Mathematical Sciences

FACULTY

**Year of initial appointment at Binghamton*

Arcones, Miguel, *Assistant Professor,* PhD, 1991, City University of New York: Mathematical statistics, probability theory. (1998)

Brewster, Benjamin C., *Professor*, PhD, 1970, University of Kentucky: Algebra, group theory. (1970)*

Brin, Matthew G., *Associate Professor*, PhD, 1977, University of Wisconsin at Madison: Geometric topology. (1978)

Farrell, F. Thomas, *Distinguished Professor,* PhD, 1967, Yale University: Topology and differential geometry. (1990)

Feingold, Alex J., *Professor*, PhD, 1977, Yale University: Algebra, Lie algebras, conformal field theory. (1979)

Ferry, Steven, *Distinguished Professor*, PhD, 1973, University of Michigan: Algebraic and geometric topology. (1988)

Geoghegan, Ross, *Professor*, PhD, 1970, Cornell University: Topology, geometric group theory. (1972)

Guzman, Fernando, *Associate Professor*, PhD, 1985, Syracuse University: Algebra, algebraic logic, theoretical computer science. (1985)

Hanson, David L., *Professor and Chair*, PhD, 1960, Indiana University: Probability, mathematical statistics. (1973)

Head, Thomas, *Professor*, PhD, 1962, University of Kansas: Theoretical computer science, algebra, and automata. (1988)

Hilton, Peter J., *Distinguished Professor Emeritus,* PhD, 1949, Oxford University: Algebraic topology, algebra. (1982)

Houghton, Charles J., *Associate Professor*, PhD, 1964, Ohio State University: Computer science. (1964)

Kappe, Luise-Charlotte, *Professor*, Dr. rer nat, 1962, University of Freiburg, Germany: Group theory, number theory. (1968)

Kappe, Wolfgang P., *Professor*, Dr. phil nat, 1961, University of Frankfurt, Germany: Algebra, group theory. (1968)

Klimko, Eugene M., *Associate Professor*, PhD, 1967, Ohio State University: Probability and statistics. (1973)

Kronk, Hudson V., *Associate Professor*, PhD, 1964, Michigan State University: Graph theory. (1964)

Lercher, Bruce L., *Associate Professor Emeritus,* PhD, 1963, Pennsylvania State University: Mathematical logic. (1962)

McAuley, Louis F., *Professor*, PhD, 1954, University of North Carolina: Topology. (1969)

McAuley, Patricia T., *Associate Professor and Director of the MAT/MST Program*, PhD, 1962, University of Wisconsin: Algebraic topology. (1969)

Pedersen, Erik, *Professor*, PhD, 1974, University of Chicago: Algebraic and geometric topology. (1989)

Pixton, Dennis G., *Associate Professor*, PhD, 1974, University of California at Berkeley: Dynamical systems, formal languages. (1977)

Riley, Robert F., *Professor*, PhD, 1980, Southampton University (England): Hyperbolic geometry, knot theory, number theory. (1982)

Schick, Anton, *Associate Professor*, PhD, 1983, Michigan State University: Statistics, probability. (1984)

Sterling, Nicholas J., *Associate Professor Emeritus*, PhD, 1966, Syracuse University: Mathematical education. (1966)

Yu, Qiqing, *Associate Professor,* PhD, 1986, University of California at Los Angeles: Statistics. (1995)

Zacks, Shelemyahu, *Professor*, PhD, 1962, Columbia University: Statistics. (1980)

Zaslavsky, Thomas, *Professor*, PhD, 1974, Massachusetts Institute of Technology: Combinatorics, graph theory. (1985)

UNDERGRADUATE PROGRAMS

Mathematics belongs both to the liberal arts and to the sciences. Not only is it the language of science (including social science), but it is also studied for its own beauty. It is therefore one of the most vital and lively subjects in the university curriculum. In the technology-oriented climate of today, the department's graduates have excellent employment opportunities.

The Mathematical Sciences Department has programs leading to BA and BS degrees and MA, MAT/MST and PhD degrees. The challenging BS degree program is excellent preparation for graduate work at any university. Students considering a BS degree should seek advice as early as possible and plan their schedules carefully to meet the demanding requirements.

Three actuarial science seminars (MATH 324, 325 and 425) are offered for students interested in this profession.

The department serves other disciplines by providing instruction in various mathematical skills. For example, the department offers MATH 220, Calculus for Management Decisions, to students in the School of Management. Traditional mathematical preparation for the hard sciences (biology, chemistry, physics) is provided by MATH 221, 222, 304, 323, 371, 375, 471, 478, 479 and other courses.

Statistics has long been a fundamental tool in a variety of fields. MATH 147 does not demand the prior knowledge of calculus required by the more rigorous (but still basic) probability and statistics two-course sequence MATH 447-448.

Grade Requirements and Prerequisites

1. A grade of C– or better is necessary for a math course to count toward the major.

2. A grade of C or better is necessary for a math course to serve as a prerequisite to another math course.

3. A Pass grade (P) does not count toward the major or as a prerequisite (unless the only grade available is Pass/Fail—and then permission of the department is required).

4. A grade-point average of 2.0 or higher in major courses is required for satisfactory completion of the major.

5. If you have received credit for a course, you may not take one of its prerequisites for credit at a later time.

BA Degree Program

The BA program is highly flexible and allows each student to fashion a course of study to meet his or her individual needs and interests.

