Prerequisites: Mathematics 216(107) or 356(131) or consent of instructor. One course. C-L: Computational Biology and Bioinformatics 573S(230S)

575(228). Mathematical Fluid Dynamics. QS Properties and solutions of the Euler and Navier-Stokes equations, including particle trajectories, vorticity, conserved quantities, shear, deformation and rotation in two and three dimensions, the Biot-Savart law, and singular integrals. Additional topics determined by the instructor. Prerequisite: Mathematics 453(133) or 551(211) or an equivalent course. Instructor: Staff. One course.

577(229). Mathematical Modeling. QS Formulation and analysis of mathematical models in science and engineering. Emphasis on case studies; may include individual or team research projects. Instructor: Staff. One course.

581(215). Mathematical Finance. QS An introduction to the basic concepts of mathematical finance. Topics include modeling security price behavior, Brownian and geometric Brownian motion, mean variance analysis and the efficient frontier, expected utility maximization, Ito's formula and stochastic differential equations, the Black-Scholes equation and option pricing formula. Prerequisites: Mathematics 212(103), 221(104), 230(135) or 340 or equivalent, or consent of instructor. Instructor: Staff. One course. C-L: Economics 673(225)

582. Financial Derivatives. A rigorous introduction to financial derivatives with applications. Topics include: binomial trees and geometric Brownian motion; European options, American options, forwards, and futures; put-call parity; the Black-Scholes-Merton pricing formula and its derivations; Delta and Gamma hedging; implied volatility; Merton jump-diffusion model; Heston model; GARCH(1,1) model. Prerequisites: Mathematics 212(103) (or 222(105)) and Math 230(135) (or 340) or consent of instructor. Instructor: Staff. One course. *(Pending approval)*

590-01(298). Special Readings. QS Instructor: Staff. One course.

601(251). Groups, Rings, and Fields. QS Groups including nilpotent and solvable groups, p-groups and Sylow theorems; rings and modules including classification of modules over a PID and applications to linear algebra; fields including extensions and Galois theory. Prerequisite: Mathematics 502(201) or equivalent. Instructor: Staff. One course.

602(252). An Introduction to Commutative Algebra and Algebraic Geometry. QS Affine algebraic varieties, Groebner bases, localization, chain conditions, dimension theory, singularities, completions. Prerequisite: Mathematics 601(251) or equivalent. Instructor: Staff. One course.

603(253). Representation Theory. QS Representation theory of finite groups, Lie algebras and Lie groups, roots, weights, Dynkin diagrams, classification of semisimple Lie algebras and their representations, exceptional groups, examples and applications to geometry and mathematical physics. Prerequisite: Mathematics 501(200) or equivalent. Instructor: Staff. One course. C-L: Physics 603(293)

605(274). Number Theory. QS Binary quadratic forms; orders, integral closure; Dedekind domains; fractional ideals; spectra of rings; Minkowski theory; fundamental finiteness theorems; valuations; ramification; zeta functions; density of primes in arithmetic progressions. Prerequisites: Mathematics 502(201) or 601(251) or consent of instructor. Instructor: Staff. One course.

607(250). Computation in Algebra and Geometry. QS Application of computing to problems in areas of algebra and geometry, such as linear algebra, algebraic geometry, differ-

ential geometry, representation theory, and number theory, use of general purpose symbolic computation packages such as Maple or Mathematica; use of special purpose packages such as Macaulay, PARI-GP, and LiE; programming in C/C++. Previous experience with programming or the various mathematical topics not required. Corequisite: Mathematics 601(251) or consent of instructor. Instructor: Staff. One course.

611(261). Algebraic Topology I. QS Fundamental group and covering spaces, singular and cellular homology, Eilenberg-Steenrod axioms of homology, Euler characteristic, classification of surfaces, singular and cellular cohomology. Prerequisite: Mathematics 501(200) and 411(205) or consent of instructor. Instructor: Staff. One course.

612(262). Algebraic Topology II. QS Universal coefficient theorems, Künneth theorem, cup and cap products, Poincaré duality, plus topics selected from: higher homotopy groups, obstruction theory, Hurewicz and Whitehead theorems, and characteristic classes. Prerequisite: Mathematics 611(261) or consent of instructor. Instructor: Staff. One course.

619(264). Computational Topology. QS One course. C-L: see Computer Science 636(236)

621(267). Differential Geometry. QS Differentiable manifolds, fiber bundles, connections, curvature, characteristic classes, Riemannian geometry including submanifolds and variations of length integral, complex manifolds, homogeneous spaces. Prerequisite: Mathematics 532(204) or equivalent. Instructor: Staff. One course.

625(272). Riemann Surfaces. QS Compact Riemann Surfaces, maps to projective space, Riemann-Roch Theorem, Serre duality, Hurwitz formula, Hodge theory in dimension one, Jacobians, the Abel-Jacobi map, sheaves, Čech cohomology. Prerequisite: Mathematics 633(245) and Mathematics 611(261) or consent of instructor. Instructor: Staff. One course.

627(273). Algebraic Geometry. QS Projective varieties, morphisms, rational maps, sheaves, divisors, sheaf cohomology, resolution of singularities. Prerequisite: Mathematics 602(252) and 625(272) or consent of instructor. Instructor: Staff. One course.

631(241). Real Analysis. QS Measures; Lebesgue integral; Lp spaces; Daniell integral, differentiation theory, product measures. Prerequisite: Mathematics 532(204) or equivalent. Instructor: Staff. One course.

633(245). Complex Analysis. QS Complex calculus, conformal mapping, Riemann mapping theorem, Riemann surfaces. Prerequisite: Mathematics 532(204) or equivalent. Instructor: Staff. One course.

635(242). Functional Analysis. QS Metric spaces, fixed point theorems, Baire category theorem, Banach spaces, fundamental theorems of functional analysis, Fourier transform. Prerequisite: Mathematics 631(241) or equivalent. Instructor: Staff. One course.

641(287). Probability. QS Theoretic probability. Triangular arrays, weak laws of large numbers, variants of the central limit theorem, rates of convergence of limit theorems, local limit theorems, stable laws, infinitely divisible distributions, general state space Markov chains, ergodic theorems, large deviations, martingales, Brownian motion and Donsker's theorem. Prerequisites: Mathematics 631(241) or Statistical Science 711(205) or equivalent. Instructor: Staff. One course. C-L: Statistical Science 811(207)

651(281). Hyperbolic Partial Differential Equations. QS Linear wave motion, dispersion, stationary phase, foundations of continuum mechanics, characteristics, linear hyperbolic systems, and nonlinear conservation laws. Prerequisite: Mathematics 557(232) or equivalent. Instructor: Staff. One course.

653(282). Elliptic Partial Differential Equations. QS Fourier transforms, distributions, elliptic equations, singular integrals, layer potentials, Sobolev spaces, regularity of elliptic boundary value problems. Prerequisite: Mathematics 557(232) and 631(241) or equivalent. Instructor: Staff. One course.

