Duke University

Handbook for

Mathematics Majors and Minors

2001 – 2002

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The *Duke University Handbook for Mathematics Majors and Minors* is published annually by the Department of Mathematics, Duke University, Box 90320, Durham, NC 27708-0320, USA.

Copies of this handbook are available from Georgia Barnes (121C Physics Building, (919) 660-2801, `barnes@math.duke.edu`). It is also available at the department web site (`http://www.math.duke.edu`).

Corrections to this handbook, proposed additions or revisions, and questions not addressed herein should be directed to Stephanos Venakides (132C Physics Building, (919) 660-2800, `dus@math.duke.edu`); electronic mail is preferred.

Questions regarding courses frequently taken by first-year students (e.g., the introductory calculus courses corresponding to Duke mathematics courses numbered 19–103) should be addressed to Lewis Blake, Supervisor of First-year Instruction (118 Physics Building, (919) 660-2800, `sfi@math.duke.edu`).

Read Your E-Mail!

Electronic mail is frequently used for official communications between the Department of Mathematics and students majoring or minoring in mathematics. Therefore, students pursuing degrees in mathematics are expected to read their electronic mail regularly.

Acknowledgments

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Duke University
Undergraduate Honor Code

An essential feature of Duke University is its commitment to integrity and ethical conduct. The honor system at Duke helps to build trust among students and faculty and to maintain an academic community in which a code of values is shared. Instilling a sense of honor, and of high principles that extend to all facets of life, is an inherent aspect of a liberal education.

As a student and citizen of the Duke University Community:

- I will not lie, cheat, or steal in my academic endeavors.
- I will forthrightly oppose each and every instance of academic dishonesty.
- I will communicate directly with any person or persons I believe to have been dishonest. Such communication may be oral or written. Written communication may be signed or anonymous.
- I will give prompt written notification to the appropriate faculty member and to the Dean of Trinity College or the Dean of the School of Engineering when I observe academic dishonesty in any course.
- I will let my conscience guide my decision about whether my written report will name the person or persons I believe to have committed a violation of this code.

I join the undergraduate student body of Duke University in a commitment to this Code of Honor.

Introduction

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 2001–2002: Undergraduate Instruction*. Much information about the Mathematics Department, including this handbook, can be found at the web site, `http://www.math.duke.edu`, especially the page for The Undergraduate Program.

This handbook is organized in three main sections. The first section, **Course Selection**, is intended to assist students in developing programs of study that meet university requirements and that serve their educational and professional objectives.

The second section, **Resources and Opportunities**, describes features of our program intended to enrich the undergraduate experience of mathematics students.

The third section, **After Graduation: Educational and Professional Opportunities**, is intended to give a brief introduction to the careers and programs of study for which mathematics provides a good foundation.

* * * * *

A popular modern dictionary[1] defines mathematics as

> **mathematics:** the science of numbers and their operations, interrelations, combinations, generalizations, and abstractions and of space configurations and their structure, measurement, transformations, and generalizations.

However, a strong case can be made that a more complete and appropriately general definition of mathematics[2] is given by

mathematics: the science of abstract structure.

Indeed the inestimable importance of mathematics arises directly from the identification of mathematics as the study of the essential structure that remains in a problem or situation after all nonessential elements have been stripped away. Consequently, mathematics is a science of extraordinary intrinsic beauty, highly deserving of study for the sake of that beauty, standing alone. But owing to its generality and breadth, mathematics is an indispensable component of rational discourse, sound public policy, scientific understanding, and technological advancement. On pages 4 and 5, in a section entitled **The Nature of Mathematics**, some excerpts are reproduced from an essay that seeks to characterize mathematics and to describe its emerging role in today's world.

[1] *Merriam Webster's Collegiate Dictionary*, 10th ed, Merriam-Webster Inc., Springfield, MA, 1993.

[2] Suggested by phrasing in *A Bridge to Advanced Mathematics* by Dennis Sentilles. Williams & Wilkins, Baltimore, 1975, p. 147.

The Nature of Mathematics

(These paragraphs are reprinted with permission from *Everybody Counts: A Report to the Nation on the Future of Mathematics Education.*

Mathematics reveals hidden patterns that help us understand the world around us. Now much more than arithmetic and geometry, mathematics today is a diverse discipline that deals with data, measurements, and observations from science; with inference, deduction, and proof; and with mathematical models of natural phenomena, of human behavior, and of social systems.

As a practical matter, mathematics is a science of pattern and order. Its domain is not molecules or cells, but numbers, chance, form, algorithms, and change. As a science of abstract objects, mathematics relies on logic rather than on observation as its standard of truth, yet employs observation, simulation, and even experimentation as means of discovering truth.

The special role of mathematics in education is a consequence of its universal applicability. The results of mathematics—theorems and theories—are both significant and useful; the best results are also elegant and deep. Through its theorems, mathematics offers science both a foundation of truth and a standard of certainty.

In addition to theorems and theories, mathematics offers distinctive modes of thought which are both versatile and powerful, including modeling, abstraction, optimization, logical analysis, inference from data, and use of symbols. Experience with mathematical modes of thought builds mathematical power—a capacity of mind of increasing value in this technological age that enables one to read critically, to identify fallacies, to detect bias, to assess risk, and to suggest alternatives. Mathematics empowers us to understand better the information-laden world in which we live.

* * * * *

During the first half of the twentieth century, mathematical growth was stimulated primarily by the power of abstraction and deduction, climaxing more than two centuries of effort to extract full benefit from the mathematical principles of physical science formulated by Isaac Newton. Now, as the century closes, the historic alliances of mathematics with science are expanding rapidly; the highly developed legacy of classical mathematical theory is being put to broad and often stunning use in a vast mathematical landscape.

Several particular events triggered periods of explosive growth. The Second World War forced development of many new and powerful methods of applied mathematics. Postwar government investment in mathematics, fueled by Sputnik, accelerated growth in both education and research. Then the development of electronic computing moved mathematics toward an algorithmic perspective even as it provided mathematicians with a powerful tool for exploring patterns and testing conjectures.