A student must complete a minimum of 10 courses as follows:

1. Calculus-Linear Algebra: MATH 221, 222, 323 and 304.

2. Introduction to Higher Mathematics: MATH 330.

3. A pairing of two courses to be selected according to the student's interests from the following: MATH 401-402, 401-404, 401-407, 351-451, 478-479, 375-478, 478-461, 461-462, 371-471, 357-358, 447-448, 381-386; CS 333-375, 333-350, 333-432 and 471-472.

4. Three additional MATH courses numbered above 330. CS 333 may be substituted for one of these three additional courses if the sequence in 3 is not a CS sequence.

No more than three transfer and independent study courses may be used to satisfy the requirements listed under 2, 3 and 4 above.

The 10-course requirement should be considered a strict minimum. Students are encouraged to take some additional mathematics courses numbered above MATH 330.

The flexibility of the BA program makes it especially important for the student to get early and regular advice from the faculty adviser. See further comments under the headings "Departmental Advising" and "Mathematics and Computer Science."

BS Degree Program

This degree affords excellent preparation for graduate study in mathematics or the teaching of mathematics. A student must complete the following courses: MATH 221, 222, 304, 323, 330, 375, 401, 402 or 404, 461, 478 and 479.

In addition, students must complete five additional departmental courses numbered above 330 (including graduate courses) or courses in the Division of Science and Mathematics above the introductory level (e.g., above PHYS 132). If courses outside the department are elected to fulfill this requirement, at least two must be chosen from one department.

Transfer and independent-study credit cannot be used for more than five courses numbered above MATH 330.

Exceptions to the requirements for the BS degree may, in rare cases, be allowed. They must be approved by the department.

Honors in Mathematics

The honors program in mathematics is designed for students who have a serious interest in advanced mathematics, particularly in research.

One requirement for the honors program is strong and broad coursework in mathematics. The student must complete, by graduation, with a grade-point average of at least B, the following: MATH 375; 401; 402 or 404; 478 and 479; and 461, or 447 and 448. Courses on the same subjects at the same or higher level may be substituted upon approval of the Mathematics Undergraduate Committee.

The additional requirements for the honors program are individually designed by the student in consultation with a faculty sponsor. A proposal for this extra work must be presented to the Mathematics Undergraduate Committee during the student's junior year, with the support of the faculty sponsor. Such a proposal typically involves extra coursework at the graduate level and/or independent research leading to a thesis. If independent study is required in the proposal, the student may register for MATH 498 under the direction of the faculty sponsor.

The Mathematics Undergraduate Committee has final authority for accepting a student into the honors program (based on the merits of the proposal) and for granting graduation with

honors (based on the student's success in fulfilling the goals of the honors proposal).

More details, including sample proposals, are available from the Department of Mathematical Sciences.

Departmental Advising

Students considering a major in mathematical sciences should seek advice from the faculty as early as possible. Every declared major should be assigned to a faculty adviser, and should meet regularly with the adviser to discuss course selection and career goals.

Mathematicians and statisticians are in demand not only in mathematics teaching and research, and in the traditional fields of physics, chemistry, computer science and engineering, but also, and increasingly, in business, economics, environmental sciences, geology, biology and the health sciences, among others. Students interested in applications of mathematics should consider a minor in another discipline or even a double major, and consult the faculty in the relevant departments.

A basic knowledge of computer programming will be useful for most mathematics majors.

Actuarial Science

Actuaries analyze and solve complex business and social problems related to insurance and pension plans. They are employed by federal and state agencies, consulting firms and universities, as well as insurance companies. Professional advancement results from passing a series of examinations administered by the actuarial societies. A strong background in mathematics is essential to success.

Students interested in an actuarial career should include MATH 221, 222, 304, 323, 447 and 448 in their programs, as well as the actuarial seminars (MATH 324, 325 and 425). They should have knowledge of computer programming equivalent to CS 140, and also take courses in accounting, economics, insurance, marketing and other areas of business administration.

The actuarial profession is instituting some major changes in its professional requirements beginning in 2000. Students with an actuarial bent should receive advice from the actuarial adviser.

Mathematics and Computer Science

The Computer Science Department in the Watson School of Engineering and Applied Science offers a minor program that can be combined with a BA in mathematics to provide a strong background leading to careers in computer science. The BA in mathematics is designed to facilitate this combination by allowing two computer science courses to be included in the degree program. Students interested in mathematics and computer science should also consult with the Computer Science Department.

Mathematics Minor

A minor in mathematical sciences requires the student to complete, with a grade higher than D, at least six departmental courses numbered above MATH 300, of which at least three are numbered above MATH 330. Transfer and independent study credit cannot be used for more than one of the latter three courses. Students interested in pursuing a mathematics minor should consult with the undergraduate director. Note that Harpur College mandates that at least 4 of the courses for the minor must be in addition to those counted toward fulfillment of the student's major.

GRADUATE PROGRAMS

The department is committed to the idea that pure and applied mathematics are two faces of the same subject. The research of the faculty and the training of the students cover a wide variety of topics in pure mathematics, as well as statistics and computer science. The department offers a lively research atmosphere. Students are encouraged to take a broad range of courses. Teaching assistants are given varied assignments intended to increase their experience and employability. The distinguished research faculty offers considerable personal attention to graduate students.