660. Introduction to Numerical PDEs. QS Introduction to the numerical treatment of partial different equations. Topics may include wave equation, systems of conservation laws, convection-diffusion, heat equation, Laplace equation, and reaction-diffusion systems. Finite

difference methods, finite element methods, spectral methods, timestepping and operator splitting. Upwind schemes and shocks in hyperbolic systems. Fast methods for the Poisson equation. Stability analysis of numerical schemes. Prerequisite: Mathematics 561, 563, or consent of instructor. Instructor: Staff. One course.

661(226). Numerical Solution of Hyperbolic Partial Differential Equations. QS Numerical solution of hyperbolic conservation laws. Conservative difference schemes, modified equation analysis and Fourier analysis, Lax-Wendroff process. Gas dynamics and Riemann problems. Upwind schemes for hyperbolic systems. Nonlinear stability, monotonicity and entropy; TVD, MUSCL, and ENO schemes for scalar laws. Approximate Riemann solvers and schemes for hyperbolic systems. Multidimensional schemes. Adaptive mesh refinement. Prerequisite: Mathematics 561(224), 563(225), or consent of instructor. Instructor: Staff. One course.

663(227). Numerical Solution of Elliptic and Parabolic Partial Differential Equations. QS Numerical solution of parabolic and elliptic equations. Diffusion equations and stiffness, finite difference methods and operator splitting (ADI). Convection-diffusion equations. Finite element methods for elliptic equations. Conforming elements, nodal basis functions, finite element matrix assembly and numerical quadrature. Iterative linear algebra; conjugate gradients, Gauss-Seidel, incomplete factorizations and multigrid. Mixed and hybrid methods. Mortar elements. Reaction-diffusion problems, localized phenomena, and adaptive mesh refinement. Prerequisite: Mathematics 561(224), 563(225), or consent of instructor. Instructor: Staff. One course.

690-00(277). Topics in Algebraic Geometry. QS Schemes, intersection theory, deformation theory, moduli, classification of varieties, variation of Hodge structure, Calabi-Yau manifolds, or arithmetic algebraic geometry. Prerequisite: Mathematics 627(273) or consent of instructor. Instructor: Staff. One course.

690-05. Topics in Number Theory. A selection of topics from algebraic number theory, arithmetic geometry, automorphic forms, analytic number theory, etc. Instructor: Staff. One course.

690-10(263). Topics in Topology. QS Algebraic, geometric, or differential topology. Consent of instructor required. Instructor: Staff. One course.

690-20(268). Topics in Differential Geometry. QS Lie groups and related topics, Hodge theory, index theory, minimal surfaces, Yang-Mills fields, exterior differential systems, harmonic maps, symplectic geometry. Prerequisite: Mathematics 621(267) or consent of instructor. Instructor: Staff. One course.

690-30(278). Topics in Complex Analysis. QS Geometric function theory, function algebras, several complex variables, uniformization, or analytic number theory. Prerequisite: Mathematics 633(245) or equivalent. Instructor: Staff. One course.

690-32. Topics in Analysis. QS Topics in analysis geared towards topics of current research interest. The prerequisites will depend on the specific topic covered. Instructor: Staff. One course.

690-40(288). Topics in Probability Theory. QS Probability tools and theory, geared towards topics of current research interest. Possible additional prerequisites based on course content in a particular semester. Prerequisites: Mathematics 230(135) or 340 or equivalent, and consent of instructor. Instructor: Staff. One course. C-L: Statistical Science 690-40(297)

690-50(283). Topics in Partial Differential Equations. QS Hyperbolic conservation laws, pseudo-differential operators, variational inequalities, theoretical continuum mechanics. Prerequisite: Mathematics 651(281) or equivalent. Instructor: Staff. One course.

Recommended Course Sequences

This section provides recommended course sequences appropriate to areas where a mathematics background is helpful, recommended, or required. For additional information on such areas, see the subsequent section, **After Graduation: Educational and Professional Opportunities** (page 25).

Applications of Mathematics

Many professions and many graduate and professional school programs regard a strong background in mathematics as highly desirable. Therefore, students having a primary interest in some other discipline may also want to pursue a major or minor in mathematics.

Basic Courses	Mathematics 356(131), 230(135) or 340, 342(136), 361S(160S) or 565(221)
Engineering and Natural Science	Mathematics 356(131), 451S(132S), 453(133), 431(139), 333(181), 476S(196S), 531(203), 532(204), 551(211), 541(216), 561(224)
Business and Economics	Mathematics 375(126), 451S(132S), 581(215), 541(216)
Computer Science	Mathematics 371(124), 375(126), 487(187), 388(188), 501(200), 502(201)

Actuarial Science

Actuaries can earn professional status by passing a series of examinations administered by the Society of Actuaries and Casualty Actuarial Society. The first two exams are:

- $ExamP$: $Probability$;
- $ExamFM$: $FinancialMathematics$.

Old copies of these exams, together with answer keys and solutions, and information about submitting an application for the exams, can be found on the web at

<div align="center">www.BeAnActuary.org</div>

The CAS Syllabus of Examinations and the Education Area of the SOA web site contain a description of the education and examination system for the Preliminary Actuarial Examinations, including the material to be covered for each examination, instructions, schedules, and applications. Students can find links to this information at www.BeAnActuary.org/exams/exam_info.cfm.

The optimal time to take the first exam is soon after completing a calculus-based probability course such as Mathematics 230(135) or 340. The following is a list of Duke courses that are useful in preparing for a career as an actuary.

Probability and statistics	Mathematics 230(135) or 340, 342(136)
Mathematical finance	Mathematics 581(215)
Applied stochastic processes	Mathematics 541(216)
Intermediate Economics III	Economics 210D(110D)
Introduction to Econometrics	Economics 208D(139D)
Financial Markets and Management	Economics 471(157)
Regression Analysis	Statistical Science 210(121)
Probability and Statistical Methods	Statistical Science 831(214)
Linear Models	Statistical Science 721(244)

As part of Preliminary Education in both the SOA and the CAS, there are three topics that require Validation by Educational Experience (VEE): Economics (macro and micro), Corporate Finance, and Applied Statistics (time series and regression). A directory of approved college courses that will satisfy VEE requirements is available at `www.soa.org/files/pdf/edu-vee-dir-approved-courses.pdf`.

If you are pursuing the SOA career path, you will start the Fundamentals of Actuarial Practice course after you finish the Preliminary Education requirements. FAP is an e-Learning course that includes both online and offline activities and exposes you to real-world situations.

For further information or additional advice about careers in the actuarial sciences, please contact Professor Dalene Stangl of the Department of Statistical Science [dalene@stat.duke.edu], Emily Reither [ere3s@allstate.com], or Andrew Tignanelli [andrew.tignanelli@prudential.com] (Emily and Andrew majored in mathematics at Duke).

