GRADUATE PROGRAMS IN MATHEMATICS
University of New Hampshire
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1. INTRODUCTION

This handbook has been prepared by the Department of Mathematics and Statistics in order to provide information about its programs. All graduate programs must meet the requirements of the Graduate School which are published in the University of New Hampshire Graduate Bulletin. This handbook defines the specific departmental requirements for each of its programs; in each case the broader requirements of the Graduate School must also be fulfilled.

The Department of Mathematics and Statistics offers programs leading to the following degrees:

- M.S.T. degree in mathematics
- M.S. degree in mathematics (options in pure mathematics, applied mathematics, or statistics)
- Ph.D. degree in Mathematics
- Ph.D. degree in Statistics
- Ph.D. degree in Mathematics Education
- Ph.D. degree in Integrated Applied Mathematics

In general, the Master's degree programs offer the student a high level of professional training for employment as well as appropriate preparation for entering programs leading to the Ph.D. degree. The Ph.D. programs are designed primarily to lead to a career in post-secondary school teaching and research.

Our graduate programs are intended to have limited enrollments so that a student has the opportunity of working closely with the faculty in their areas of expertise.

2. PROGRAMS OF STUDY

Overarching Point of View.

The components of a graduate degree program should coalesce and thereby enable graduate students to develop professionally and to become fully qualified members of the mathematical sciences community with skills and knowledge that are appropriate for contributing to that community. To this end, the Department of Mathematics and Statistics expects that its graduates will have attained the following:

with a master's degree (MS) in mathematics: (options in pure mathematics, applied mathematics, or statistics)

- A basic knowledge of the mathematical sciences (as a whole) and
- sufficient depth of experience and knowledge to pursue a doctoral degree;

with a professional master's (MST) degree:

- *depth and knowledge of the mathematical sciences beyond the bachelor's degree level, and*
- *professional and pedagogical content knowledge in mathematics education in order to provide leadership and direction in K-12 mathematics reform;*

with the doctoral (Ph.D.) degree:

- A comprehensive base of knowledge of the mathematical sciences,
- skills and experiences that enable continued professional growth, and
- experience in creating and writing a work of originality and creativity that is worthy of publication within a field of the mathematical sciences.

First-Year Assessment for all programs.

Intent. For a student making the transition from a bachelor's degree program (or a master's degree program at another institution), the first-year assessment is intended to provide information which will insure that the student is properly advised and that the Graduate Program Committee is fully informed of the progress and potential of each student.

Nature. The graduate program committee in collaboration with faculty who are teaching courses in which the first-year students are enrolled will collectively evaluate the prospects and progress of all first-year students. This evaluation will occur early in the spring semester, as soon as grades and teaching evaluations from the fall are available.

Evaluation. The result of this evaluation will be conveyed (in writing) to the individual student by mid-semester of the spring semester. This evaluation will include an assessment of teaching activities, when this applies.

COMPONENTS of:

Master of Science (MS) degree in mathematics: option in pure mathematics.

BASIC KNOWLEDGE OF THE MATHEMATICAL SCIENCES

For information about University requirements for the Master's degree, see the Academic Regulations and Degree Requirements section of the Graduate Catalog.

Purpose. This component is intended to provide an intensive study in several areas of mathematics and to give an overview of the scope of the mathematical sciences.

Thus, the MS degree program in mathematics is designed for the student who may wish to explore mathematics in preparation for pursuing the doctoral degree in mathematics or in mathematics education. The program also allows a student to concentrate on a particular field of mathematics in greater depth than is possible in the undergraduate major and introduces the student to the skills that are necessary for pursuing the doctoral degree.

Nature. The program requires that the student satisfactorily complete ten approved courses, usually chosen from MATH courses numbered 801-899 and 931-978 or IAM courses 830-962, with the following stipulations:

- At least five of these ten courses must be chosen from Math 931-978 or 900-level IAM classes.
- At least three must be chosen from MATH courses 931-956;
- the courses MATH 900-929 may not be used to satisfy course requirements;
- with the approval of the graduate program committee (and in some cases the Graduate School) a student may be allowed the following exceptions for at most two courses: (i) graduate courses transferred from another university or (ii) non-MATH courses taken at UNH.

Students are encouraged to take courses in a wide range of mathematical disciplines, including mathematics education, applied mathematics and statistics, since this will enrich the mathematical foundation on which future career, as well as academic, decisions will be made. The departmental colloquium series and other activities within the department and the college provide and environment in which the student can continue to develop.

The Master's Examination.

Intent. This experience is intended to demonstrate that the student has achieved a breadth and depth of knowledge that is consistent with the Department's expectation for earning the MS degree in mathematics. As such, this is not to be viewed as a "final examination" on the courses that the student has taken. Rather, the examiners attempt to assess the level of mathematical development that the student has achieved as a result of the educational experience.

Nature. The examination is an oral examination, usually of two hours in duration, that is administered by a three-person master's examination committee. Based on nominations submitted by the student, the graduate program coordinator recommends three graduate faculty members from the Department of Mathematics and Statistics to the dean of the Graduate School, who in turn appoints the committee members.

The format of the examination is determined by the appointed committee. Often examination questions will probe for the depth of student understanding and development. The student is encouraged to seek advice from the committee while preparing for the examination.