The department offers the MA, MAT, MST and PhD degrees. Research areas of faculty expertise include algebra, combinatorics, dynamical systems, geometry, graph theory, probability, statistics, theoretical computer science and topology.

The MA program is intended to give the student a solid professional basis either for proceeding to the PhD program or for work in government, industry or teaching at the community college level. The PhD degree prepares a student for university or college teaching and for higher-level employment in government and industry. The MAT and MST degrees are preparation for careers in high school teaching. Entering students having substantial graduate level training may enter the PhD program, skipping the MA.

The department is noted for its method of graduate education. In first-year courses, the emphasis is on training the student to do mathematics in depth. Many students report that

these courses are the formative experiences of their professional lives.

Teaching assistantships are available. They provide not only financial support but also valuable experience, either in teaching a variety of courses or assisting faculty in special courses. The aim is to enhance students' training with actual experience helpful in obtaining employment.

Department members assist students in obtaining suitable employment and offer advice for career development.

Minors

Although there is no official requirement of a minor, the department supports the concept of suitable study outside the area of primary emphasis, particularly for doctoral students. Doctoral students in pure mathematics are encouraged to obtain expertise in an area of applied mathematics sufficient for competency in instruction in that area at the undergraduate level. Students in statistics and other applied areas naturally obtain appropriate training in pure mathematics in the regular course of study.

Note: A departmental graduate student handbook is available on request.

Requirements

ADMISSION TO REGULAR STANDING

For admission to regular standing, a student should have a bachelor's degree and have completed (with an average of at least 3.0) a set of mathematics courses approximately equivalent to those required for a bachelor's degree at Harpur College with a specialization in mathematics. The department encourages submission of Graduate Record Examination scores for the aptitude and advanced tests that are useful in evaluating applicants.

MASTER OF ARTS PROGRAM

The official requirement for a master's degree is a minimum of 30 credit hours at the graduate level. This requirement can technically be satisfied in three semesters. However, the 30-hour requirement is regarded as minimal, and most students take four semesters to complete the master's degree. Each student's program is worked out in consultation with an adviser, under the general supervision of the graduate committee. While it is possible for a student to fulfill up to eight hours of course requirements by writing a master's essay, only in certain circumstances is this encouraged. Students writing a master's essay must pass an oral examination covering the subject matter of the essay.

MA students who do not write master's essays must pass an oral examination in the last semester of their MA program. For this purpose, a committee of three or more faculty members is appointed. Usually these are faculty members who have taught the student. The examination syllabus is arranged by the committee in consultation with the student; in general it covers 30 hours of the student's coursework.

Master of Arts in Teaching and Master of Science in Teaching

The Department of Mathematical Sciences offers jointly with the Division of Education the MAT (master of arts in teaching) and the MST (master of science in teaching) degrees.

The MAT degree program is for those with no preservice teacher preparation at the undergraduate level. The MST degree program is for those already provisionally certified to teach in New York State. Requirements for these degrees are listed elsewhere in this *Bulletin*. Mathematics courses specifically designed for these programs are indicated by MAT/MST following the course title.

Inquiries about these programs should be directed to the MAT/MST adviser, Mathematical Sciences Department, Binghamton University, Binghamton, New York 13902-6000.

Doctor of Philosophy Program

A minimum of 14 courses at the graduate level (including those counted for the MA) is required. A total of five or six years of full-time graduate study (including study toward the MA) is normally required to complete the doctorate.

Admission to PhD candidacy begins with informal discussions among the student, the adviser and other members of the department on whether it is wise for the student to consider pursuing a doctorate. Such discussions generally take place early in the student's fourth semester of graduate study, near the end of the master's program, when department members are able to assess the student's abilities. Then, or later, the student finds a prospective dissertation adviser who is an active and established researcher and who is willing (at least provisionally) to supervise the student's doctoral dissertation.

At an appropriate time, the adviser presents to the Graduate Committee a format for the "admission to candidacy" examination of the student. This format, worked out in consultation with the student, might be one or several examinations, written or oral, in several areas; an oral presentation of research papers; or a combination of these. The adviser provides

syllabi for the areas to be covered on the examination. The Graduate Committee either accepts the adviser's recommendation or suggests alternatives; it then appoints an examining committee to carry out its instructions. The examining committee reports the results of its examination and its recommendations to the Graduate Committee. The Graduate Committee makes the final decision on the student's admission to candidacy. A detailed explanation of this procedure is available in the department.

It is department policy that the PhD candidate have working experience in at least two foreign languages. The chair of the candidate's thesis guidance committee is responsible for implementing this policy.

DISSERTATION

The student must, of course, do research and write a dissertation. It is the student's responsibility to find an adviser willing to supervise the research and guide the student in writing the thesis. The Graduate Committee then appoints a guidance committee for the student. The dissertation must be defended in an oral examination.

Components in Mathematics and Statistics

Within the one MA or PhD program there are two components or areas of emphasis. The flavor of these components can be indicated as follows:

MATHEMATICS COMPONENT

The department is committed to the idea that the student whose primary interest is pure mathematics should also be acquainted with some applications. Thus, even students pursuing the PhD degree in mathematics are encouraged to take some courses in computer science and/or statistics. The department has special emphasis in algebra, combinatorics, dynamical systems, functional analysis, geometry, graph theory, probability, statistics, theoretical computer science and topology. The department has a tradition of developing intellectual independence in its graduate students. Much time is given to the education of graduate students, both individually and in small classes.