At the end of the nineteenth century, the axiomatization of mathematics on a foundation of logic and sets made possible grand theories of algebra, analysis, and topology whose synthesis dominated mathematics research and teaching for the first two thirds of the twentieth century. These traditional areas have now been supplemented by major developments in other mathematical sciences—in number theory, logic, statistics, operations research, probability, computation, geometry, and combinatorics.

In each of these subdisciplines, applications parallel theory. Even the most esoteric and abstract parts of mathematics—number theory and logic, for example—are now used routinely in applications (for example, in computer science and cryptography). Fifty years ago, the leading British mathematician G.H. Hardy could boast that number theory was the most pure and least useful part of mathematics. Today, Hardy's mathematics is studied as an essential prerequisite to many applications, including control of automated systems, data transmission from remote satellites, protection of financial records, and efficient algorithms for computation.

In 1960, at a time when theoretical physics was the central jewel in the crown of applied mathematics, Eugene Wigner wrote about the "unreasonable effectiveness" of mathematics in the natural sciences: "The miracle of the appropriateness of the language of mathematics for the formulation of the laws of physics is a wonderful gift which we neither understand nor deserve." Theoretical physics has continued to adopt (and occasionally invent) increasingly abstract mathematical models as the foundation for current theories. For example, Lie groups and gauge theories—exotic expressions of symmetry—are fundamental tools in the physicist's search for a unified theory of force.

During this same period, however, striking applications of mathematics have emerged across the entire landscape of natural, behavioral, and social sciences. All advances in design, control, and efficiency of modern airliners depend on sophisticated mathematical models that simulate performance before prototypes are built. From medical technology (CAT scanners) to economic planning (input/output models of economic behavior), from genetics (decoding of DNA) to geology (locating oil reserves), mathematics has made an indelible imprint on every part of modern science, even as science itself has stimulated the growth of many branches of mathematics.

Applications of one part of mathematics to another—of geometry to analysis, of probability to number theory—provide renewed evidence of the fundamental unity of mathematics. Despite frequent connections among problems in science and mathematics, the constant discovery of new alliances retains a surprising degree of unpredictability and serendipity. Whether planned or unplanned, the cross-fertilization between science and mathematics in problems, theories, and concepts has rarely been greater than it is now, in this last quarter of the twentieth century.

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	
<200	Undergraduate courses.
200–206	Primarily undergraduate courses. These courses are recommended for students planning graduate study in mathematics.
211–239	Graduate courses for students in mathematics and related disciplines. These courses are also appropriate for advanced undergraduates, especially those interested in the applications of mathematics.
>239	Primarily graduate courses for students in mathematics. However, sufficiently prepared undergraduates are encouraged to enroll. Standard first-year graduate courses in pure mathematics include 241, 245, and 251.

The department intends to offer all of the courses listed in this handbook regularly, assuming sufficient enrollment. The courses that are offered every year are usually offered according to the schedule below. A dagger (†) indicates a course offered through the Institute of Statistics and Decision Sciences.

Fall and spring:	104, 111, 114, 121, 131, 135, 139
Fall:	132S, 200, 203, 217†
Spring:	104C, 104X, 128S, 133, 136,† 160, 201, 204, 206
Fall or spring:	124, 126, 187

Rapid Reference Course List

Listed below are the mathematics courses, numbered 104 and above, that are most often taken by undergraduates. Detailed course descriptions and prerequisites are given in a subsequent section, beginning on page 15.

104. Linear Algebra and Applications
104C. Linear Algebra with Scientific Computation
104X. Honors Linear Algebra
111. Applied Mathematical Analysis I
114. Applied Mathematical Analysis II
121. Introduction to Abstract Algebra
123S. Geometry
124. Combinatorics
126. Introduction to Linear Programming and Game Theory
128. Number Theory
131. Elementary Differential Equations
132S. Nonlinear Ordinary Differential Equations
133. Introduction to Partial Differential Equations
135. Probability (C-L: STA 104)
136. Statistics (C-L: STA 114)
139. Advanced Calculus I
149S. Problem Solving Seminar
150. Topics in Mathematics from a Historical Perspective
160. Mathematical Numerical Analysis
181. Complex Analysis
187. Introduction to Mathematical Logic
188. Logic and its Applications (C-L: PHIL 150 and CPS 148)
191, 192, 193, 194. Independent Study
196S. Seminar in Mathematical Model Building
197S. Seminar in Mathematics
200. Introduction to Algebraic Structures I
201. Introduction to Algebraic Structures II
203. Basic Analysis I
204. Basic Analysis II
205. Topology
206. Differential Geometry
211. Mathematical Methods in Physics and Engineering
216. Applied Stochastic Processes (C-L: STA 253)
217. Introduction to Linear Models (C-L: STA 244)
218. Introduction to Multivariate Statistics (C-L: STA 245)
221. Numerical Analysis (C-L: CPS 250)
224. Scientific Computing I
225. Scientific Computing II
228. Mathematical Fluid Dynamics
233. Asymptotic and Perturbation Methods

Requirements for the Mathematics Major

The Department of Mathematics offers both the A.B. degree and the B.S. degree. Students who plan to attend graduate school in mathematics or the sciences should consider working toward the B.S. degree, which requires at least eight courses in mathematics numbered above 104. The A.B. degree requires at least six and one-half courses numbered above 104. Beginning with students matriculating in fall 1996, both degrees have a minimum of ten required courses, at least eight of which are at the 100 level or above (see p. 26 of the *Bulletin of Duke University 2001–2002: Undergraduate Instruction*). The specific requirements for the A.B. and B.S. degrees are listed below.