The committee will convey the committee's evaluation to the graduate program coordinator, who has full responsibility for communicating the results to the Graduate School.

Evaluation. The master's examination committee, in private session, will make one of the following judgements:

- The student has PASSED WITH DISTINCTION;
- the student has PASSED;
- the student has FAILED.

This decision is conveyed to the student immediately. The Graduate School allows only two opportunities for passing the master's examination. Two failures will result in the student's dismissal from the MS degree program in mathematics.

Notes.

1. The masters' examination for each student will be announced to the department.
2. A student may petition for a waiver of the masters' exam if he/she has completed all coursework, satisfied all Graduate School requirements for the degree, and has passed any two of the doctoral comprehensive exams in Algebra, Analysis, or Topology.
3. The M.S. degree program is designed to be completed in two years. The Graduate School requires that the program be completed within a period of six years.
4. As in all graduate programs, a student who receives a grade lower than a B- in nine or more credits of graduate course work will be dismissed from the Graduate School.
5. Certain administrative tasks, such as filing an Intent-to-Graduate form, must be completed in the semester when the student expects to graduate.

COMPONENTS of:

Master of Science (MS) degree in mathematics: option in applied mathematics.

BASIC KNOWLEDGE OF THE MATHEMATICAL SCIENCES

For information about University requirements for the Master's degree, see the Academic Regulations and Degree Requirements section of the Graduate Catalog.

Program Requirements for the Applied Mathematics Option:

- PHYS 931, Mathematical Physics
- IAM 933, Applied Functional Analysis
- An approved 2-course sequence, such as
  - MATH 967/MATH 977 (Topics in Applied Mathematics I-II)
  - IAM 830 – IAM 932 (Intro to ODE's, Intro to PDE's)
  - IAM 961 – IAM 962 (Numerical Analysis I-II)
  - Any IAM 2-course specialization sequence, for example, the sequences in Dynamical Systems, Fluid Dynamics, or Plasma Physics.
- MATH 899 (Master's thesis: 6 credits) or MATH/IAM 898 (Master's Project: 3 credits)
- Four electives (12 credit hours) in the thesis option, one of which is an approved technical elective, generally chosen from Statistics courses or courses in other departments. Five electives (15 credit hours) in the project option, two of which are approved technical electives.

Notes.

1. If a student in the Ph.D. program in integrated applied mathematics wishes to leave that program, the masters' program in applied mathematics is an appropriate option.
2. Various Graduate School requirements apply. These include, but are not limited to, the following:
   - 30 credit hours of approved course work
   - For students in the Thesis option: a minimum of six thesis credits (MATH 899), and a maximum of ten.
   - The master's thesis must be approved by a committee including the student's research advisor and two members of the graduate faculty,

typically chosen from the department. The thesis must be prepared according to Graduate school requirements and two copies of the thesis must be submitted to the Graduate School.

- For students in the Project option: a minimum of three project credits (MATH 898) and a maximum of six. The project must satisfy the Graduate School requirements for a "capstone experience" as part of the M.S. degree. The completed project must be judged satisfactory by a committee of at least two faculty in the student's program. The project must be approved by the IAM Graduate Program Director.
- Students in the project option will present their work in a project seminar (20-30 minute presentation). They will complete a research report in the form of a journal article, typically 20-40 pages.

3. The student must present a written proposal which must list all of the courses that the student will take, with a schedule showing when each course will be taken. This proposal must be presented to the Graduate Program Coordinator in the Department of Mathematics and Statistics no later than the start of the student's second semester.

   The proposal must represent a coherent program leading to completion of all program requirements. The proposal and any subsequent changes must be approved by a committee including all faculty in applied mathematics and the graduate program coordinator.

   For students who started in the IAM program and changes to the MS program in applied mathematics, the proposal must be presented and approved no later than the end of the semester during which the change occurred.

COMPONENTS of:

Master of Science (MS) degree in mathematics: Statistics option

Applicants to this program typically have an undergraduate degree in the mathematical sciences, engineering or one of the physical, biological and social sciences. The program allows for considerable flexibility reflecting preparation for a variety of professional opportunities in statistics and related fields, as well as preparation for entry into a Ph.D. degree program in statistics or one with a concentration in statistics. Applicants to this program must have completed mathematical coursework through multivariate calculus, and basic linear algebra.

Degree Requirements: The program requires ten semester courses approved by the department, which includes completion of a Master's Project (MATH 898) consisting of the substantial application of statistical methodology to a real problem. Courses in the program will normally be taken from the department's statistics courses, numbered 837 through 979, and must include MATH 839, MATH 840, MATH 855 and MATH 856, unless equivalent courses are taken prior to enrollment in the program. At most three courses may be taken from approved courses offered in other departments.

The Master's Project (MATH 898) is conducted under the supervision of a faculty advisor and may be awarded 3 or 6 credits, depending on the level of research and the methodological development that is required. A Master's Committee, consisting of at least two members of the statistics faculty, oversees the student's progress and determines the appropriateness of the credits earned for the Master's Project. The project concludes with a written report and a departmental colloquium presentation that meets the approval of the Master's Committee.