STATISTICS COMPONENT

The statistics component gives broad training. The master's degree prepares students for jobs as statisticians and data analysts in government and industry. The PhD degree prepares students for university teaching and research, as well as consulting and research roles in industry and government. Students are given training in many diverse statistical methods used to analyze data, as well as the mathematical, statistical and probabilistic foundation.

COURSE OFFERINGS/ UNDERGRADUATE

NOTE: Unless otherwise noted, all undergraduate courses carry 4 credits and are offered every year.

MATH 101. BASIC MATHEMATICS *2 credits*
Ratios and percents, geometric concepts and measurement; introduction to algebra. Credit given only to students with deficiencies in the mathematics admission requirement. Does not fulfill all-college distribution requirements. Not open to students who have credit for any higher-numbered mathematics course.

MATH 102. BASIC ALGEBRA *every semester, 2 credits*
Polynomials and rational fractions. Solving equations and inequalities. Functions and graphing. Roots and exponents. College credit given only to students with deficiencies in the mathematics admissions requirement. May not be used to satisfy major requirements or all-college distribution requirements. Not open to students who have credit for any higher-numbered mathematics course. Prerequisite: MATH 101 or equivalent with a grade of C or better.

MATH 103. BASIC ALGEBRA *every semester, 2 credits*
Continuation of MATH 102. The same restrictions apply. Prerequisite: MATH 102 or equivalent with a grade of C or better.

MATH 104. INTRODUCTION TO FUNCTIONS *every semester, 2 credits*
The concepts of functions and their graphs. Logarithm and exponential functions. Right triangle trigonometry. This course is preparation for MATH 108. Credit given only to students with deficiencies in the mathematics admissions requirement. May not be used to satisfy major requirements or all-college distribution requirements. Not open to students who have credit for any higher-numbered mathematics course. Prerequisite: MATH 103 or equivalent with a grade of C or better.

MATH 107. BASIC INTEGRATED MATHEMATICS
Development of basic algebraic skills with some geometry. The course is designed as a bridge between high school mathematics and elementary statistics. It is not adequate preparation for calculus. Prerequisite: grade of C or higher in MATH 104 or two years of high school math.

MATH 108. ALGEBRA AND TRIGONOMETRY *every semester*
Topics essential for study of calculus, including elements of trigonometry, complex numbers, logarithms and basic algebra. Skill development in algebraic and trigonometric manipulations.

MATH 147. ELEMENTARY STATISTICS *every semester*
Classification of data, frequency distributions, probability and the normal curve, elementary sampling theory. Not open to students who have credit for any other course in

statistics. Prerequisite: MATH 108 or equivalent with a grade of C or better.

MATH 220. CALCULUS FOR MANAGEMENT DECISIONS *every semester*
Elements of calculus; emphasis on maximum and minimum problems. Primarily for School of Management students, who may satisfy their mathematics requirement with either MATH 220 or 221. Not equivalent to MATH 221 as prerequisite for MATH 222. Credit not given for both MATH 220 and 221. Prerequisite: MATH 108 or equivalent with a grade of C or better.

MATH 221. CALCULUS I *every semester*
Differentiation and integration of elementary functions. Credit not granted for both MATH 221 and 220. Prerequisite: MATH 108 or equivalent with a grade of C or better.

MATH 222. CALCULUS II *every semester*
Techniques and application of integration. Sequences and series. Prerequisite: MATH 221 with a grade of C or better.

MATH 304. LINEAR ALGEBRA *every semester*
Vector spaces, linear transformations, determinants, characteristic values. Prerequisite: MATH 221 with a grade of C or better.

MATH 314. DISCRETE MATHEMATICS *every semester*
Logic, sets, relations, functions. Induction, recursion, counting methods. Graphs, trees. Some abstract algebra. Prerequisite: MATH 221 with a grade of C or better.

MATH 323. CALCULUS III *every semester*
Calculus of functions of several variables. Prerequisite: MATH 222 with a grade of C or better.

MATH 324. SEMINAR IN ACTUARIAL SCIENCE I *2 credits*
Advanced problem solving seminar for students interested in careers as actuaries. Does not satisfy major requirements. Prerequisites or corequisites: MATH 304 and 323 with grades of C or better. P/F only.

MATH 325. SEMINAR IN ACTUARIAL SCIENCE II *2 credits*
Advanced problem-solving seminar In probability and statistics; extends materials covered in MATH 448. Does not satisfy major requirements. Prerequisite or corequisite: MATH 448 with a grade of C or better. P/F only.

MATH 330. INTRODUCTION TO HIGHER MATHEMATICS *every semester*
Exposure to basic mathematical methods and concepts, including introductory set theory and mappings. Prerequisite: MATH 222 with a grade of C or better.

MATH 335. MATHEMATICAL LOGIC
Development of predicate calculus. Introduction to metatheory of propositional and predicate calculus: completeness, consistency, decidability. Axiomatics. Prerequisite: MATH 314, 330 with grades of C or better, or consent of department.