The curriculum in Statistics and Operations Research at the University of North Carolina at Chapel Hill includes an Actuarial Science option through which students may take specialized courses in Long-Term Models (STOR 471, fall semester) and Short-Term Models (STOR 472, spring semester). Descriptions of these courses can be found at the curriculum's web site, `http://stat-or.unc.edu/teaching/ug_courses`. Under a reciprocal agreement between the two universities, students at Duke may enroll concurrently in these courses offered by UNC–Chapel Hill (see page 76 of the *Bulletin of Duke University, 2012–2013: Undergraduate Instruction*). Note, however, that prior approval from the Director of Undergraduate Studies must be sought for such courses to count toward mathematics major or minor credit.

Duke students are welcome to participate in activites sponsored by the UNC undergraduate student actuarial club. See the website at `http://www.unc.edu/caso` for more information.

Charles W. Dunn (`cwdunn@email.unc.edu`), a Duke graduate and Fellow of the Society of Actuaries, teaches the UNC courses and will be happy to answer questions about them or about actuarial science in general.

Teaching Mathematics

The following courses are recommended for students planning careers as teachers of mathematics in secondary schools:

Geometry (Mathematics 323S(123S))
Advanced Calculus (Mathematics 431(139) or 531(203))
Abstract Algebra (Mathematics 401(121) or 501(200))
Computer Science (Computer Science 94(4) or 101(6))
Probability/Statistics (Mathematics 230(135) or 340 /342(136))

The following courses would also be helpful:

Combinatorics (Mathematics 371(124))
Logic (Mathematics 487(187))
Number Theory (Mathematics 305S(128S))
Mathematical Modeling (Mathematics 476S(196S))
Differential Equations (Mathematics 356(131))
Two courses in Physics (*See page 3.*)

There are several paths that one might pursue to major in mathematics and also to be qualified to teach:

1. A math major who is interested in teaching at the high school level is encouraged to earn a Math Teaching License while working on the requirements for the mathematics major. The teaching license, which is earned by fulfilling the requirements prescribed by the State of North Carolina, is generally accepted in most of the 50 states by reciprocal agreement. With the goal that all classrooms be led by highly qualified professionals, schools are now required by federal mandate to ensure that teachers hold appropriate licensure in their respective content area.

   Requirements for the Math Teaching License include a variety of courses in education and one in psychology, and other courses in mathematics. Students who complete the licensure program also earn a minor in Education.

   The last semester of the senior year is devoted to the student teaching block, including two education courses and 10-12 weeks of full-time teaching and observation in a Durham Public School working with a licensed high school teacher and PiE faculty. The student teaching practicum counts as two course credits. Because of the time constraints this may impose on the planning of courses, students considering teaching high school math should confer with the faculty in the Program in Education (919-660-3075; `www.duke.edu/web/education/`) prior to the preparation of a long-range plan.

2. Alternatively, a student may complete the undergraduate degree in mathematics and proceed directly to graduate school to obtain a master of arts in teaching (MAT) or a master of arts in mathematics education. Either degree prepares one for a secondary school teaching position with an advanced pay scale, and some junior colleges employ teachers who hold these degrees. Duke has one of the most innovative MAT programs in the country. It is virtually unique with its emphasis on extensive classroom experience and on advanced mathematics courses rather than on education courses. The Mathematics Department has recently received a 3-year grant from the National Science Foundation that awards Fellowships to students who complete the MAT program in mathematics. The only requirement upon completion is to teach mathematics for two years in a high need school [the Durham public schools qualify]. For information about this program see the Director, Alan Teasley (01 West Duke, 684-4338, `alan.teasley@duke.edu`) or the representative for the Mathematics Department, Richard Hodel (209 Physics, 660-2846, `hodel@math.duke.edu`).

3. To teach in a private school, only an undergraduate degree with a major or minor in mathematics may be required. However, a mathematics major is highly recommended.

Graduate Study in Mathematics

A student planning to pursue graduate study in mathematics should develop a program of study that provides both variety of experience and a strong background in fundamental areas. The core courses for either pure or applied mathematics are Mathematics 333(181), 501(200)–502(201), and 531(203)–532(204); one of the sequences 501(200)–502(201)/531(203)–532(204) should be taken no later than the junior year. Mathematics 356(131), 411(205), and 421(206) are recommended. Students interested in applied mathematics should consider Mathematics 451S(132S), 453(133), 230(135), 342(136), 361S(160S), 476S(196S), 581(215), 541(216), 565(221) and 561(224). Advanced students are encouraged to take standard graduate–level courses (numbered 555 and above) in their senior (and occasionally in their junior) years: in particular, Mathematics 631(241), 633(245), and 601(251) are recommended.

Graduate programs usually expect that applicants will take the Graduate Record Examination Subject Test in mathematics, which emphasizes linear algebra, abstract algebra, and advanced calculus, but also includes questions about complex analysis, topology, combinatorics, probability, statistics, number theory, and algorithmic processes.

Statistics

Students who plan to pursue graduate work in statistics or operations research should follow a program similar to that given above for graduate study in mathematics and should include some of the following electives: Mathematics 340, 342(136), 581(215), and 541(216), as well as Computer Science 101(6) and 201(100). A strong background in mathematics (especially analysis and linear algebra) and computing is the best basis for graduate work in statistics. As an alternative, a student might major in statistics. See http://www.stat.duke.edu.

Students who do not intend to pursue graduate work should elect Mathematics 230(135), 342(136), 581(215), Computer Science 101(6) or 201(100) as well as some of the following courses: Mathematics 541(216), 361S(160S) (or 565(221)), Computer Science 308(108). Statistics students at all levels are encouraged to take computer programming courses.

At present, job prospects are good at all degree levels for those who have a strong background in statistics and some computer programming experience. For further information, see Dalene Stangl, Director of Undergraduate Studies in the Department of Statistical Science (213 Old Chemistry, 668-5227, dalene@stat.duke.edu).

Advising

Advising. Usually, a student prepares a long-range plan and declares a first major in mathematics through the Premajor Advising Center; the student is then assigned an official faculty advisor by the Director of Undergraduate Studies. First majors are required to meet with their advisors each semester during the registration interval. The student and advisor should work together to ensure that the program of study is consistent with the student's interests and professional goals.

A student who has declared a second major or a minor in mathematics will receive formal advising in the department of his or her first major; however second majors and minors and students considering a degree in mathematics may see the Director of Undergraduate Studies for advice or for referral to an appropriate member of the mathematics faculty. A second major or a minor in mathematics (or a change of major or minor) may be declared in the Office of the Registrar.

Math majors can schedule an appointment with the dean for mathematics students by calling 684-6217.