RATIONALE

The program provides flexibility to accommodate a broad group: applicants with an undergraduate mathematics degree, an undergraduate science degree, and applicants from industry who seek professional development.

The program also provides flexibility to work toward offering courses over the internet.

COMPONENTS of:

Master of Science for Teachers (MST) degree in mathematics.

BASIC KNOWLEDGE OF THE MATHEMATICAL SCIENCES

Purpose. The program leading to the Master of Science for Teachers (MST) degree in mathematics is designed to enable experienced teachers, primarily at the secondary school level, to deepen and broaden their mathematical knowledge in core areas of geometry, algebra and analysis, to explore additional content areas of mathematics, and to provide opportunities for teachers to consider alterative approaches to pedagogy.

Nature. The program requires that the student satisfactorily complete 30 credits of coursework approved by the Department of Mathematics along with successful completion of a concluding experience.

Required Courses.

MATH 900 - Bridges From Classroom to Mathematics (1 credit)
MATH 905 - Euclidean and Non-Euclidean Geometries from a Synthetic Perspective
MATH 906 - Analytic and Transformational Geometry
MATH 909 - Probability and Statistics for Teachers
MATH 913 - Graph Theory and Discrete Mathematics
MATH 915 - Algebraic Structures
MATH 918 - Analysis – Real Numbers and Real Functions
MATH 925 - Problem Solving Seminar

Elective Courses.

MATH 902 – Classroom Practicum
MATH 910 – Topics in Mathematics Education
MATH 914 – Topology for Teachers
MATH 916 – Number Theory
MATH 917 – Proof and Problem Solving
MATH 920 – History of Mathematics
MATH 928 – Topics in Mathematics
MATH 929 – Directed Reading

Assessment.

In addition to successfully completing **30 graduate credits,** MST degree candidates will be required to complete a concluding experience in which they:

- Develop a **mathematical portfolio,** with specific components due annually;
- Successfully complete a **comprehensive problem set** in conjunction with a problem-solving seminar.

Remarks. The MST degree program is designed to be completed in 2 to 3 years.. The Graduate School requires that the program be completed within a six-year period. As in all graduate programs, a student who receives a grade lower than B– in nine or more credits of graduate course work will be dismissed from the Graduate School.

It is possible to enroll in MST courses without enrolling in the MST degree program. This option is particularly popular with individuals who are interested in obtaining certification to teach secondary school mathematics, since MST courses have traditionally satisfied the content area requirements in teacher certification programs. Please note that the MST Program does **not** grant teaching certification or licensure.

COMPONENTS of:

Ph.D. degree in mathematics

1. COMPREHENSIVE BASE OF KNOWLEDGE

Purpose. This component is intended to provide a mathematical foundation (1) from which the student has enough information to make decisions concerning a minor and major area of study and yet (2) that is broad enough so that the student may communicate with the mathematical community at large.

Nature. Formally, the Department offers courses of study. Informally, the Department provides an environment and resources that promote the development of the desired attributes, skills and knowledge.

<u>Required Courses</u>.

MATH 951-952. Algebra I and II,
MATH 953-954. Analysis I and II,
MATH 955-956. Topology I and II.

<u>Elective Courses</u>.

Student in the Ph.D. degree program in Mathematics must take at least seven courses from the following list so that at least two sequences of the form 96N-97N are included:

MATH 961, 971. Topics in Algebra I, II
MATH 963, 973. Functional Analysis, Topics in Operator Theory
MATH 964, 974. Topics in Analysis I, II
MATH 965, 975. Topics in General Topology I, II
MATH 966, 976. Topics in Algebraic Topology I, II
MATH 967, 977. Topics in Applied Mathematics I, II
MATH 968, 978. Topics in Mathematics Education I, II
MATH 969, 979. Topics in Probability and Statistics I, II

One sequence of courses will likely lead to a minor program of study; a second would normally lead to additional reading courses and the thesis area.

A student may petition to waive formal enrollment in a particular course or courses by passing the appropriate section of the comprehensive examination or by documenting that an equivalent course was taken at another university.

Assessment.

First-Year Assessment. See MS degree program.

The Comprehensive Examination.

Intent. The comprehensive examination is intended to judge the knowledge and the aptitude of the student in several areas of the mathematical sciences. The examination is not intended to signify the end of coursework; rather, it is intended to measure the depth of the student's understanding and mastery of a broad spectrum of mathematical disciplines.

Philosophically, the comprehensive examination measures the competence of the student in those areas that the Department expects any Ph.D. in mathematics or mathematics education to understand. Practically, it is used to judge whether the student has the background and the ability to complete the program and, thereby, is used to determine whether the student will be permitted to continue in the program.

Nature. The examination is a series of written examinations consisting of four parts, three required and one elective.

The required exams are Algebra, Analysis, and Topology. The elective exam could be Representation Theory (advanced algebra), Functional Analysis, or Algebraic Topology. Other electives are possible, depending on student and faculty interest, with the approval of the Graduate Program Coordinator.

A comprehensive examination committee will be appointed by the Graduate Program Committee to formulate the examination parts and to evaluate student performance.