MATH 339. PROBLEM SOLVING SEMINAR *1 credit*
Techniques of problem solving. Focus on hard problems not usually addressed in ordinary coursework. Problems chosen from a variety of mathematical topics and levels. Prerequisite: consent of department. P/F only.

MATH 341. PROBABILITY WITH STATISTICAL METHODS *3 credits*
Development of probabilistic concepts in discrete and absolutely continuous cases. Classical combinatorial methods, independence, random variables, distributions, moments, transformations, conditioning, confidence intervals, estimation. Open only to students in the Watson School. Does not serve as a prerequisite for MATH 448. Prerequisite: MATH 222 with a grade of C or better, or consent of department.

MATH 357. OPERATIONS RESEARCH
Theory and applications of operations research, including linear programming, mathematical programming and queueing theory. Prerequisites: MATH 222 and 304 with grades of C or better. No computer programming experience is required.

MATH 358. NUMERICAL ANALYSIS I
Floating-point arithmetic, error analysis, root finding, interpolation and approximation by polynomials, numerical integration and differentiation, numerical differential equation methods, solutions of linear systems by Gaussian elimination with pivoting, direct factorization of matrices. Prerequisites: MATH 222 and 304 with grades of C or better, and CS 140 or equivalent.

MATH 371. MATHEMATICAL METHODS IN SCIENCE I
Ordinary differential equations. Emphasis on applications to problems in physics, chemistry, biology, economics, etc. Prerequisite: MATH 323 with a grade of C or better.

MATH 375. COMPLEX VARIABLES
Analytic functions. Cauchy's integral theorem, power series. Prerequisite: MATH 323 with a grade of C or better.

MATH 381. GRAPH THEORY
Directed and undirected graphs, trees, connectivity, Eulerian and Hamiltonian graphs, planar graphs, coloring of graphs, graph parameters, optimization and graph algorithms. Prerequisite: MATH 304, and either MATH 314 or 330 with grades of C or better, or consent of department.

MATH 386. COMBINATORICS
Topics from among counting techniques, generating function and recurrence relations, pigeonhole principle, Ramsey's Theorem, Latin squares, combinatorial designs. Prerequisite: MATH 304 and either MATH 314 or 330 with grades of C or better, or consent of department.

MATH 391. PRACTICUM IN COLLEGE TEACHING *1 credit*
Independent study through teaching in particular mathematics course. Various assignments closely directed by instructor in course, including development of syllabi and other course materials; construction and reading of examinations; lecturing and/or discussion leadership; laboratory supervision; academic counseling of student. May be repeated for total of no more than eight credits. Credits may not be earned in conjunction with course in which student is currently enrolled. Does not satisfy major or all-college requirements. Prerequisite: consent of instructor. P/F only.

MATH 401. MODERN ALGEBRA I
Groups, rings, integral domains, fields. Prerequisites: MATH 304 and 330 with grades of C or better, or consent of department.

MATH 402. MODERN ALGEBRA II
Further study of topics in MATH 401. Vector spaces,

modules, lattices, Galois theory. Prerequisite: MATH 401 with a grade of C or better.

MATH 404. ADVANCED LINEAR ALGEBRA
Modules, normal forms of linear transformations, quadratic forms. Prerequisite: MATH 304 and 330 with grades of C or better, or consent of department.

MATH 407. INTRODUCTION TO THE THEORY OF NUMBERS
Classical number theory. Divisibility, prime numbers, quadratic reciprocity, Diophantine equations. Prerequisite: MATH 330 with a grade of C or better, or consent of department.

MATH 425. SEMINAR IN ACTUARIAL SCIENCE III
2 credits
Advanced problem-solving seminar in numerical analysis and operations research. Prerequisite: MATH 358. Recommended prerequisite: MATH 357 with a grade of C or better. Pass/Fail only.

MATH 447. INTRODUCTION TO PROBABILITY AND STATISTICS I
Development of probabilistic concepts, sampling distributions, estimation, confidence intervals, tests of hypotheses. Prerequisite: MATH 323 with a grade of C or better, or consent of department.

MATH 448. INTRODUCTION TO PROBABILITY AND STATISTICS II
Methods of probability applied to estimation and testing on hypotheses, both parametric and nonparametric; random variables, limit theorems, Markov chains, stochastic processes. Prerequisite: MATH 447 with a grade of C or better.

MATH 461. TOPOLOGY I
Study of topological spaces. Metric spaces, separation properties, connectivity, compactness. Prerequisites: MATH 304, 323 and 330 with grades of C or better, or consent of department.

MATH 462. TOPOLOGY II
Topology of the plane, introductory algebraic topology, local connectivity, applications of topology to analysis. Prerequisite: MATH 461 with a grade of C or better.

MATH 465. FOUNDATIONS OF GEOMETRY
Postulational treatment of geometric systems, including projective, affine and non-Euclidean geometries. Prerequisites: MATH 304 and 330 with grades of C or better, or consent of department.

MATH 471. MATHEMATICAL METHODS IN SCIENCE II
Vector calculus, Fourier series, partial differential equations, with emphasis on applications. Prerequisite: MATH 371 with a grade of C or better.

MATH 478. REAL ANALYSIS I
Geometry and topology of R^n, functions and limits, calculus of functions on R^n and higher dimensional spaces. Prerequisites: MATH 304, 323 and 330 with grades of C or better, or consent of department.