Choosing courses. Every mathematics major must take one course in abstract algebra (Mathematics 401(121) or Mathematics 501(200)) and one course in advanced calculus (Mathematics 431(139) or Mathematics 531(203)). To avoid conflicts during the final semesters of a major's program, these courses should be taken as early as practicable. An essential part of these courses is proving mathematical theorems. Students with little exposure to proofs should probably take the 400–level version of these courses. Students who are comfortable with abstract ideas, and especially those students who are contemplating graduate work in mathematics, should consider taking the 500–level courses. The remaining courses may be chosen from both pure and applied areas of mathematics.

Probability and statistics courses. The introductory sequences in probability and statistics are Mathematics 230(135)–342(136) and Mathematics 340–342(136). Mathematics 230(135) and 340 cover the basics of probability, the latter providing more depth and rigor. Mathematics 342(136) covers statistics, building on the material in Mathematics 230(135) and 340. Those desiring a further course in probability should select either Mathematics 581(215) or 541(216) or both.

The Department of Statistical Science offers a number of courses in statistics at various levels for students of varied mathematics backgrounds. Usually, such courses cannot be counted for mathematics major or minor credit unless they are cross-listed in the Department of Mathematics. The Director of Undergraduate Studies may approve certain statistics courses numbered above 500 for credit, but usually only courses that have a prerequisite of Mathematics 342(136) or its equivalent will be considered.

Transfer Credit

Before enrolling at another school in a course for which transfer credit is wanted, a student must

(1) obtain departmental approval for the course, and

(2) obtain approval from the student's academic dean.

To obtain departmental approval a student must contact

- the Director of Undergraduate Studies (DUS) for courses in mathematics numbered above 212 to be taken abroad;

- the Associate Director of Undergraduate Studies (ADUS) for courses in mathematics numbered above 212 to be taken in the United States;

- the Supervisor of First-year Instruction (SFI) for courses numbered 212 and below.

The departmental approval of any summer courses should be requested **before the last week of classes** of the spring semester.

Although the decision to approve or disapprove a particular course will be made by the Director, the Associate Director of Undergraduate Studies or the Supervisor of First Year Instruction, a student can often make a preliminary determination by following the procedure below.

1. Verify that the number of transfer credits complies with limits set by the university (see *Bulletin of Duke University 2013-2014 Undergraduate Instruction*, in the section on Degree Programs and Academic Credit, under **Major, Minor, and Certificate Programs**.) At least half of the major/minor courses should be taken at Duke. In particular, Math 401(121) and 431(139) must be taken at Duke except for special circumstances for which students should petition to the DUS.

2. Obtain the regular catalog (or at least a copy of the pages containing descriptions of the mathematics courses) from the other school. All undergraduate mathematics courses should be included, so the course in question can be considered in the context of the other school's mathematics program. Summer catalogs seldom contain enough information; and some regular catalogs are not sufficiently detailed; and in such a case, the petitioning student must obtain a syllabus or other official written description of the contents of the course.

3. Determine whether the school is on the semester system or the quarter system. If it is on the quarter system, two courses are needed to obtain one credit at Duke.

4. For summer courses, determine the number of contact hours, which is the product of the length of the class period in hours and the number of days that the class meets. Only courses with 35 or more contact hours are acceptable for transfer credit.

5. After determining that a course qualifies under all the criteria above, see the Director or Associate Director of Undergraduate Studies or the Supervisor of First Year Instruction, as appropriate for the course (see above).

6. If transfer credit is approved by the Department of Mathematics, seek the approval of the appropriate academic dean.

For more information on Transfer Credit, students should see the "T-Reqs" page at: `http://trinity.duke.edu/academic-requirements?p=transfer-credit`. Students can also ask their academic deans.

To receive transfer credit, a course grade of C– or higher is required; however, the university does not include a grade earned at another school as part of a student's official transcript.

Students should note that, independent of receiving transfer credit, they will not be allowed to repeat at Duke a course taken elsewhere either for credit with a grade of C- or higher, or as an audit or pass/fail. For more information see `http://trinity.duke.edu/academic-requirements?p=repeating-a-course`.

A student considering a course offered during a summer term should bear in mind that such courses are frequently cancelled, owing to low enrollment.

General questions about university policy on transfer credit should be addressed to Deborah Shoffner (`deborah.shoffner@duke.edu`, 684-9029) or Harry Nelson (`harry.nelson@duke.edu`, 684-5655), to whom the required approval forms and transcripts are sent (103 Allen Building, facsimile: 684-4500).

Credit for Courses Taken Abroad

Many Duke students study abroad as part of their academic program. Students make plans through the Global Education Office. See `www.studyabroad.duke.edu` and especially the Step-by-Step Guide. Study abroad requires careful planning for a mathematics major or minor, since learning in mathematics is cumulative and courses abroad may not correspond well to those at Duke. Serious planning should begin several semesters in advance. Obtain detailed information about the contents and prerequisites of courses at the foreign university. Then draw up a plan of study with the Director of Undergraduate Studies. More information is available at `http://www.math.duke.edu/undergraduate/studyabroad.html`. Note that at least half of the major/minor courses must be taken at Duke. In particular, Math 401(121) and 431(139) must be taken at Duke except in special circumstances with prior approval of the Director of Undergraduate Studies.

Courses taken abroad must be approved through the Global Education Office before you go. (See Step 5 of their Step-by-Step Guide and their web page Course Approval and Database.) If a course has not already been approved, the Global Education Office consults with the Director of Undergraduate Studies in mathematics. To obtain approval the student should furnish specific information about the course to the Global Education Office, such as the address of a web site with a catalog description of the course, including prerequisites, and if possible a syllabus for the course. Regardless of advanced planning, courses scheduled to be offered abroad may be canceled with little advance notice, or they may differ from a student's expectations. In such a case, the student is responsible for contacting the Global Education Office or the Director of Undergraduate Studies for advice and approval of alternate courses.

Resources and Opportunities

Independent Study

An independent study course offers a student the opportunity for advanced study in an area of mathematics not usually covered in a regular course (Math 391(191), 392, 491(193), 492) and to pursue a research project with a mentor (Math 393(192), 394, 493(194), 494). A student may not obtain credit for independent study for a course that is offered regularly.

A student wishing to register for an independent study course must first make arrangements with a faculty member having expertise in the desired area. The supervision of an independent study is a significant commitment by a faculty member, and no faculty member is obligated to agree to supervise an independent study.

The student must complete the independent study permission form which is available at `http://trinity.duke.edu/academic-requirements?p=independent-study`. Particular attention must be given to planning the course of study and/or research in detail and to carefully describing this plan. Please follow the instructions at: `http://www.math.duke.edu/undergraduate/indepstudy.html`. The completed application should be submitted to the Director of Undergraduate Studies. The proposal will be considered in the context of the student's interests, academic record, and professional goals. If the proposal is approved, the Director of Undergraduate Studies will issue a permission number for course registration.