Bachelor of Arts Degree

Prerequisites: Mathematics 31 or 31L or an equivalent course (Advanced Placement course credit allowed); Mathematics 32 or 32L or 41 or an equivalent course (Advanced Placement course credit allowed); Mathematics 103 and Mathematics 104 or equivalent courses. (Many upper level mathematics courses assume programming experience at the level of Computer Science 4. Students without computer experience are encouraged to take Computer Science 6.[†]) (*Revised 4/14/95.*)

Major Requirements: Six and one-half courses in mathematics numbered above 104 including Math 121 or 200, and Math 139 or 203. (*Revised 7/6/98.*)

Bachelor of Science Degree

Prerequisites: Mathematics 31 or 31L or an equivalent course (Advanced Placement course credit allowed); Mathematics 32 or 32L or 41 or an equivalent course (Advanced Placement course credit allowed); Mathematics 103 and 104 or equivalent courses. (Many upper level mathematics courses assume programming experience at the level of Computer Science 4. Students without computer experience are encouraged to take Computer Science 6.[†]) (*Revised 4/14/95.*)

Major Requirements: Eight courses in mathematics numbered above 104 including Mathematics 121 or 200; Mathematics 139 or 203; and one of Mathematics 136, 181, 201, 204, 205, 206. Also, one of Physics 41L, 51L, 53L and one of Physics 42L, 52L, 54L. (*Revised 8/16/01.*)

Requirements for the Mathematics Minor

Prerequisites: Mathematics 103 or the equivalent. (Many upper-level courses assume programming experience at the level of Computer Science 4. Students without programming experience are encouraged to take Computer Science 6.[†])

Minor requirements: Five courses as follows: either Mathematics 104 or Mathematics 111, but not both; four additional courses in mathematics numbered above 111, to include at least one course (or its equivalent) selected from the following: Mathematics 121, 132S, 135, 139, 160, 181, 187, or any 200-level course. (*Approved 4/14/95.*)

[†]Students with considerable programming experience are encouraged to take Computer Science 100E.

Advising and Advice

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.

Choosing courses. Every mathematics major must take one course in abstract algebra (Mathematics 121 or Mathematics 200) and one course in advanced calculus (Mathematics 139 or Mathematics 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 100–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 200–level courses. The remaining courses may be chosen from both pure and applied areas of mathematics.

There have been some recent changes in the mathematics major requirements, so it should be noted that "Students are responsible for meeting the requirements of a major as stated in the bulletin for the year in which they matriculated in Trinity College although they have the option of meeting requirements in the major changed subsequent to their matriculation" (see page 26 of the 2001–2002 undergraduate *Bulletin*).

Probability and statistics courses. The standard sequence in probability and statistics is Mathematics 135–136. Mathematics 135 covers the basics of probability and Mathematics 136 covers statistics, building on the material in Mathematics 135. Those desiring a further course in probability should select Mathematics 216; a further course in statistics is Mathematics 217.

The Institute of Statistics and Decision Sciences (ISDS) 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 200 for credit, but usually only courses that have a prerequisite of Mathematics 136 or its equivalent will be considered.

Transfer Credit

For university policy on transfer credit for courses taken elsewhere, see pages 46–47 in the *Bulletin of Duke University 2001–2002: Undergraduate Instruction.* Note specifically the sentence on page 47 that reads, “Students wishing to transfer credit for study at another regionally accredited college while on leave or during the summer must present a catalog of that college to the appropriate dean and director of undergraduate studies and obtain their approval prior to taking the courses.”

Thus, **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 meet

- with the Director of Undergraduate Studies for courses in mathematics to be taken abroad;
- with the Associate Director of Undergraduate Studies for courses in mathematics numbered above 103 to be taken in the States and
- with the Supervisor of First-year Instruction for courses numbered 103 and below. (Additional considerations, not cited below, may apply to courses numbered 103 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, Associate Directior 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 2001-2002: Undergraduate Instruction* p. 26-27 under **The Major** and under **The Minor**.)
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 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.

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.

A student who has obtained transfer credit may still enroll in the corresponding Duke course, but transfer credit will then be lost.

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 Jean Ross, to whom the required approval forms and transcripts are sent (103 Allen Building, 684-9008, facsimile: 684-4500, `jean.ross@duke.edu`).

Credit for Courses Taken Abroad

Students frequently study abroad through programs administered by the Office of Foreign Academic Programs. The Department of Mathematics encourages study abroad and expects that increasing number of students will complete course work, including courses in mathematics, at foreign universities. However, students who study abroad must take care to ensure that the mathematics courses taken abroad count toward the mathematics major (or minor) and and that the requirements of the mathematics major (or minor) are met.

Courses to be taken abroad must be preapproved by the Director of Undergraduate Studies, by the dean responsible for study abroad, and by the student's academic dean; and final credit will not be awarded until the content of the actual courses taken has been reviewed by the Director of Undergraduate Studies. Courses scheduled to be offered abroad may be cancelled with little advance notice, or they may differ from a student's expectations. Students are responsible for contacting the DUS and the deans by electronic mail, facsimile, or telephone to obtain advance approval for alternative courses.

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 26).

Applications of Mathematics

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

Students with an interest in the applications of mathematics should take Mathematics 131, 135, 136, and 160 (or 221). Other electives depend on particular interests; recommendations are given below.

Engineering and Natural Science	MTH 114, 132S, 133, 181, 196S, 216, 224, 238
Business and Economics	MTH 126, 132S, 216
Computer Science	MTH 124, 126, 187, 188, 200, 201

A student planning to enter professional school (e.g., business, law, or medicine) can choose a program of study based mainly on interest. A student intending to enter graduate school in an area other than mathematics should formulate a program in consultation with representatives of that area, at Duke or at other potential graduate institutions.

Actuarial Science

Actuaries earn professional status, in part, by passing a series of examinations administered by the Casualty Actuarial Society and the Society of Actuaries. A student should begin taking the examinations while still an undergraduate. The sophomore or junior year is the optimal time to take the first examination, Calculus and Linear Algebra. The first two examinations should be passed before college graduation, else employment opportunities will be greatly diminished. To help decide if one is suited to an actuarial career, a summer internship with an insurance company or consulting firm may be helpful. Summer openings are limited and are often filled by January or February; one's chances of being accepted are greatly improved by having passed the first examination.

Some of the topics of the earlier examinations along with recommended supporting Duke courses are:

Calculus and linear algebra	MTH 31, 32, 103, 104
Probability and statistics	MTH 135, 136
Applied statistical methods	MTH 217
Operations research	MTH 126, 216
Numerical methods	MTH 160, 221

Additional information about the examinations can be obtained from the Director of Undergraduate Studies.