MATH 479. REAL ANALYSIS II
Sequences and series of functions, more advanced study of differentiation and integration. Prerequisite: MATH 478 with a grade of C or better.

MATH 480. SEMINAR IN ALGEBRA *variable credit*
Current research. Prerequisites: MATH 401 with a grade of C or better and consent of department. May be repeated for credit.

MATH 488. TOPICS IN HIGHER MATHEMATICS
as needed
Some topic in higher mathematics not normally part of regular curriculum. Prerequisite: consent of department. May be repeated for credit.

MATH 497. INDEPENDENT WORK *variable credit*
Individual study under direct supervision of faculty member. Prerequisite: consent of department. May be repeated for credit with maximum of eight credit hours of MATH 497 allowed toward major requirements.

MATH 498. HONORS STUDY IN MATHEMATICS
Independent studies/research open only to students who have been accepted in the mathematics honors program. May be repeated for credit, with maximum of 4 credit hours of MATH 498 allowed toward major requirements. Prerequisite: consent of department.

COURSE OFFERINGS/ GRADUATE

It should be noted that a substantial number of the department's advanced graduate courses are offered under the "Topics" number 590, and are therefore not described. This allows for flexibility and the offering of once-only courses on topics of current research interest. Recent topics have included: geometric topology, differential geometry, dynamical systems, geometric methods in group theory, Lie algebras, group theory, recent developments in knot theory, theoretical computer science, homological algebra, algebraic K-theory, stochastic differential equations, recursive estimation and control theory, sequential analysis, reliability theory, finite state structures and varieties of formal languages.

MATH 501. PROBABILITY
Basic probability notions, classical combinatorial methods, conditional probabilities. Random variables and properties of distributions. Moments, moment generating functions, covariances, correlations. Transformations, order statistics. Convergence in probability and large sample properties. Prerequisite: MATH 323 or equivalent.

MATH 502. STATISTICAL INFERENCE
Likelihood functions and sufficient statistics. Theory of estimation; completeness and UMVU estimators. Blackwell-Rao theorem; information inequality. MLEs and their asymptotic properties. Confidence intervals. Testing hypotheses and Neyman-Pearson theory. Introduction to linear models and nonparametric methods. Prerequisite: MATH 501 or equivalent.

MATH 503-504. ALGEBRA
Higher algebra, especially groups, rings, fields and modules. Prerequisites: MATH 401 and 402, or consent of department.

MATH 505-506. ANALYSIS
Real analysis including theory of Lebesque measure, integration and elementary theory of Banach and Hilbert spaces. Complex analysis. Prerequisites: MATH 478 and

479, or consent of department.

MATH 507. LINEAR ALGEBRA AND MATRIX THEORY
Linear algebra over the complex numbers and finite fields, eigenvectors and eigenvalues, quadratic forms, normal forms of matrices, selected topics in matrix theory. Prerequisite: consent of department.

MATH 508. COMPLEX ANALYSIS
A rigorous introduction to complex analysis. Rational functions; conformal maps; Cauchy's Integral Theorem with applications; representations of analytic functions as series, products, integrals; topics selected by instructor. Prerequisite: MATH 479 or consent of department.

MATH 509. GRADUATE COMPUTER SCIENCE FOR MATHEMATICIANS
Graduate level introduction to computer science from mathematician's point of view, models of computation, automata theory, programming languages, program semantics, proof theory for programs. Prerequisite: undergraduate degree in mathematical sciences.

MATH 513-514. GENERAL TOPOLOGY
Topological spaces, metric spaces, separation axioms, compactness, connectedness, quotient spaces. Topics from geometric topology, including fundamental group, complexes and homotopy.

MATH 517-518. ALGEBRAIC TOPOLOGY
Concept of homotopy, fundamental group, covering spaces, categories and functors, simplicial complexes, simplicial homology and cohomology, singular homology and cohomology, cup product structure, CW-complexes, higher homotopy groups. Prerequisite: MATH 461, 513-514, or equivalent.

MATH 519. THEORY OF FIBER SPACES
Various types of fibrations (Serre, Hurewicz, Dold fibrations, fiber bundles, covering spaces), applications of homotopy theory, topics from classical theory of bundles, classification theorems, spectral sequences. Prerequisites: MATH 513, 514, consent of department.

MATH 520. HOMOLOGICAL ALGEBRA
Modules, chain complexes, tensor products, derived functors, homology of groups, other topics selected by the instructor. Prerequisite: MATH 504 or consent of department.

MATH 521-522. DIFFERENTIAL TOPOLOGY
Differentiable manifolds, imbeddings and immersions, Whitney's imbedding theorem, tangent and cotangent bundles, Morse theory. Prerequisite: MATH 513-514.

MATH 523-524. GROUP THEORY
Properties of groups, extensions, transfer, generators, defining relations. Prerequisite: MATH 503-504 or equivalent.

MATH 525-526. RINGS AND ALGEBRAS
Advanced study of rings and algebras; special topics selected from current literature. Prerequisite: MATH 503-504 or equivalent.

MATH 527. REPRESENTATION THEORY
Representations of groups and rings by linear transformations, characters, applications in structure theory of groups and rings. Prerequisite: consent of department.

MATH 532. ADVANCED NUMERICAL ANALYSIS
Solution to nonlinear equations, differential equations, eigenvalue problems, finite element method, discretization error, iterative methods, computer implementation. Prerequisites: undergraduate differential equations, linear algebra, advanced calculus, some programming experience.