Evaluation. The comprehensive examination committee will arrive at one of the following judgments:

- The student has PASSED;
- the student has NOT PASSED and is thereby assigned an additional assessment task (most often, but not always, in the form of repeating certain portions of the examination at the next opportunity);
- the student has FAILED and will be excluded from the program (typically after not passing an exam on the second attempt).

The graduate program coordinator will contact students in May, to ask which exams they intend to take. Students have access to syllabi and sample questions for most exams.

The graduate program coordinator has responsibility for administration of the comprehensive examination and for conveying the results of the examination (in writing) to the student.

Notes. The comprehensive examinations will be offered each August, usually during the last week before classes begin.

A student who enters the program with a bachelor's degree must begin the comprehensive examinations in August following the second year; a student entering with a master's degree must begin the comprehensive examinations after one year of study.

Remarks. The Graduate School requires that a student make "satisfactory progress" toward the completion of the degree program in order that a graduate assistantship position be continued; this "review" takes place at the mid-point of each semester. In particular, if a student does not follow the suggested timeline for the exams, or if a student fails a particular exam two times, renewal of a TAship is in jeopardy, and expulsion from the doctoral program may result.

2. PROFESSIONAL DEVELOPMENT

The student's guidance committee will normally serve as a steering committee for carrying out the following components of professional development. The three-person Guidance Committee consists of an "adviser" in the major area of study, a second faculty member with expertise in the major area and the faculty member who will direct the minor program. The adviser would normally become the research adviser for the student's dissertation work.

The graduate program coordinator serves informally in the capacity of a "guidance committee" until a formal committee is appointed (by the dean of the Graduate School upon the recommendation of the graduate program coordinator).

a. Program of Study in a Minor.

Purpose. The Ph.D. minor program of study is intended to enhance the student's understanding in a secondary discipline within the mathematical sciences. As such, this program is expected to enrich the student's fundamental background in the mathematical sciences and to add breadth to the student's professional preparation. This is viewed as a strength, especially for those graduates who might seek employment at institutions that are primarily interested in undergraduate teaching potential.

Nature. The minor program of study is an individually designed program, which is developed by the student in consultation with the student's adviser and a faculty member who is expected to direct the study. The student and advisor select a Minor committee, consisting of the minor advisor and two other faculty. One faculty member may be chosen from outside the Department of Mathematics and Statistics.

A proposal for the minor program will be presented to the Graduate Program Committee for approval and will become part of the student's file. The objectives of the program will be clearly identified from the start. The purpose here is to provide a process that insures that a minor program has been thoughtfully designed and that the student has a clear idea of what it is and what is expected. In particular, this experience should not be open-ended.

The program will normally include a sequence of courses that culminates with a final project of some sort (typically a presentation before the department) in which the student shares the acquired expertise with a wider community.

The area of study for the minor program might be one that is quite different from the major area so that the student can demonstrate a breadth of knowledge. Or, the area might be one that further enriches the major area (for example, mathematics education and psychology of learning). The area of study and the faculty adviser may reside in a department other than mathematics.

Assessment. Completion of the minor program will be determined by the Ph.D. Minor Committee. The student may ask for a status report at any time (in order that progress toward completion of the minor program might be clear to both the committee and the student).

Remarks. The Ph.D. Minor component is a departmental requirement. It must be completed before a student can advance to candidacy with the Graduate School.

b. Teaching Experience and Development.

New graduate students are required to attend the Departments' "micro-teaching session," held each August during the last week before classes being. In advance of the session, each new TA will be assigned a particular topic from the course s/he will assist. Each TA will give a 5-minute presentation in the topic, before an audience of experienced TAs and faculty. After this brief talk, there will be a discussion among the group, including constructive criticism and comments.

The micro-teaching session is intended solely to introduce new TAs to issues that arise in college teaching. New TAs should not feel intimidated by this requirement. The atmosphere of the teaching session is relaxed and informal.

New TAs may request that a faculty member visit their classroom to observe the class. This can be followed by an informal discussion between the professor and the TA.

As part of UNH policy, each instructor is evaluated by his or her students near the end of the semester. Evaluations are reviewed by the department chair and graduate program coordinator as part of deliberations about renewal of TAships for the following year. TAs are encouraged to review their evaluations thoughtfully. TAs should keep their evaluations as part of a developing teaching portfolio.

Graduate students are encouraged to participate in informal opportunities to discuss the teachings of mathematics and general issues of collegiate teaching. As one example, experienced TAs have recently organized and run a 1-credit seminar in Best Teaching Practices. TAs are encouraged to join in Graduate School events to improve their teaching.

TAs should be aware of various graduate school and college teaching awards.

3. RESEARCH AND PUBLICATION

Doctoral students are required to carry out a research investigation that results in the creation of a written work originality, worth of publication in a field of the mathematical sciences.

a. The Ph.D. Major Presentation

The Ph.D. Major Presentation enables the student to demonstrate that a depth of knowledge in a major area of study has been attained. A successful presentation shows that the student is qualified to carry out research in the major area of specialization. The presentation takes on different forms, depending on whether the student will work in pure or applied mathematics, statistics, or mathematics education.

The student, after consultation with the Graduate Program Coordinator, will chose the Ph.D. Major Committee, including the Major (dissertation) advisor, a second faculty member, in a closely related field, and the Ph.D. Minor advisor.