Courses in accounting, finance, economics, and computer science are also helpful preparation for a career in actuarial science.

The curriculum in Mathematical Sciences at the University of North Carolina at Chapel Hill includes an Actuarial Science option through which students may take specialized courses in actuarial mathematics during the spring semester. Under a reciprocal agreement between the two universities, students at Duke may enroll concurrently in these courses offered by UNC–Chapel Hill (see page 66 of the *Bulletin of Duke University, 1999–2000: 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.

Inquiries about the courses at UNC or about actuarial science in general may be made to Charles W. Dunn, a Duke graduate and Fellow of the Society of Actuaries. He works in Raleigh (phone 919-787-8989) and also teaches at UNC, email `cwd0926@aol.com`).

Teaching Mathematics

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

Geometry (MTH 123S)	Advanced Calculus (MTH 139 or 203)
Abstract Algebra (MTH 121 or 200)	Computer Science (CPS 4 or 6)
Probability/Statistics (MTH 135/136)	

The following courses would also be helpful:

Combinatorics (MTH 124)	Logic (MTH 187)
Number Theory (MTH 128)	Mathematical Modeling (MTH 196S)
Differential Equations (MTH 131)	Two courses in Physics (e.g., PHY 51,52)

A student interested in becoming a secondary mathematics teacher should contact Jack Bookman (027A Physics Building, 660-2831, `bookman@math.duke.edu`). There are several paths that one might pursue to major in mathematics and also to be qualified to teach:

1. To become certified to teach so that one can go directly into secondary school teaching upon completion of an undergraduate degree, a student should complete the requirements for the mathematics major, meet the requirements for certification in North Carolina (which includes a prescribed list of mathematics and education courses), and complete a teaching internship during the spring semester of the senior year. Contact Ginger Wilson in the Program in Education (213 West Duke Building, East Campus, 660-3075) for a more complete description of these requirements.

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 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 a program that leads to a master of arts in teaching; for more information about this program see Rosemary Thorne (138B Social Sciences, 684-4353, `mat@acpub.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 181, 200–201, and 203–204; one of the sequences 200–201/203–204 should be taken no later than the junior year. Mathematics 131, 160 (or 221), 205, and 206 are recommended. Students interested in applied mathematics should consider Mathematics 132S, 133, 135, 136, 196S, 216, and 224. Advanced students are encouraged to take standard graduate–level courses (numbered 231 and above) in their senior (and occasionally in their junior) years: in particular, Mathematics 241, 245, and 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 135, 136, 216, and 217, as well as CPS 6 and 100. A strong background in mathematics (especially analysis and linear algebra) and computing is the best basis for graduate work in statistics.

Students who do not intend to pursue graduate work should elect Mathematics 135, 136, 217, CPS 6 or 100 as well as some of the following courses: Mathematics 216, 218, 160 (or 221), STA 242, CPS 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 Institute of Statistics and Decision Sciences (212 Old Chemistry, 684-4263, `dalene@stat.duke.edu`).

Course Descriptions

Given below are catalog descriptions of the mathematics courses numbered 104 and above that are most often taken by undergraduates. Comments are in italics. For a complete listing of courses see the undergraduate *Bulletin*.

104. Linear Algebra and Applications. 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. Prerequisite: Mathematics 32, 32L, or 41.

Note: Math 104 is a prerequisite for the mathematics major. Potential majors should take Math 104 or 104C, rather than Math 111 (see below), for an introduction to linear algebra.

104C. Linear Algebra with Scientific Computation. Introductory linear algebra developed from the perspective of computational algorithms. Similar to Mathematics 104, but emphasizes matrix factorizations and includes the programming of basic algorithms and the use of software packages. Three lectures and one computer laboratory meeting per week. Prerequisite: Mathematics 32, 32L, or 41. (*Approved 2/3/98.*)

111. Applied Mathematical Analysis I. First and second order differential equations with applications; matrices, eigenvalues, and eigenvectors; linear systems of differential equations; Fourier series and applications to partial differential equations. Intended primarily for engineering and science students with emphasis on problem solving. Students taking Math 104, especially mathematics majors, are urged to take Math 131 instead. Not open to students who have had Math 131. Prerequisite: Mathematics 103. (*Revised 6/9/98.*)

Note: Math 111 is not recommended for mathematics majors or students taking Math 104. Mathematics majors should take Math 104 (Linear Algebra and Applications), and then Math 131 for a first course in differential equations, rather than Math 111.

114. Applied Mathematical Analysis II. Boundary value problems, complex variables, Cauchy's theorem, residues, Fourier transform, applications to partial differential equations. Not open to students who have had Mathematics 133, 181, or 211. Prerequisites: Mathematics 111 or 131, or 103 and consent of instructor.

121. Introduction to Abstract Algebra. Groups, rings, and fields. Students intending to take a year of abstract algebra should take Mathematics 200-201. Not open to students who have had Mathematics 200. Prerequisites: Mathematics 104 or 111.

123S. Geometry. Euclidean geometry, inversive 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 32, 32L, or 41 or consent of instructor.

124. Combinatorics. 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. Prerequisites: Mathematics 104 or consent of instructor.

126. Introduction to Linear Programming and Game Theory. Fundamental properties of linear programs; linear inequalities and convex sets; primal simplex method, duality; integer programming; two-person and matrix games. Prerequisite: Mathematics 104.

128. Number Theory. 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 32, 32L, or 41, or consent of instructor.

131. Elementary Differential Equations. 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 111. Prerequisite: Mathematics 103; corequisite: Mathematics 104. One course. Staff. (*Revised 8/19/97.*)

132S. Nonlinear Ordinary Differential Equations. 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 111 or 131 or consent of instructor. (*Revised 4/24/96.*)

133. Introduction to Partial Differential Equations. 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. Not open to students who have had Mathematics 114 or 211. Prerequisite: Mathematics 111 or 131 or consent of instructor. (*Approved 9/12/95.*)

135. Probability. Probability models, random variables with discrete and continuous distributions. Independence, joint distributions, conditional distributions. Expectations, functions of random variables, central limit theorem. Prerequisite: Mathematics 103. C-L: Statistics 104.