Independent study in the math department is not generally eligible for writing code (W) designation.

Research Opportunities

An increasing number of math majors participate in summer research programs and internships. Of particular note are the REU (research experiences for undergraduates) programs sponsored by the National Science Foundation at dozens of colleges and universities throughout the country. See a list at `http://www.nsf.gov/crssprgm/reu/reu_search.cfm`.

Since 2000, the Duke Mathematics Department has provided stipends for up to eight math majors each summer for a six week mentored research project leading to Graduation with Distinction. See `http://www.math.duke.edu/vigre/pruv/index.html` for more information.

In addition, the Mathematics Department offers eight summer research stipends for students interested in the applications of mathematics to the life sciences and medicine. More information about this program can be found at `www.math.duke.edu/mathbio` and clicking on "undergraduate program" or by emailing the Director, Michael Reed.

Finally there are up to 10 openings per summer for students working on the structure of complex data sets. See `http://www.math.duke.edu/dataRTG/undergraduate.html`.

Employment in the Department

The Department of Mathematics employs undergraduate students as office assistants, graders, help room/session tutors, and laboratory teaching assistants. Working as a laboratory teaching assistant can be valuable preparation for a student planning to become a mathematics teacher.

Applicants for the positions of grader, help room/session tutor, and laboratory teaching assistant should have taken the course involved and received a grade no lower than B. However, a student who received a good grade in a higher level course or who has advanced placement may be eligible to grade for a lower level course not taken.

Students wishing to apply for available positions may obtain an application in the Department of Mathematics Offices, Physics Building, Suite 117B.

Library Facilities

The library's mathematics collection was recently merged with the main library. Currently mathematics books are located on the fourth floor of the Bostock Library and must be checked out in Perkins. The library has a comprehensive collection of textbooks, monographs, journals, and reference works treating mathematics, statistics, physics, and astronomy. In addition, the library maintains materials on reserve for specific courses.

Talks for Undergraduates

From time to time a mathematician is invited to give a talk that is specifically for undergraduates. Recent speakers and their topics are listed below.

Frank Morgan (Williams, Princeton)	*Soap Bubble Geometry Contest*
Martin Nowak (IAS)	*Fairness and Cooperation*
Sir Roger Penrose (Oxford University)	*Science and the Mind*
Walter Mientke (Nebraska)	*Approximations of Arithmetic Sums*
Dusa McDuff (SUNY Stony Brook)	*4-Dimensional Polytopes*
Jordan Ellenberg (Princeton)	*The Mathematics of the Card Game Set*
Alex Hartemink (Duke)	*Bayesian Machine Learning and Systems Biology*
Jeanne Nielsen Clelland (Colorado)	*The Poincaré Conjecture*
Jeff VanderKam (IDA-CCR)	*Why the Riemann Hypothesis is True*
Paul Dreyer (Rand Corp.)	*How Hard Is It To Defend the Roman Empire?*
Luis Von Ahn (Carnegie Mellon)	*Human Computation*
Craig Gentry (IBM)	*Computing on Encrypted Data*
Ingrid Daubechies (Duke)	*Wavelets and Their Applications*
Melanie Matchett Wood (Wisconsin)	*The Chemistry of Primes*
Robert Palais (Utah Valley University)	*Math in Molecular Medicine*

Duke University Mathematics Union

The Duke University Mathematics Union (DUMU) is a club for undergraduates with an interest in mathematics. Recent activities include sponsoring talks for undergraduates (see above) and hosting a mathematics contest for high school students; the contest attracts participants from throughout the southeast. Information about meetings and activities will be distributed by electronic mail and posted in the department. For current information about DUMU, see the Undergraduate Program page at the department's web site, and click on the link for DUMU.

Graduation with
Distinction in Mathematics

Mathematics majors with strong academic records and the desire to pursue original research in mathematics and its applications are encouraged to apply for graduation with distinction in mathematics.

Applications for graduation with distinction for May graduates should be made at or before registration time in the fall semester of the senior year. For December graduates, this application is due by the previous spring registration period. Early applications are encouraged.

The **requirements** for Graduation with Distinction are:

1. An overall GPA of at least 3.3 and a mathematics GPA of at least 3.5.

2. A paper demonstrating significant independent work in mathematics. This paper is normally written under the supervision of a faculty member in the Department of Mathematics. Students ordinarily pursue their work in Research Independent Study in Mathematics (Math 393, 394, 493 and/or 494). See `http://www.math.duke.edu/undergraduate/researchindepstudy.html` for details on applying.

3. A draft of the paper is due by April 1 of the senior year (November 15 for December graduates). An oral presentation, open to the public, and the final version of the paper are due before the last day of classes of the student's senior year. The Director of Undergraduate Studies will name a committee, normally containing the student's supervisor, to evaluate the paper and oral presentation. In consultation with the DUS, the committee will determine whether Distinction should be awarded and, if so, the level of distinction.

Graduation with Distinction: the paper should demonstrate significant independent research and be a substantial intellectual accomplishment.
Graduation with High Distinction: the paper must include noteworthy original results derived by the student. In particular, the results should involve significant new ideas discovered by the student beyond applications of standard or established methods in the field.
Graduation with Highest Distinction: reserved for truly outstanding research. In particular, such theses should be deemed publishable in reputable journals.

Senior theses in the past few years have been archived by Duke University. See `http://www.math.duke.edu/news/awards/research.html#senior` for titles.

Competitions and Awards

Competitions

A half-credit Problem Solving Seminar (Mathematics 281S(149S)) is offered each fall to help students develop creative strategies for solving challenging mathematical problems; admission is by consent of the instructor. Each year students are encouraged to participate in the Virginia Tech Mathematics Contest, the William Lowell Putnam Mathematics Competition, and the Mathematical Contest in Modeling. Duke Putnam teams placed _first_ in the nation in 1993, 1996 and 2000, _second_ in 1990 and 1997 and _third_ in 1999 and from 2001 to 2005. In the Mathematical Contest in Modeling, a team from Duke has been ranked Outstanding in all but two years from 1998 through 2008. Three teams from Duke in 2006 and four teams in 2007 were named Outstanding in the MCM and/or the related Interdisciplinary Contest in Modeling.

Karl Menger Award

The Karl Menger Award, first given in 1989, is a cash prize awarded annually by the Department of Mathematics for outstanding performance in mathematical competitions. The selection committee is appointed by the Director of Undergraduate Studies.

Karl Menger (1902–1985) was a distinguished mathematician who made major contributions to a number of areas of mathematics. The Karl Menger Award was established by a gift to Duke University from George and Eva Menger-Hammond, the daughter of Karl Menger.

The Julia Dale Prize in Mathematics

The Julia Dale Prize is a cash prize awarded annually by the Department of Mathematics to a mathematics major (or majors) on the basis of excellence in mathematics. A selection committee is appointed by the Director of Undergraduate Studies.