The student will give a one-hour presentation of the Ph.D. Major work, with an opportunity for question from those in attendance. The date, time and location of the presentation, together with the title and abstract, should be communicated to the Graduate Program Coordinator two weeks in advance of the presentation. The Coordinator will announce details of the Presentation to encourage the broadest possible attendance.

After a period of general questions following the Major Presentation, the student's Major Committee may question the student further in private session.

Successful completion of the Ph.D. Major requires the unanimous decision by the Major committee that the student has passed the presentation.

This presentation (a part of a qualifying exam) is a requirement of the Graduate School, but it is defined by the department. The concluding presentation serves two purposes: it encourages and broadens the scholarly activity within the department, and it beings the research component of the doctoral degree with an activity that parallels its completion (the dissertation defense).

When the student has completed the qualifying examination and the language competency, the Graduate School "advances" the student (upon notification by the graduate program coordinator) to the status of "Candidate for the Ph.D. degree". There is a specific timeline that is set by the Graduate School and within which advancement to candidacy must be completed.

b. The Dissertation Defense.

<u>Intent</u>. The defense provides the candidate with the opportunity to present the results of the thesis. The public format provides a forum in which the candidate may "defend" the research results before a panel of knowledgeable colleagues.

<u>Nature</u>. The defense consists of a colloquium presentation for the University community.

Evaluation. The doctoral committee (formed by adding two additional graduate faculty members to the three-person guidance committee) judges the merits of the work on the basis of its originality and its publishability in research journals in the area of specialization. A majority vote of the doctoral committee is required for a successful dissertation defense.

Notes. The dissertation defense is a requirement of the Graduate School.

Remarks. It is this component which sets the Ph.D. degree apart from all other academic degrees.

COMPONENTS of:

Ph.D. degree in Mathematics Education

1. COMPREHENSIVE BASE OF KNOWLEDGE

Purpose. This component is intended to provide a strong mathematical foundation as well as a foundation in mathematics education research. The mathematical foundation should provide the student with information to make a decision concerning a minor area of study, and broad knowledge so that the student may communicate with the mathematical community at large. The foundation in mathematics education should provide the student with knowledge to communicate about multiple areas of education and to conduct research in a particular area of study.

Nature.

Required Courses.

MATH 951-952	Algebra I and II
MATH 953-954	Analysis I and II
MATH 955	Topology I
MATH 958	Introduction to Mathematics Education
MATH 968A	Theories of Learning and Teaching Mathematics
MATH 986B	Curriculum and History of Mathematics Education
MATH 978	Topics in Mathematics Education (must enroll in this course for at least 2 semester)
Research Methods	Once course in either *quantitative* or *qualitative* research methods, although one of each is encouraged. Current course offerings in research methods include: Qualitative Methods: MATH 835/MATH 840/EDUC 981 Qualitative Methods: EDUC 941/EDUC 982

Elective Courses.

Student in the Ph.D. degree program in Mathematics Education must take at least three additional courses from the following list.

MATH 961, 971. Topics in Algebra I, II
MATH 963, 973. Functional Analysis, Topics in Operator Theory
MATH 964, 974. Topics in Analysis I, II
MATH 965, 975. Topics in General Topology I, II
MATH 966, 976. Topics in Algebraic Topology I, II
MATH 967, 977. Topics in Applied Mathematics I, II
MATH 969, 979. Topics in Probability and Statistics I, II
MATH 998H Reading Course in Mathematics Education (students may register multiple times when different topics are offered

Other appropriate courses are offered through the Department of Education (with advisor approval).

A student may waive formal enrollment in any required courses by passing the appropriate comprehensive examination or by documenting that an equivalent course was taken at another university.

Assessment.

First-Year Assessment. First year assessment is the same for all Ph.D. programs in the department, and is described earlier in this handout.

The Comprehensive Examination. The comprehensive examinations are intended to judge the knowledge and aptitude of the students in several areas of the mathematical sciences as well as mathematics education. They are used to judge whether the student has the background and ability to complete the program, and are used to determine whether the student will be permitted to continue in the program.

Each Mathematics Education Ph.D. candidate will take four exams, three required and one elective. Typically, the student will take two exams after the first of second year of study, and an additional two exams after the second or third year of study. This may vary depending on the student's background. Comprehensive exams are administered in mid-August of each school year.

- Three required exams: Algebra, Analysis, General Mathematics Education
- One elective may be chosen by the student: Advanced Mathematics Education, Advanced Algebra, Topology, Algebraic Topology, Advanced Complex Analysis, Functional Analysis, Applied Mathematics, Probability and Statistics (Technical or Theoretical).

The mathematics education exams are written over 3 to 4 weeks time. All other exams are written on campus with a predetermined time limit (typically 2 to 3 hours).

A comprehensive exam committee will be appointed by the Graduate Program Committee to formulate, proctor and evaluate the exams.

<u>Evaluation:</u> The comprehensive exam committee will arrive at one of the follow judgments for each exam taken during an examination period:

- The student has PASSED the exam;
- The student has NOT PASSED the exam and must repeat the exam during the next exam period;
- The student has FAILED and will be excluded from the program (typically after not passing exam on the second try).