MATH 537. ANALYSIS OF ALGORITHMS
Time and space analysis of algorithms for applications such as sorting, searching, graphics manipulation, pattern matching and algebraic calculation. Statistical analysis. Empirical analysis of complex algorithms arising in computer systems. Prerequisite: MATH 509.

MATH 538. COMPILERS AND FORMAL LANGUAGES
Formal description of syntax and semantics of computer languages. Transition from formal description to implementation as compiler or interpreter. Various languages compared as to their data structures, procedures and input-output. Prerequisite: MATH 509.

MATH 545. TOPOLOGICAL GROUPS
Locally compact topological groups, open homomorphism and closed graph theorems, measure and integration on locally compact topological groups. Prerequisite: MATH 505-506, 513-514 or consent of department.

MATH 547-548. DECOMPOSITION SPACES
Upper and lower semi-continuous decompositions, properties inherited by decomposition spaces, applications (in particular to manifolds). Prerequisites: MATH 513-514 and consent of department.

MATH 549. KNOT THEORY
Knots and knot types, presentation of a knot group, combinatorial covering spaces, absolute calculus, cubes with holes. Prerequisites: MATH 513-514 and consent of department.

MATH 551-552. POLYHEDRAL TOPOLOGY
Regular neighborhood theory, general position, unknotting balls and spheres, engulfing techniques, handlebody theory and s-cobordism. Prerequisites: MATH 513-514 and consent of department.

MATH 553. NONPARAMETRIC INFERENCE
Order statistics and quantiles, nonparametric confidence intervals, nonparametric measures of association, tests based on ranks, tests of independence, symmetry, location differences, chi-square and Kolmogorov-Smirnov goodness of fit tests, nonparametric regression, robustness, asymptotic relative efficiency of tests, concepts of nonparametric density estimation. Prerequisite: MATH 448 or 502.

MATH 554. SAMPLING FROM FINITE POPULATIONS
The classical model and sampling strategies. Sampling distributions of estimators of population quantities. Simple random sampling, stratified sampling, two-stage and multistage cluster sampling, optimal allocation of resources, and other design aspects. Sampling inspection techniques for quality control. Other topics as time permits. Prerequisite: MATH 447 or 501.

MATH 555. LINEAR MODELS

Inference in linear models based on the least squares approach: Point estimation, confidence regions, hypothesis testing, model building and verification, residual analysis, selection of best regression, influential observations. Prerequisites: MATH 448 or 502 and MATH 404 or 507.

MATH 556. DESIGN OF EXPERIMENTS
The role and principles of DE in scientific research. Reference distributions, ANOVA, multiple comparisons. Randomized complete block designs, latin squares, P^n factorial design and the calculus of factorial experiments. Balanced incomplete block designs, the recovery of intrablock information. Exploration of response surfaces. Prerequisite: MATH 555.

MATH 558. MULTIVARIATE STATISTICAL ANALYSIS
Multivariate normal distributions, Wishart distributions, inferences on means and covariances, Hotelling's T^2, multivariate linear models, regression, ANOVA, tests of independence, discriminant analysis, principal components, canonical correlations and variables, factor analysis. Prerequisite: MATH 555.

MATH 559. TIME-SERIES ANALYSIS
Trend analysis and smoothing. Estimation, testing, modeling, and forecasting for ARMA and ARIMA models. Prerequisite: MATH 555.

MATH 561. ALGEBRA SEMINAR *1-4 credits*
Prerequisite: consent of department.

MATH 564. PROBABILITY SEMINAR *1-4 credits*
Prerequisite: consent of department.

MATH 565. TOPOLOGY SEMINAR I *1-4 credits*
Prerequisite: consent of department.

MATH 567. TOPOLOGY SEMINAR II *1-4 credits*
Prerequisite: consent of department.

MATH 570. APPLIED MULTIVARIATE ANALYSIS
Multivariate normal distributions, Wishart distributions, Hotelling's T, tests of independence, large sample distribution theory, multivariate linear models, discriminant analysis, factor analysis, principal components and other selected topics. Prerequisite: MATH 558.

MATH 571. ADVANCED PROBABILITY THEORY *5 credits*
Measure theoretic probability. Axiomatic foundations, random variables, conditional probability and expectation, characteristic functions, infinite divisibility and stable laws, types of convergence, law of large numbers, central limit theorem, other topics as time permits. Prerequisite: MATH 447 or 501, and MATH 506 or consent of instructor.

MATH 572. STOCHASTIC PROCESSES *5 credits*
A continuation of the subject matter presented in MATH 571. Martingales and Markov processes (if not covered in MATH 571), orthogonality, stationary processes, other topics as time permits. Prerequisite: MATH 571.

MATH 573. APPLIED PROBABILITY AND STOCHASTIC PROCESSES
Introduction to Markov chains, Markov processes with emphasis on applications. Classification of states, stationarity. Continuity, integration, and differentiation of second order processes. Stochastic differential equations. Prerequisite: MATH 501.

MATH 574. NUMBER THEORY (MAT/MST)
Elementary number theory, divisibility, fundamental theorem of arithmetic, prime numbers, quadratic reciprocity, Diophantine equations. Prerequisite: consent of instructor.