Julia Dale, an Assistant Professor of Mathematics at Duke University, died early in her career in 1936. Friends and relatives of Professor Dale established the Julia Dale Memorial Fund; the Julia Dale Prize is supported by the income from this fund, which was the first memorial fund established in honor of a woman member of the Duke faculty.

Computational Resources

All mathematics majors and minors are encouraged to develop computer skills and to make use of electronic mail (every Duke student is assigned a university electronic mail address upon matriculation). Some courses in mathematics may require students to use computers. In some cases, university-maintained computer clusters will suffice; in other cases, students may be required to use a workstation in our Unix Cluster.

General information. The department maintains a cluster of Unix Workstations in Room 274J, Physics Building. ACPUB logins are not accepted on these machines; a Mathematics Account is required (see below). There are nine Fedora Linux Workstations and a laser printer (designated `lw3`). This cluster is for undergraduate and graduate instruction and other appropriate purposes; it is open 24 hours a day except when in use by classes or for scheduled laboratory instruction. Students doing mathematics work have priority for use of the workstations. These Workstations, which utilize the Linux®

operating system, provide access to electronic mail and the World Wide Web; more-over, original or previously written programs in FORTRAN, Pascal, C, and C++ may be run on these machines, and the mathematical software packages Maple® (`xmaple`), Mathematica® (`mathematica`) and Matlab® (`matlab`) are available to all users.

Opening an account. Mathematics first majors may obtain individual accounts to use the department's network of Unix Workstations. Applications can be submitted online from the Computing Resources Web Page at `http://www.math.duke.edu/computing`. Accounts for mathematics first majors will expire upon graduation, withdrawal from the university, or change of first major.

Other undergraduate students will be granted access to joint class accounts or to individual temporary accounts when they are enrolled in mathematics classes that require access to the department's network. Class accounts and temporary accounts will expire automatically at the end of each academic term.

Students are responsible for copying materials that they wish to preserve before the accounts expire. Files may be transferred to another networked computer via Secure Copy (`scp`) or Secure FTP (`sftp`) using software available from OIT at `http://www.oit.duke.edu/comp-print/software/license/index.php`, or through our web based file transfer system, called the Global Desktop Environment, at `https://www.math.duke.edu/gde` BEFORE the account expires. A CDROM image of your home directory can be created upon account termination. Please contact the Systems Staff for info regarding CD creation.

Electronic mail. Users can send and receive electronic mail through the department's network; a typical electronic mail address has the form `userid@math.duke.edu`. The easiest way to read mail is through one of our Web Based Email programs. You can read mail through the Global Desktop Environment at `http://www.math.duke.edu/gde` by selecting the MailBox icon at the top of the page or through Twig at

> `http://www.math.duke.edu/secure/twig/index.php3`

To read or send mail, the user can choose from the several available mail applications, such as `Thunderbird` or the text based mail reader `pine`. The program `Thunderbird` is recommended for use within the department and is compatible with `pine` (useful over slow network links) so both programs can be used interchangeably.

Website: Department of Mathematics Home Page. A wide variety of current departmental information, including course information, departmental policies, and pointers to other mathematical web servers, can be found on the WWW home page. An internet browser program, such as `mozilla`, can be used to view the home page; the Uniform Resource Locator (URL) is `http://www.math.duke.edu`. Information about Computing Resources and Secure Remote Access to the Mathematics Department is located at `http://www.math.duke.edu/computing`. Current versions of this handbook and the local UNIX guide ("Using UNIX in the Duke Mathematics Department") can be accessed from the department's home page.

Inquiries and help. Routine questions (e.g., "How do I use this program? Why doesn't this work? How do I set up the defaults?") should be addressed by electronic mail to `req@math.duke.edu`. IMPORTANT : Please include as much specific information as possible, e.g., the workstation name, the exact command syntax used, any error messages encountered, and a log of the session.

Some *Frequently Asked Questions* about how to use the Linux systems in the depart-

ment are answered at `http://www.math.duke.edu/computing/faq.html`. Please check here for answers before contacting support.

Remote Access. The Mathematics Department Firewall prevents telnet, ftp, imap, pop, and all other forms of unencrypted access. You will need to use SSH, available from `http://www.openssh.com`, or a Secure Web Browser (Netscape, Mozilla, Internet Explorer) to access resouces in the department from remote locations. The Global Desktop Environment at `http://www3.math.duke.edu/cgi-bin/gde` is a good place to start if you need remote access to departmental resources. There are also several links and tips on the Computing Security Page available at

    `http://www.math.duke.edu/computing/secure.html`.

Security. The UNIX operating system is only secure if users take responsibility for its protection. Every user is responsible for the security of his or her own account. Departmental policy prohibits the sharing of passwords or accounts and any other activity that undermines the security of the university's computer systems. Users should be sure to log out when they finish using the machines in university clusters. Any suspicious activities related to the computers or accounts should be reported immediately to the system administrators. More complete information on security can be found in the local UNIX guide.

User policy. The computer system of the Department of Mathematics is provided to support mathematical instruction and research. To ensure that the system is fully available for these purposes, the Department of Mathematics has established a policy on responsible use of its computer system. This policy can be found on the web at `http://www.math.duke.edu/computing/policy.html`. Violations of the user policy may lead to suspension of the user's account or referral to the appropriate authority for disciplinary action. University policies and regulations, including the Duke Undergraduate Honor Code, and state and federal statutes, including the North Carolina Computer Crimes Act, cover many potential abuses of computers and computer networks.

After Graduation:
Educational and Professional
Opportunities

Career Information

The web is the best and most up-to-date source of information on career opportunities in mathematics. The following organizations have useful web sites:

(1) American Mathematical Society
(2) Association for Women in Mathematics
(3) Mathematical Association of America
(4) American Statistical Association
(5) Institute of Mathematical Statistics
(6) Society of Actuaries
(7) Society for Industrial and Applied Mathematics

An easy way to access these web sites is to use **Google**; search for *American Mathematical Society,* or *mathematical societies,* and so on.

The **Career Center** (Smith Warehouse, Bay 5, 2nd Floor) is an excellent source of information on career opportunities in mathematics. Call (919) 660-1050 to see a career advisor in mathematics and related fields.

The Career Center administers electronic job posting tools and mailing lists for information about summer jobs, internships, on-campus employment, temporary positions, long-term employment, and on-campus recruiting by various employers. To subscribe to the mailing list for mathematics and related disciplines, go to the Career Center's extensive website at `http://studentaffairs.duke.edu/career`.

Business, Law, and Health Professions

Business and law schools welcome and even actively recruit applications from students with a major in mathematics. Business schools require a strong quantitative background like that provided by an undergraduate degree in mathematics. Law schools value the analytical reasoning that is a basic part of a mathematical education. Medical schools regard mathematics as a strong major, and a number of mathematics majors at Duke have been successful in their applications to medical school. A mathematics background is also a strong credential for other health professions, e.g., dentistry, veterinary medicine, and optometry. Although the department receives some information about professional programs, more detailed information, including pamphlets, handouts, etc., is available from the offices of the deans listed below.