The graduate program coordinator has responsibility for conveying the results of the exams (in writing) to the student.

2. PROFESSIONAL DEVELOPMENT

The Guidance Committee is typically chosen by the Ph.D. candidate (in consultation with faculty) about the time that the student is completing comprehensive exams. The three-person committee consists of the MAJOR ADVISOR (faculty member of the department who agrees to direct the student's dissertation research), the MINOR ADVISOR (university faculty who agrees to direct the student's minor program- may not be a member of the department), and another university faculty member with expertise in the major area of study.

Minor Program of Study.

Purpose: The minor program of study is intended to enhance the student's understanding in a secondary discipline within the mathematical sciences or within educational research. As such, this program is expected to add breadth to the student's professional preparation.

Nature: The minor program of study is an individually designed program which is developed by the student in consultation with the student's major advisor and a faculty member who will direct the minor program of study (minor advisor).

A proposal for the minor program of study will be presented to the three-member Guidance Committee for approval prior to the start of the minor. The objectives of the minor program will be clearly identified and thoughtfully designed. The program will normally include a sequence of courses that culminates in a final project- typically a written paper and a formal presentation to the department- so that the student may share the acquired expertise with a wider community.

The area of study for the minor program should be different from mathematics education research so that the student can demonstrate a breadth of knowledge (e.g. topology, complex analysis, or applied mathematics). Alternately, the area of study might be one that further enriches the major area (e.g. psychology of learning, ethnographic research methods, or statistical methods for analyzing mathematics placement test data).

Assessment: The minor program of study must be completed and must meet the approval of the Guidance Committee before the study may be advanced to candidacy.

Teaching Experience.

Purpose: The teaching component is intended to provide all students with experiences interacting with undergraduates in the mathematics classroom, to develop an awareness of pedagogical issues in the teaching and learning of mathematics, and to explore resources to enhance teaching effectiveness. Most graduates from the Ph.D. program will find employment in higher education settings in which teaching is a major responsibility. Having opportunities to teach and to develop one's teaching skills are invaluable for future employment possibilities.

Nature:

- Teach or TA departmental mathematics courses for at least 2 semesters while in the Ph.D. program;
- At least one semester teaching own course (but perhaps with faculty mentor);
- Develop a teaching portfolio (show range of experiences, sample lessons and other materials used, student evaluations, faculty evaluations, teaching philosophy statement)

Assessment:

Evaluation of portfolios- TBD

Review of student evaluation- TBD

Other Professional Experiences (optional).

There are many other possible professional development opportunities for Ph.D. candidates in mathematics education. These experiences would be particularly beneficial for the student wishing to secure a job in higher education after graduation. The list below is not comprehensive.

- Apprenticeship in a methods course (mentor with instructor to plan and teach one of the department's courses for pre-service teachers such as MATH 700/703/708/709);
- Apprenticeship in supervision of student teachers (this may be considered as a teaching assistantship, as needed);
- Research assistantship- may take the place of a teaching assistantship
- Tutoring experiences (volunteer or paid tutoring opportunities are always available in the local area- ask about Seacoast Math tutoring)
- Other university teaching and research opportunities (as advertised through the Office of Professional Development and Training or through the Carsey Institute for Policy Research on Families and Communities)

3. RESEARCH AND PUBLICATION

Purpose. To carry out a research investigation that results in creating and writing a work of originality and creativity that is worthy of publication in the field of mathematics education.
Nature.

- Coursework and independent study (with approval from major advisor) in area of interest;
- Development of defense of dissertation proposal under guidance of major advisor (see details of major presentation, below);
- Dissertation research and written dissertation.

Assessment.

Major Presentation. The major presentation (or qualifying exam) for the Mathematics Education Ph.D. program is the student's defense of the dissertation proposal, and enables the student to demonstrate that he or she is qualified to conduct research in mathematics education and, more specifically, in the intended area of specialization.

The dissertation proposal is written by the student in consultation with the major advisor. Prior to the formal major presentation (or proposal defense) the reaction of other members from the Guidance Committee should be solicited by the student or by the chair. The proposal should include the following:

- Statement of the problem/purpose of the study
- Research questions
- Significance of the study
- Explication of a theoretical framework
- An outline of an appropriate literature review
- Description of the methodology to be used (including descriptions of and/or copies of instruments to be used)
- Description of procedures for analyzing the data
- Projected time schedule for collecting data

The student should give a copy of the full text of the dissertation proposal to each committee member to review at least 10 days prior to the oral defense.

The student will present a one hour departmental colloquium, with opportunity for questions from those in attendance, after which the student's Guidance Committee may question the student in a private session (if determined to be necessary). A unanimous vote of the Guidance Committee is required for successful completion.

When the student has completed the major presentation (and minor), the Graduate School "advanced" the student to the status of "Candidate for the Ph.D. Degree."

Dissertation Defense: Same for all Ph.D. programs

CURRENT FACULTY IN MATHEMATICS EDUCATION
Karen Graham (Professor), Sharon McCrone (Associate Professor)

COMPONENTS of:

Ph.D. degree in Statistics

3: Program Description

Students entering with a B.S. degree are required to take 14 courses at outlined below. Students entering with an M.S. in statistics or closely related field are required to take a subset of at least 10 courses that should be chosen in consultation with the program advisor.