MATH 575. SPECIAL TOPICS FOR TEACHERS (MAT/MST) *1-4 credits*
Special topics of interest to teachers. Prerequisite: consent of instructor.

MATH 576. COMPUTER APPLICATIONS IN MATHEMATICS EDUCATION (MAT/MST)
Computer usage in education from historical point of view, evaluation of various levels of computer usage in learning situation (low key approach, interactive CAI approach, artificial intelligence approach). Prerequisite: consent of instructor.

MATH 577. RECREATIONAL MATHEMATICS (MAT/MST)
Sources of recreational mathematics, magic squares, dissection problems, map coloring problems, traversing of mazes, chessboard recreations, instant insanity, arithmetical and geometrical fallacies. Prerequisite: consent of instructor.

MATH 578. COMBINATORICS (MAT/MST)
Combinations and permutations, enumeration techniques, recursion, sum and difference sequences, partitions, applications to precollege mathematics. Prerequisite: consent of instructor.

MATH 579. ADVANCED STATISTICAL INFERENCE
Weak convergence of probability measures on Euclidean spaces. Interval estimation, point estimation, and hypothesis testing. General decision theory including the minimax theorem, the complete class theorem, the abstract Rao-Blackwell theorem, the theorem of Hunt and Stein, and Bayes methods. Asymptotic decision theory. Prerequisite: MATH 571 and 502.

MATH 580. TOPICS IN COMBINATORIAL ANALYSIS
Variable subject matter chosen from field of combinatorial analysis. Prerequisite: MATH 401. May be repeated for credit with consent of department.

MATH 581. TOPICS IN GRAPH THEORY
Theoretical and applied graph theory. Applications including personnel assignment problem, construction of reliable communications networks, chromatic polynomials. Prerequisite: MATH 401 or consent of instructor. May be repeated for credit with consent of department.

MATH 582. ALGEBRA (MAT/MST)
Classical theory of equations, algebraic systems (including groups, rings, fields, modules) and their properties. Prerequisite: consent of instructor.

MATH 583. METRIC AND AFFINE GEOMETRY (MAT/MST)
Affine and metric geometry from transformational point of view. Finite and infinite geometries, Euclidean geometry, applications to precollege mathematics. Prerequisite: consent of instructor.

MATH 584. EUCLIDEAN AND NON-EUCLIDEAN GEOMETRY (MAT/MST)
Algebraic (analytic) approach to classical geometries (Euclidean, hyperbolic, projective). Prerequisite: consent of instructor.

MATH 588. PROBABILITY AND STATISTICS (MAT/MST)
Finite probability and probability related statistical problems. Mixture of formal development and problem solving with applications to precollege mathematics. Prerequisite: consent of instructor.

MATH 589. HISTORY AND CONCEPTUAL DEVELOPMENT OF THE CALCULUS (MAT/MST)
Historical and conceptual development of mathematical ideas underlying modern calculus, including problems of infinity and of continuity as treated in ancient and modern times. Applications to precollege mathematics wherever appropriate.

MATH 590. TOPICS IN MODERN MATHEMATICS
1-4 credits
Study (at graduate level) of some topic in mathematics not a part of regular graduate curriculum. Content changes from term to term. With consent of department, students may repeat course for credit. Prerequisite: consent of department.

MATH 591. THE TEACHING OF COLLEGE MATHEMATICS *1-4 credits*
Required for teaching assistants, suggested for graduate assistants interested in college teaching. Does not count toward required number of courses for MA or PhD.

MATH 597. INDEPENDENT WORK *1-4 credits*
Reading and research on special topic, under direction of adviser. May be repeated for credit with consent of department. Commonly taught topics under Independent Work include but are not limited to the following:
MATH 597A. STUDIES IN MODERN ALGEBRA I,
MATH 597B. STUDIES IN MODERN ALGEBRA II,
MATH 597C. STUDIES IN REAL ANALYSIS I,
MATH 597D. STUDIES IN REAL ANALYSIS II

MATH 599. THESIS *1-4 credits*

MATH 601. TOPICS IN TOPOLOGY
Variable subject matter chosen from field of topology. May be repeated for credit with consent of department.

MATH 603. TOPICS IN ALGEBRA *1-4 credits*
Variable subject matter chosen from field of algebra. May be repeated for credit with consent of department.

MATH 604. ADVANCED TOPICS IN THE THEORY OF GROUPS
Topics selected from current research. May be repeated for credit with consent of department.

MATH 605. SEMINAR IN STATISTICS *1-4 credits*
Variable subject matter chosen from field of statistics. Topics selected from current research. May be repeated for credit with consent of department.

MATH 698. PREDISSERTATION RESEARCH
1-9 credits/semester
Independent reading and/or research in preparation for comprehensive examinations for admission to PhD candidacy and/or preparation of dissertation prospectus. Graded on S/U basis only.

MATH 699. DISSERTATION *1-12 credits/semester*
Research for and preparation of the dissertation.

MATH 700. CONTINUOUS REGISTRATION
1 credit/semester
Required for maintenance of matriculated status in graduate program. No credit toward graduate degree requirements.

MATH 707. RESEARCH SKILLS *1-4 credits*
Development of research skills required within graduate programs. May not be applied toward course credits for any graduate degree. Prerequisite: approval of relevant graduate program directors or department chairs.