136. Statistics. 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. Prerequisites: Mathematics 104 and 135. C-L: Statistics 114.

139. Advanced Calculus I. 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 203. Prerequisite: Mathematics 103.

149S. Problem Solving Seminar. Techniques for attacking and solving challenging mathematical problems and writing mathematical proofs. Course may be repeated. Consent of instructor required. Half course.

150. Topics in Mathematics from a Historical Perspective. Content of course determined by instructor. Prerequisite: Mathematics 139 or 203 or consent of instructor.

160. Mathematical Numerical Analysis. 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. Prerequisite: Mathematics 103 and 104 and basic knowledge of a programming language (at the level of COMPSCI 6), or consent of instructor. Not open to students who have had Computer Science 150 or 250.

181. Complex Analysis. Complex numbers, analytic functions, complex integration, Taylor and Laurent series, theory of residues, argument maximum principles, conformal mapping. Not open to students who have had Mathematics 114 or 212. Prerequisite: Mathematics 139 or 203.

187. Introduction to Mathematical Logic. Propositional calculus; predicate calculus. Gödel completeness theorem, applications to formal number theory, incompleteness theorem, additional topics in proof theory or computability; contributions of Aristotle, Boole, Frege, Hilbert, and Gödel. Prerequisites: Mathematics 103 and 104 or Philosophy 103.

188. Logic and its Applications. 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, mathematics, and philosophy. Prerequisite: a course in logic or permission of one of the instructors. C-L: Computer Science 148; Philosophy 150. (*Approved 2/8/96.*)

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. (*See additional information on page 22 of this Handbook.* *Revised 8/30/01.*)

192. Research Independent Study. 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. (*See additional information on page 22 of this Handbook.* *Revised 8/30/01.*)

193. Independent Study. Same as 191, but for seniors.

194. Research Independent Study. Same as 192, but for seniors.

196S. Seminar in Mathematical Modeling. Introduction to techniques used in the construction, analysis, and evaluation of mathematical models. Individual modeling projects in biology, chemistry, economics, engineering, medicine, or physics. Prerequisite: Mathematics 111 or 131 or consent of instructor. (*Revised 4/24/96.*)

197S. Seminar in Mathematics. Intended primarily for juniors and seniors majoring in mathematics. Required research project culminating in written report. Prerequisites: Mathematics 103 and 104.

200. Introduction to Algebraic Structures I. 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 121. Prerequisite: Mathematics 104 or equivalent. (*Revised 2/3/98.*)

201. Introduction to Algebraic Structures II. Fields and field extensions, modules over rings, further topics in groups, rings, fields, and their applications. Prerequisite: Mathematics 200, or 121 and consent of instructor. (*Revised 2/3/98.*)

203. Basic Analysis I. Topology of R^n, continuous functions, uniform convergence, compactness, infinite series, theory of differentiation, and integration. Not open to students who have had Mathematics 139. Prerequisite: Mathematics 104.

204. Basic Analysis II. Differential and integral calculus in R^n. Inverse and implicit function theorems. Further topics in multi-variable analysis. Prerequisite: Mathematics 104; Mathematics 203, or 139 and consent of instructor. (*Revised 2/3/98.*)

205. Topology. Elementary topology, surfaces, covering spaces, Euler characteristic, fundamental group, homology theory, exact sequences. Prerequisite: Mathematics 104.

206. Differential Geometry. Geometry of curves and surfaces, the Serret-Frenet frame of a space curve, the Gauss curvature, Cadazzi-Mainardi equations, the Gauss-Bonnet formula. Prerequisite: Mathematics 104.

207. Topics in Mathematical Physics. Topics selected from general relativity, gravitational lensing, classical mechanics, quantum mechanics, string theory, critical phenomena and statistical mechanics, or other areas of mathematical physics. Consult on-line Course Synopsis description each semester.

211. Mathematical Methods in Physics and Engineering I. Heat and wave equations, initial and boundary value problems, Fourier series, Fourier transforms, potential theory. Not open to students who have had Mathematics 133 or 230. Prerequisites: Mathematics 114 or equivalent. (*Revised 2/26/96.*)

216. Applied Stochastic Processes. 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. Not open to students who have taken Mathematics 240. Prerequisite: Mathematics 135 or equivalent. C-L: Statistics 253. (*Renumbered 10/10/95; formerly MTH 240.*)

217. Introduction to Linear Models. Multiple linear regression. Estimation and prediction. Likelihood, Bayesian, and geometric methods. Analysis of variance and covariance. Residual analysis and diagnostics. Model building, selection, and validation. Not open to students who have taken the former Mathematics 241. Prerequisites: Mathematics 104 and Statistics 113 or 210. C-L: Statistics 244. (*Renumbered 10/10/95; formerly MTH 241.*)

218. Introduction to Multivariate Statistics. Multinormal distributions, multivariate general linear model, Hotelling's T^2 statistic, Roy union-intersection principle, principal components, canonical analysis, factor analysis. Not open to students who have taken the former Mathematics 242. Prerequisite: Mathematics 217 or equivalent. C-L: Statistics 245. (*Renumbered 10/10/95; formerly MTH 242.*)

221. Numerical Analysis. Error analysis, interpolation and spline approximation, numerical differentiation and integration, solutions of linear systems, nonlinear equations, and ordinary differential equations. Prerequisites: knowledge of an algorithmic programming language, intermediate calculus including some differential equations, and Mathematics 104. C-L: Computer Science 250.

(Mathematics 160 or 221, but not both, may count toward the requirements for a major or minor in mathematics; see the course description for Mathematics 160.).