3.1 Course Requirements (14 courses)

(all courses below have the "MATH" prefix and we show frequency when they are offered)

Core: Statistics, 11 courses:

Required (8 courses):

836 Advanced Statistical Methods for Research	(Spring)
839 Applied Regression Analysis	(Fall)
840 Design of Experiments I	(Fall)
855 Probability and Stochastic Processes	(Fall)
856 Principles of Statistics Inference	(Spring)
941 Bayesian Statistics	(Every other Fall)
945/946 Advanced Theory of Statistics I & II	

(sequence to be created, offered initially every other year)

Electives (3 courses): any three of the remaining statistics courses

837 Statistical Methods for Quality Improvement	(Summer)
841 Survival Analysis	(Every other Spring)
843 Time Series Analysis	(Every other Spring)
844 Design of Experiments II	(Every other Spring)
942 Beyond ANOVA	(Occasionally)
944 Spatial Statistics	(Every other Fall)
969 Topics in Probability and Statistics	(Occasionally)
979 Research Topics in Statistics	(Occasionally)

(969, 979 may be taken repeatedly)

Breadth Requirement, 3 courses:

Required (1 course): 867 (One dimensional Real Analysis) or 953 (Analysis I)

Electives (2 courses):

Any focused sequence of two courses which should be chosen in consultation with the program advisor.

Some Possible Examples within the department: (any two courses from one group)

Numerics/Computing	MATH 853	Introduction to Numerical Methods
	IAM 851	High Performance Computing
	IAM 961	Numerical Linear Algebra
Mathematicsl Modeling	IAM 930	Graduate Differential Equations
	IAM 932	Graduate PDE's
	IAM 933	Applied Functional Analysis
	MATH 847	Nonlinear Dynamics and Chaos
Math & Stats Education	MATH 958	Foundations of Mathematics Education
	MATH 968	Topics in Mathematics Education
Analysis	MATH 954	Analysis II
	MATH 963	Functional Analysis

Students may in consultation with the program advisor customize their electives by choosing two courses from areas possibly outside of the department's programs, focusing on an emerging interdisciplinary theme. Areas may include for example bioinformatics, genomics, remote sensing, econometics, predictive analytics, data mining.

3.2: EXAMS:

Each exam will be planned and administered by at least two faculty of the statistics program. Exam syllabi and practice exams will be made available to students.

First Year Qualifying Exams: (Two Exams):

To be taken together in May after the first year of study. Material is upper-level undergraduate to lower level masters. The purpose of the exams is to determine a student's general ability to pursue a Ph.D. in statistics.

1) Statistics Theory Exam
   (based on material of MATH 855, Probability, and MATH 856 Statistical Inference)

2) Applied Statistics Exam
   (based on material from MATH 839 Linear Regression, and MATH 840: Design of Experiments)

Qualifying exam results will be combined into one of the following: a pass, a partial pass (one exam will need to be retaken), or a fail. Students who earn a "fail" are not permitted to continue the Ph.D. program but my be encouraged to complete their studies with a master's degree in statistics.

Comprehensive Exams (Two Exams):

A required and an elective exam to be taken after additional course work has concluded typically at the end of the second or third year of study. The purpose of the exams is to determine the student's general ability to perform research at the Ph.D. level, and to test the student's knowledge in the likely area of specialization for dissertation research. Students are allowed to fail at most one of the two exams, in which case it will need to be retaken as soon as possible.

Required Exam:

Statistics Theory at the Ph.D. level. Based on course material of 945, 946. To be given in August of the year after the sequence has been offered.
(945-946 is a new proposed course sequence. Description is provided in the appendix)

Elective Exam:

Upper level statistics based on at least two related courses of the student's choice and likely will be in the anticipated dissertation area. (note that if based on 800 level courses, this will require additional work beyond what is covered in the courses).

Possible Examples:
- Bayesian Statistics and Spatial Statistics (941, 944)
- Survival Analysis and Time Series (841, 843)
- Design of Experiments II and Statistics for Research II (844, 836)
- Semiparametric regression/Smoothing and Topics (942, 969)
- Any coherent sequence that may also contain one or two of the topics courses (969, 979)

Alternate Example:

A student who wants to pursue a more computational and/or interdisciplinary dissertation may select an elective exam based on a coherent sequence of courses, which could include one or more courses offered outside the department (genomics, remote sensing, GIS, advanced computation, etc.) in combination with courses offered within the department as well as some reading assignment. The exam and the additional reading assignment will require approval by the student's preliminary dissertation advisor and will be contingent upon one of the outside instructors to be available for providing exam questions and for dissertation committee service.

Alternate Example: **Math & Stats Education**

A student who wishes to pursue a dissertation in the emerging field of "stats education" should take breadth elective courses in Math Education offered in the department (see Section 3.1) and should choose an elective comprehensive exam offered by the department's Math Education program. Further such a student would seek substantial involvement of at least one Math Education faculty member in the dissertation committee.