Business School	**Law School**	**Health Professions**
Dean Sabrina Thomas	Dean Gerald Wilson	Dean Daniel Scheirer
02 Allen Building	116 Allen Building	011H Allen Building
684-2075 (Fax: 668-6393)	684-2865 (Fax: 684-3414)	684-6221 (Fax: 660-0488)
`slthomas@duke.edu`	`gerald.wilson@duke.edu`	`dan.scheirer@duke.edu`

First-year students and sophomores interested in the health professions are encouraged to visit the website at `http://prehealth.duke.edu/`.

First- and second-year students have assigned prehealth advisors: If you live(d) in Alspaugh, Bassett, Brown, or Pegram, it is Dean Donna Kostyu (`donna.kostyu@duke.edu`); if you live(d) in Gilbert-Addoms or Southgate, it is Dean David Rabiner (`drabiner@duke.edu`); if you live(d) in Bell Tower, Blackwell, or Randolph, it is Dean Alyssa Perz-Edwards (`akperz@duke.edu`); if you live(d) in Aycock, Epworth, Giles, Jarvis, or Wilson, it is Dr. Chris Roy (`chris.roy@duke.edu`). Appointments with Deans Kostyu, Rabiner and Perz-Edwards can be made by calling 684-6217; for an appointment with Dr. Roy, contact him directly at 660-1518.

Teaching Mathematics

Duke graduates who have majored in mathematics and have teaching certification are in strong demand in the field of secondary education. Each year a few students graduate from Duke with teaching certification in secondary school mathematics, and they find that high schools—both public and private—are very interested in hiring them. A mathematics major can receive secondary mathematics certification either as an undergraduate, through the Program in Education, or through the Masters of Arts in Teaching (MAT) Program, a one-year program following graduation. The MAT Program allows qualified students to begin study during their final undergraduate semester and has substantial scholarship support available for qualified students. Duke's MAT program has an emphasis on extensive classroom experience and on advanced mathematics courses rather than on education courses.

For information on the Program in Education, contact Susan Wynn (213 West Duke, 660-3075). For information on Duke's MAT program, contact the Director, Alan Teasley (01 West Duke, 684-4338, `alan.teasley@duke.edu`). For advice about MAT program from a member of the Mathematics Department, see Richard Hodel (209 Physics Building, 660-2846, `hodel@math.duke.edu`). Students considering teaching as a profession can get excellent experience working as graders, lab T.A.'s and/or help room assistants in the Department of Mathematics.

Graduate Study in Mathematics

A Doctor of Philosophy (Ph.D.) in pure or applied mathematics requires roughly five years of graduate work beyond the bachelor's degree. The earlier years are spent in course work, while the later years are spent primarily doing original research culminating in a dissertation. Most graduate students in mathematics can get financial support for their study—both tuition and a stipend for living expenses. In return for this support the student usually performs some service for the department, most commonly teaching introductory undergraduate courses. Highly qualified students may receive fellowships or research assistantships that require little or no teaching.

About one-half of Ph.D.'s in mathematics find long-term employment at academic institutions, either at research universities such as Duke or at colleges devoted primarily to undergraduate teaching. At research universities, the effort of most faculty members is divided between teaching and conducting research in mathematics. The employment situation for Ph.D.'s in mathematics for academic positions is currently very tight. Most nonfaculty mathematicians are employed by government agencies, the private service

sector, or the manufacturing industry.

Students considering graduate school in mathematics are urged to consult with the mathematics faculty and with the Director of Graduate Studies. The choice of graduate school and the area of study may make a significant difference in future job prospects. Information about graduate programs is available through the World Wide Web; to find out about Duke's graduate program in mathematics, go to `http://www.math.duke.edu`.

Other Opportunities

Graduate school in statistics, operations research, computer science, and mathematics-related scientific fields. Information about graduate programs in fields closely related to mathematics is available on the web. Students can also consult with corresponding graduate programs at Duke.

United States Government. A number of U.S. Government agencies hire graduates with strong preparation in mathematics; for example:

- Air Force and Navy
- Bureau of Census
- National Security Agency
- Peace Corps
- National Laboratories

All of these organizations have a web page with information about employment opportunities.

Financial Services Industry, Management, etc. There are many occupations that do not use mathematics directly but for which a major in mathematics is excellent preparation. Many employers are looking for individuals who have skills that are obtained by mathematical training: clear, logical thinking; ability to attack a problem and find the best solution; prompt attention to daily work; ability to handle numerical data; analytical skills. Because many companies provide specific on-the-job training, a broad range of courses may be the best preparation for such occupations.

Recent Graduates. About 35% of graduates with majors or minors in mathematics proceed directly to graduate or professional school. Most other graduates are employed in the private or public sectors. The following is a list of typical positions taken by recent Duke alumni with undergraduate degrees in mathematics:

2009

- Researcher, IRTA, National Institute of Health
- Investment banking analyst, Deutsche Bank
- Product developer, Hawkes Learning Systems
- Actuarial analyst, Aetna
- Medical student, Emory University

2010

- Medical student, Harvard University
- Energy Marketing Analyst, J.P. Morgan
- Senior Actuarial Analyst, CIGNA Corporation
- Neuroscience doctoral student, Harvard University
- Secondary Math Education, Peace Corps

2011

- Software Engineer, Apple
- Global Markets Analyst, Deutsche Bank
- Operations Management doctoral student, U. Penn, Wharton School
- Technology Consulting Analyst, Accenture
- Business Technology Analyst, Deloitte

2012

- Software development engineer, Google
- Consulting, McKinsey
- Analyst, Morgan Stanley
- Business analyst, Groupon
- Associate engineer, Verizon

2013

- Associate software consultant, Red Hat
- Software engineer, Google
- Investment banking analyst, Goldman Sachs
- Web developer, ESPN
- Data analytics associate, Deloitte

Research Interests of the Faculty

Faculty members, their undergraduate/graduate schools, and research areas are listed below; more detailed information can be found via the department's WWW server (`http://www.math.duke.edu`). An asterisk (*) indicates a joint appointment with the Physics Department.