224. Scientific Computing I. Well-posedness of ODEs; method, order, and stability. Methods for hyperbolic, parabolic, and elliptic PDEs. Structured programming and graphical user interfaces. Programming in C++, C, and Fortran. Prerequisite: Mathematics 103, plus some familiarity with ODEs and PDEs. (*Approved 9/13/96.*)

225. Scientific Computing II. Compressible fluid flow. Shock-capturing methods for conservation laws. Incompressible fluid flow. Vortex and probabilistic methods for high Re flow. Viscous Navier-Stokes equations and projection methods. Prerequisite: Mathematics 224. (*Approved 9/13/96.*)

228. Mathematical Fluid Dynamics. 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. Prerequisites: Mathematics 133 or 211 or an equivalent course. (*Approved 2/3/98.*)

233. Asymptotic and Perturbation Methods. 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 114 or equivalent.

Resources and Opportunities

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 250AB, Physics Building. ACPUB logins are not accepted on these machines, a Mathematics Account is required (see below). There are nine RedHat 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 UNIX® operating system, provide access to electronic mail and the World Wide Web; moreover, 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. File should be transferred to another networked computer via Secure Copy (`scp`), or through our web based file transfer system, called the Global Desktop Environment, located at http://www3.math.duke.edu/cgi-bin/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. Files may also be copied onto a DOS-formatted, high-density 3.5-inch floppy disk from any Mathematics computer in room 250AB. Insert the disk and issue the command `mount /mnt/floppy`. You may then copy your files to the directory /mnt/floppy (which is in fact your disk). BEFORE you take your disk out, be sure to issue the command `umount /mnt/floppy` or your files may not be written properly.

Electronic mail. Users can send and receive electronic mail through the department's network; a typical e-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://www3.math.duke.edu/cgi-bin/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. From the UNIX prompt, the command for sending mail is `mail userid@node`, where `userid` is the user login identity of the recipient, and `node` is the address of the machine one is mailing to. To read or send mail, the user can choose from the programs `mail`, `pine`, or `netscape`; one must be in the X-Windows program (`graphics screen`) to use `netscape`. The program `pine` is the easiest to use, and it is supported on the academic computing network.

World Wide Web (WWW): 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 `netscape`, 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.

The UNIX system has an on-line manual that can be called up by the `man` command. To find out how to use a particular command or program, type `man` (or `man -k` for a keyword search of all man pages) followed by the name of the command or program. To find out how to use the manual pages, enter `man man`. For references regarding Linux Machines, you should check out the Linux HOWTO's at

`http://sunsite.unc.edu/pub/Linux/docs/HOWTO`.

Remote Access. The Mathmatics 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, 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 resposibility 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.

Math-Physics Library

The Math-Physics Library has merged with Vesic Engineering Library, and is located in Room 210 Teer Building (660-5368, facsimile: 681-7595). 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.

Independent Study

An independent study course (i.e., Mathematics 191, 192, 193, or 194) offers a student the opportunity to pursue advanced study in a particular area of mathematics; alternatively, independent study may be pursued in an area in which courses are not usually offered by the department. (A student may not obtain credit by independent study for a course that is offered frequently.)

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 then submit a proposal to the Director of Undergraduate Studies. The proposal should be prepared in consultation with the supervising faculty member, and it should contain a title, a brief plan of study, and a statement of how the work will be evaluated. The proposal must be typewritten, and it must signed by both the student and the supervising faculty member. 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.

By faculty regulation, the student and supervising professor must meet at least once every two weeks during the fall or spring semester and at least once each week during a summer term.

Summer Opportunities

Many students participate in summer research programs and internships, mostly at other colleges and universities and in businesses and government agencies. Of particular note are "Research Experiences for Undergraduates," which are sponsored by the National Science Foundation and conducted by mathematics faculty at a number of colleges and universities. Links can be found at the department's web site.

Summer opportunities will be advertised on departmental bulletin boards and through electronic mail, usually in the late fall and early winter months; students should apply as early as practicable.

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 121.

Graduation with Distinction in Mathematics

Mathematics majors who have strong academic records are eligible for graduation with distinction in mathematics. The requirements are:

1. An overall GPA of at least 3.5 and a mathematics GPA of at least 3.7, maintained until graduation;
2. The completion of one or more math courses numbered 200 or above;
3. A paper demonstrating significant independent work in mathematics, normally written under the supervision of a tenured or tenure-track faculty member of the Department of Mathematics. Usually the paper will be written as part of an independent study taken in the senior year (Mathematics 193, 194).

A student must apply for graduation with distinction in the spring of the junior year. The application should be prepared according to the specifications for an independent study course application (see page 20), and the application should state the intention to pursue graduation with distinction in mathematics.

In the spring of the senior year, the Director of Undergraduate Studies will name a committee to evaluate the paper. The faculty will be given the opportunity to read the paper and make comments to the committee, and the candidate for distinction will present his or her work in a seminar intended for both faculty and students. The evaluation committee will determine whether distinction will be awarded, and if so, the level of distinction: Graduation with Distinction in Mathematics, Graduation with High Distinction in Mathematics, or Graduation with Highest Distinction in Mathematics. (*Approved 12/16/1996.*)

Recent Recipients of Latin Honors by Honors Project and Graduation with Distinction

Awardee	Title of Paper	Advisor
Andrew Dittmer (1998)	*The Circumradius and Area of Cyclic Polygons*	Hain
Alexander Brodie (1999)	*Studies in Set Theory*	Hodel
Jeffrey DiLisi (1999)	*The Biology and Mathematics of the Hypothalamic-Pituitary-Testicular Axis*	Reed
Garrett Mitchener (1999)	*Lattices and Sphere Packing*	Hain
Luis von Ahn (2000)	*Models of Set Theory*	Hodel
Carl Miller (2001)	*Exponential Iterated Integrals and Relative Solvable Completions of Fundamental Groups*	Hain

Competitions and Awards

Competitions

A half-credit Problem Solving Seminar (Mathematics 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. In 2000, each of the Duke Putnam team members, Kevin Lacker, John Clyde, and Jonathan Curtis was ranked among the *top fifteen* in the entire competition. From 1998 to 2001, four years in a row, the Duke team in the Mathematical Contest in Modeling was ranked Outstanding; the team members in 2001 were Samuel Malone, Carl Miller and Daniel Neill.

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. Recent recipients of the Karl Menger Award are listed below.

Year	Awardees
1998	Jonathan Curtis, Andrew Dittmer, and Noam Shazeer
1999	John Clyde, Jonathan Curtis, and Kevin Lacker
2000	John Clyde, Michael Colsher, and Kevin Lacker
2001	John Clyde, Nathan Curtis, Kevin Lacker and Carl Miller

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. Recent first–prize recipients are listed below.