Faculty Member	Research Area
P. Agarwal (Roorkee, NYU)	Computational geometry, computational biology
A. Aristotelous (U. Cyprus, U. Tennessee)	Numerical analysis, scientific computing
W. K. Allard (Villanova, Brown)	Scientific computing
P. S. Aspinwall* (U.C., Oxford)	String theory
J. T. Beale (Cal Tech, Stanford)	Partial differential equations, fluid mechanics
P. Bendich (Grinnell, Duke)	Topology, applied math
O. Bobrowski (Open, Technion)	Probability, applied algebraic topology
H. Bray (Rice U., Stanford U.)	Differential geometry
R. L. Bryant (N. C. State, UNC)	Nonlinear partial differential equations, differential geometry
R. Calderbank (Warwick, Oxford, Cal Tech)	Information theory and coding, algebra, combinatorics, and applications
G. Chen (U. Sci. & Tech China ,U. Minn.)	Analysis of high-dimensional data, machine learning
C. Cornwell (BYU, Michigan St.)	Low-dimensional topology, contact geometry, knot theory
I. Daubechies (Vrije, Vrije)	Applied functional analysis, signal and data analysis
L. Di Cerbo (La Sapienza, Stony Brook)	Geometry, complex algebraic geometry, global analysis on manifolds
R. Durrett (Emory, Stanford)	Probability problems that arise from biology
J. Getz (Harvard, U. Wisconsin)	Number theory, automorphic representation theory arithmetic geometry

H. Hahn (Sookmyung, U. Illinois)	Number theory, trace formula, arithmetic geometry
R. M. Hain (U. Sydney, U. Illinois)	Topology of algebraic varieties, Hodge theory
J. L. Harer (Haverford, Berkeley)	Geometric topology, combinatorial group theory
D. Herzog (U. Tennessee, U. Arizona)	Probability, analysis, mathematical physics
M. Iwen (U. Wisconsin, U. Michigan)	Signal processing, algorithms, scientific computing, analysis of high-dimensional data
D. P. Kraines (Oberlin, Berkeley)	Algebraic topology, game theory
A. Layton (Duke, U. of Toronto)	Mathematical physiology, scientific computing
D. Lawlor (U. Chicago, Michigan St.)	Computational harmonic analysis, high-dimensional data analysis
H. E. Layton (Asbury, Duke)	Mathematical physiology
J.G. Liu (Fudan, UCLA)	Computational fluid dynamics, partial differential equations, numerical analysis
J. Lu (Peking, Princeton)	Applied mathematics
M. Maggioni (Milano, Washington U.)	Harmonic analysis, applications to machine learning
I. Matic (U. Belgrade, UC Berkeley)	Partial differential equations, probability, statistical mechanics
J. Mattingly (Yale, Princeton)	Probability, stochastic processes
K. McGoff (U. North Carolina, U. Maryland)	Dynamical systems, ergodic theory, probability, statistics
E. Miller (Brown, UC Berkeley)	Geometry
S. Mukherjee (Princeton, MIT)	Computational biology, geometry, topology, machine learning
R Moss (Melbourne, Melbourne)	Mathematical physiology and epidemiology
L. Ng (Harvard, MIT)	Geometry, topology
J. Nolen (Davidson, U. Texas)	Applied math, analysis, probability
W. L. Pardon (Michigan, Princeton)	Algebra, geometry of varieties

M. Patel (Rochester, NYU)	Mathematical and computational neuroscience
J. Perea (U. del Valle, Stanford)	Algebraic topology, applied mathematics
A. O. Petters (Hunter College, MIT)	Gravitational lensing, general relativity, astrophysics, singularity theory
R. Plesser* (Tel Aviv, Harvard)	String theory, quantum field theory
M. C. Reed (Yale, Stanford)	Applications of mathematics to physiology and medicine
D. Rose (Berkeley, Harvard)	Numerical analysis, scientific computing
M. Ryser (EPFL, McGill)	Mathematical biology, probability theory, applied mathematics
R. Saab (Amer. U. Beirut, U. British Columbia)	Compressed sensing, sparse representation, quantization
L. D. Saper (Yale, Princeton)	Analysis and geometry on singular spaces
D. G. Schaeffer (Illinois, MIT)	Partial differential equations, applied mathematics
C. L. Schoen (Haverford, Chicago)	Algebraic geometry
D. Sivakoff (U. Maryland, UC Davis)	Probability, random graph theory, network theory
M. A. Stern (Texas A & M, Princeton)	Geometric analysis
A. Thompson (Cambridge, Edinburgh)	Compressed sensing, data-reduction techniques, inverse problems
J. A. Trangenstein (U. Chicago, Cornell)	Nonlinear conservation laws, environmental clean-up, shocks in fluids
N. Totz (Knox, U. Michigan)	Analysis, mathematical physics
S. Venakides (Nat'l Tech. U. Athens, NYU)	Partial differential equations, integrable systems
J. Vogelstein (Washington U., Johns Hopkins)	Statistical pattern recognition of graphs, Scaling up Bayesian computations
T. P. Witelski (Cooper Union, Cal Tech)	Differential equations, mathematical biology, perturbation methods
Y. Wang (Huazhong, U. Minnesota)	Image processing, low-dimensional modeling, machine learning
X. Zhou (Chinese Acad. of Sciences, Rochester)	Partial differential equations, integrable systems

Undergraduate Calendar

Fall 2013 — Spring 2014

August
20   Tuesday. New undergraduate student orientation
26   Monday. 8:30 A.M. Fall semester classes begin; Drop/Add continues

September
6   Friday. Drop/Add ends

October
6   Sunday. Founders' Day
11   Friday, Last day for reporting mid semester grades
11   Friday. 7:00 P.M. Fall break begins
16   Wednesday. 8:30 A.M. Classes resume

November
6   Wednesday. Registration begins for spring semester, 2014
8   Friday. Last day to withdraw with W
20   Wednesday. Registration ends for spring semester, 2014
21   Thursday. Drop/Add begins for Spring 2014
26   Tuesday. 10:30 P.M. Thanksgiving recess begins

December
2   Monday. 8:30 A.M. Classes resume
6   Friday. Undergraduate classes end
7-9   Saturday-Monday. Undergraduate reading period
10   Tuesday. 9:00 A.M. Final examinations begin
15   Sunday. 10:00 P.M. Final examinations end

January
8   Wednesday. 8:30 A.M. Spring semester classes begin; Drop/Add continues
20   Monday. M.L. King holiday: no classes
22   Wednesday. Drop/Add ends

February
17   Monday. Registration begins for Summer 2014
21   Friday. Last day for reporting mid semester grades

March
7   Friday. 7:00 P.M. Spring recess begins
17   Monday. 8:30 A.M. Classes resume
26   Wednesday. Last day to withdraw with W

April
2   Wednesday. Registration begins for Fall semester 2014
11   Friday. Registration ends for Fall semester 2014
12   Saturday. Drop/Add begins for Fall semester 2014
23   Wednesday. Undergraduate classes end
24-27   Thursday-Sunday. Undergraduate reading period
28   Monday. Final examinations begin
30   Wednesday. Undergraduate reading period (9:00 A.M.-2:00 P.M.)

May
3   Saturday. 10:00 P.M. Final examinations end
9   Friday. Commencement begins
11   Sunday. Graduation exercises; conferring of degrees