Year	Awardees
1998	Andrew O. Dittmer (First Prize)
	James W. Harrington and Noam M. Shazeer (Second Prize)
1999	Christopher Beasley, Johanna Miller, and Garrett Mitchener
2000	Sarah Dean (First Prize)
	Jeffrey Mermin and Luis von Ahn (Second Prize)
2001	Carl Miller (First Prize)
	Michael Colsher and John Thacker (Second Prize)

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 below) and hosting a mathematics contest for high school students; the contest attracted 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.

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.

David Morrison (Duke)	*Stalking the Shape of the Universe*
J. H. Conway (Princeton)	*Some Tricks with String*
Persi Diaconis (Harvard)	*The Mathematics of Shuffling Cards*
Joseph Gallian (U. Minn. Duluth)	*Touring the Torus*
Robert Devaney (Boston)	*The Mathematics behind the Mandelbrot Set*
Donald Knuth (Stanford)	*Leaper Graphs*
Colin Adams (Williams)	*Real Estate in Hyperbolic Space*
Jeffrey Weeks (Minnesota)	*Visualizing Four Dimensions*
Lloyd N. Trefethen (Cornell)	*Computational Mathematics in the 1990's*
Underwood Dudley (DePauw)	*Formulas for Primes*
Lisa Fauci (Tulane)	*Modeling Biofilm Processes in a Moving Fluid*
Barry Cipra (Mathematical writer)	*Solved and Unsolved Problems in Grade School Math*
Frank Morgan (Williams, Princeton)	*Soap Bubble Geometry Contest*
Martin Nowak (Inst. for Advanced Studies)	*Fairness and Cooperation*
Sir Roger Penrose (Oxford University)	Science and the Mind

After Graduation: Educational and Professional Opportunities

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 Martina Bryant	Dean Gerald Wilson	Dean Kay Singer
02 Allen Building	116 Allen Building	303 Union West
684-2075 (Fax: 668-6393)	684-2865 (Fax: 684-3414)	684-6221 (Fax: 660-0488)
mbryant@asdean.duke.edu	gwilson@asdean.duke.edu	kay.singer@duke.edu

First-year students and sophomores interested in the health professions should see Dr. Milton Blackmon (telephone preferred, 684-6217; `blackmon@pmac.duke.edu`).

Actuarial Science

An actuary was once thought of as an insurance mathematician, but today an actuary is likely to be a manager or consultant applying quantitative thinking to business problems of all types. Actuaries earn professional status by developing a high degree of insurance and financial expertise, both on the job and by passing examinations administered by the Casualty Actuarial Society and the Society of Actuaries (see pages 12-13 of this *Handbook*).

Although successful actuaries have come from diverse college majors, the obvious candidates are those demonstrating skill in mathematics, verbal communication, and leadership. Indeed, the problems an actuary is likely to face may often involve business, social, and political considerations. Thus there may be more than one solution, or there may be no practical solution at all. Insurance companies actively recruit Duke mathematics majors, and each year several students accept positions with such firms.

Judging from the amount of material received from major companies, actuaries are in substantial demand; a number of announcements, booklets, and pamphlets are available in 121A Physics, including application forms for actuarial examinations.

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 (M.A.T.) Program, a one-year program following graduation. The M.A.T. Program allows qualified students to begin study during their final undergraduate semester and has substantial scholarship support available for qualified students.

For information on the Program in Education, contact Ginger Wilson (213 West Duke Building, 660-3075). For information on the Master of Arts in Teaching Program, see Rosemary Thorne (213 West Duke, 684-4353, `rrt@acpub.duke.edu`). For advice about these programs, from a representative of the Mathematics Department, contact Jack Bookman (027A Physics Building, 660-2831, `bookman@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 (see **Employment in the Department**, page 22).

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 first 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. The Director of Undergraduate Studies receives material on graduate programs in mathematics from all over the country; this material is posted near the departmental office (121A Physics) or kept on file there. Frequently, much information about these programs is available through the World Wide Web; information about Duke's program is available at `http://www.math.duke.edu`.

Other Opportunities

Graduate school in statistics, operations research, computer science, and mathematics-related scientific fields. Some information about graduate programs in fields closely related to mathematics is available in 121 Physics. Students are urged, however, to consult with corresponding Duke departments and with prospective graduate programs.

Mathematical Occupations. For an evaluation of professional opportunities in actuarial science, computer science, mathematics, operations research, and statistics, a section titled "Computer, Mathematical, and Operations Research Occupations" from the *Occupational Outlook Handbook*, published by the U.S. Department of Labor, is available on the internet, at `http://stats.bls.gov/ocohome.htm`, or in hardcopy in Room 121A Physics. The complete *Occupational Outlook Handbook* is available for examination in the Depository of U.S. Documents in Perkins Library.

United States Government. A number of U.S. Government agencies hire graduates with strong preparation in mathematics. Information from a number of these agencies (such as those listed below) is kept on file in 121A Physics.

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

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 indicated by mathematical training: clear, logical thinking; ability to attack a problem and find the best solution; prompt attention to daily work; sureness in handling 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.

Some information about opportunities in the finance, industry, and management is on file in 121A Physics.

Career Center. The Career Center (located in Room 110, Page Building) is an excellent source of information on career opportunities in mathematics. Kara Heisey (`kara.heisey@duke.edu`) is the career specialist in mathematics and related fields; appointments can be made by calling 660-1050.

The Career Center administers electronic 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://career.studentaffairs.duke.edu`.

Summary of Information on File. Information on opportunities for mathematics majors and minors after graduation is on file in 121 Physics as follows:

- Internships, summer programs, etc.
- Actuarial examinations
- Careers in actuarial science and statistics
- Employment opportunities with corporations
- Employment opportunities with the U.S. Government
- Graduate school in business school and management
- Graduate school in science
- Graduate school in computer science, operations research, and statistics
- Careers in mathematics
- Graduate school in mathematics

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:

1998

- Actuarial technician, State Auto Insurance Co.
- Financial analyst, Lehman Brothers
- High school teacher
- Investment banking analyst, Wheat First
- Project manager, Captial One Financial Corp.

1999

- Actuary, William M. Mercer
- Information technology consultant, IBM
- Research analyst, The Brattle Group
- Software design engineer, Microsoft Corp.
- Software developer, Lucent Technologies

2000

- Program manager, Microsoft Corp.
- Information technology consultant, Amer Management Systems
- Project manager, Capital One
- Software engineer, IBM
- Ensign, US Navy

2001

- Derivatives analyst, Goldman Sachs
- Investment banking analyst, Lehman Brothers
- Computer Programer, ViASIC
- Information technology consultant, Pricewaterhouse Corp.
- Analyst, Accenture (formerly Andersen Consulting)

General Information

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 department of physics.

Faculty Member	Research Area
W. K. Allard (Villanova, Brown)	Scientific computing
P. S. Aspinwall* (Oxford)	String theory
J. T. Beale (CalTech, Stanford)	Partial differential equations, fluid mechanics
P.Berman (Washington U, NCSU)	Field theory and polynomials
A. L. Bertozzi* (Princeton, Princeton)	Nonlinear partial differential equations, applied mathematics
M. Bowen (U. Nottingham, U. Norringham)	Degenerate diffusion equations, scientific computing, free boundary problems. from fluid mechanics
R. L. Bryant (N. C. State, UNC)	Nonlinear partial differential equations, differential geometry
A. Degeratu (U. Bucharest, MIT)	Differential geometry, algebraic geometry, mathematical physics
E. Fuller (U. Georgia, U. Georgia)	Knot theory and contact geometry
K. Glasner (U. Wyoming, U. Chicago)	Partial differential equations
C. Haase (Tech. U. Berlin, Tech. U. Berlin)	Convex and discrete geometry
R. M. Hain (U. Sydney, U. Illinois)	Topology of algebraic varieties, Hodge theory
J. L. Harer (Haverford, Berkeley)	Geometric topology, combinatorial group theory
R. E. Hodel (Davidson, Duke)	Set-theoretic topology
M. Huber (Harvey Mudd C., Cornell U.)	Probability theory and stochastic processes

N. Ju (Indiana)	Applied mathematics, numerical analysis
C. Kim (U. Seoul, Texas A & M)	Numerical analysis
J. W. Kitchen (Harvard, Harvard)	Functional analysis
D. P. Kraines (Oberlin, Berkeley)	Algebraic topology, game theory
G. F. Lawler (Virginia, Princeton)	Probability, statistical physics
H. E. Layton (Asbury, Duke)	Mathematical physiology
J. Matthews (NCSU, NCSU)	Applied mathematics, scientific computing
L. C. Moore (N. C. State, CalTech)	Functional analysis
D. R. Morrison (Princeton, Harvard)	Algebraic geometry, mathematical physics
W. L. Pardon (Michigan, Princeton)	Algebra, geometry of varieties
O. Patashnick (Brandeis, Chicago)	Arithmetic geometry
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
B. Rider (MIT, Courant)	Probability theory and stochastic processes
M. Romeo (Tulane, Brouwn)	Dynamical systems and ergodic theory, mathematical biology
A. Rosenshon (U. Maryland, U. Maryland)	Algebraic geometry
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
S. P. Shipman (U. Arizona, U. Arizona)	Differential equations, spectral theory, asymptotic analysis
D. A. Smith (Trinity, Yale)	Numerical analysis
M. A. Stern (Texas A & M, Princeton)	Geometric Analysis
J. A. Trangenstein (U. Chicago, Cornell)	Nonlinear conservation laws, environmental clean-up, shocks in fluids
A. Vartanian (McGill U., U. de Bourgogne)	Partial differential equations
S. Venakides (Nat'l Tech. U. Athens, NYU)	Partial differential equations, integrable systems
T.Washington (Spelman C., U. Connecticut)	Partial differential equations, mathematical biology
T. P. Witelski (Cooper Union, CalTech)	Differential equations, mathematical biology, perturbation methods
I. Zharkov (Moscow Inst. of Phy. & Tech, U. Penn)	Algebraic geometry
X. Zhou (Chinese Acad. of Sciences, Rochester)	Partial differential equations, integrable systems

Undergraduate Calendar

Fall 2001

August	
21	Tuesday—New undergraduate student orientation
27	Monday, 8:00 A.M.—Fall semester classes begin; Drop/Add continues
September	
7	Friday—Drop/Add ends
October	
7	Sunday—Founders' Day
12	Friday, 7:00 P.M.—Fall break begins; Last day for reporting midsemester grades
17	Wednesday, 8:00 A.M.—Classes resume
24	Wednesday—Registration begins for spring semester, 2002
26–28	Friday–Sunday—Parents' Weekend
November	
16	Friday—Registration ends for spring semester, 2002
17	Saturday—Drop/Add begins
21	Wednesday, 12:40 P.M.—Thanksgiving recess begins
26	Monday, 8:00 A.M.—Classes resume
December	
6	Thursday, 7:00 P.M.—Fall semester classes end
7–9	Friday–Sunday—Reading period
10	Monday—Final examinations begin
15	Saturday, 10:00 P.M.—Final examinations end

Spring 2002

January	
8	Tuesday—Registration and matriculation of new undergraduate students
9	Wednesday, 8:00 A.M.—Spring semester classes begin; Drop/Add continues
21	Monday—M. L. King holiday: no classes
23	Wednesday—Drop/Add ends
February	
22	Friday—Last day for reporting midsemester grades
March	
8	Friday, 7:00 P.M.—Spring recess begins
18	Monday, 8:00 A.M.—Classes resume
27	Wednesday—Registration begins for fall semester, 2002, and summer, 2002
April	
12	Friday—Registration ends for fall semester, 2002; summer 2002 registration continues
13	Saturday—Drop/Add begins
24	Wednesday, 7:00 P.M.—Spring semester classes end
25–28	Thursday—Sunday—Reading period
29	Monday—Final examinations begin
May	
4	Saturday, 10:00 P.M.—Final examinations end
10	Friday—Commencement begins
12	Sunday—Graduation exercises; conferring of degrees