3.3 Dissertation Proposal, Advancement to Candidacy

During Years 2 and 3 students begin to develop their interest and focus area, that will lead to a dissertation and will select a preliminary major advisor. During this time the dissertation committee will be formed. At least one member of the dissertation committee must be from outside statistics. By the end of Year 3 or beginning of Year 4 students will give a public presentation of their dissertation proposal as part of the statistics seminar (see below) with a follow-up question and answer session by the dissertation committee. This serves as the Ph.D. Qualifying exam and, if passed, advances the student to the Ph.D. candidacy. The dissertation proposal serves the purpose to convince the committee that the proposed research is doable in a reasonable amount of time, and it should also contain a time plan that leads to conclusion of the dissertation.

3.4 Statistics Seminar:

This is a 1 credit seminar consisting of weekly to bi-weekly meetings organized by the statistics Ph.D. students with supervision by a statistics faculty member. The seminar will consist of mostly informal presentations of faculty members, students, and outside guest presenters. Seminar meetings are open to the great public. Statistics Ph.D. students are required to enroll in the seminar during the semesters between conclusion of the First Year Qualifying Exam and the advancement to candidacy (after passing the dissertation proposal) for at least 3 semesters. Attendance is mandatory by those students who are enrolled in the seminar. In addition it is expected that Ph.D. statistics students attend the seminars regularly even if they are not enrolled during a particular semester. Dissertation proposal presentations will be part of this seminar series.

3.5 Dissertation and Dissertation Defense: (see Graduate School guidelines)

3.6 Typical Program Schedule

Year 1 855, 856, 940, plus two additional courses
First Year Qualifying Exam at the end of Year 1 (End of May)

Year 2 945, 946, Theory sequence (*)
Set of two courses for additional comprehensive exam
Two additional courses
Statistics Seminar (1 credit)
Comprehensive exams at the end of Year 2 (August)

Year 3 Additional courses in focus area, additional required statistics electives
Additional math courses and/or additional quantitative science courses if applicable
Statistics Seminar (1 credit)
Dissertation Proposal

(*) Note: We anticipate offering 945/946 in alternate years, in which case the required comprehensive exam will be taken after Year 3, and if passed, the Dissertation proposal will be in the first semester of Year 4.

Year 4 & 5 Dissertation Research, concluding with Dissertation Defense

Tables of Typical Schedules:

Case 1: 945/946 offered during 2nd year

	Fall	Spring	Exams
Year 1	855, 839, 840	856, 836 841 or 843 or other course	First year qualifying exam (May)
Year 2	945, 953 (or 867) Course 1 for elective comp, exam	946 Course 2 for elective exam Stats Seminar	Both comprehensive exams (August)
Year 3	2 additional courses Stats Seminar	2 additional courses Stats Seminar	
Year 4/5	Diss. Proposal Diss. Research	Dissertation Research	Ph.D. Defense

Case 2: 945/ 946 offered during 3rd year

	Fall	Spring	Exams
Year 1	855, 839, 840	856, 836 841 or 843 or other course	First year qualifying exam (May)
Year 2	953 (or 867), 1 course Course 1 for elective comp, exam	One course Course 2 for elective exam Stats Seminar	Elective comprehensive exam (August)
Year 3	945, Additional course(s) Stats Seminar	946, Additional course(s) Stats Seminar	Required comprehensive exam (August)
Year 4/5	Diss. Proposal Diss. Research	Dissertation Research	Ph.D. Defense

GRADUATE FACULTY

Kenneth I. Appel, emeritus
PhD, University of Michigan
Combinational Group Theory

Maria Basterra
PhD, University of Chicago
Algebraic topology, category theory and homological algebra

Homer F. Bechtell, emeritus
PhD, University of Wisconsin
Finite Group Theory

Albert B. Bennett, Jr., emeritus
EdD, University of Michigan
Mathematics Education

Orly Buchbinder
Ph. D.,
Mathematics Education

David M. Burton, emeritus
PhD, University of Rochester
Number Theory

Arthur H. Copeland, Jr., emeritus
PhD, MIT
Algebraic Topology

David V. Feldman
PhD, Wesleyan University
Number Theory, Theoretical C.S.

Tim Fukawa-Connelly
PhD, University of Maryland
Mathematics Education, teaching and learning of abstract algebra and proof

Marie A. Gaudard, emeritus
PhD, University of Massachusetts
Statistics, Quality Improvement

Liming Ge
PhD, __________
____

John Gibson
PhD, Cornell University
Applied Mathematics, Fluid Mechanics, Dynamical Systems

Karen J. Graham
PhD, University of New Hampshire
Mathematics Education

Donald W. Hadwin
PhD, Indiana University
Operator Theory, C*-Algebras

Rita Hibschweiler
PhD, SUNY at Albany
Complex Analysis

Edward K. Hinson
PhD, Northwestern University
Algebra, Commutative Rings

Robb Jacoby
PhD, University of Chicago
Algebraic Geometry, Algebraic Numbers

Linyuan Li
PhD, Michigan State University
Non-parametric statistics and asymptotics

Ernst Linder
Ph.D., Pennsylvania State University
Statistics, Environmental Statistics

Mark Lyon
PhD, California Institute of Technology
Numerical Analysis, optimization partial differential equations

Loren David Meeker, emeritus
PhD, Stanford University
Control Theory, Applied Mathematics

Sharon McCrone
PhD, University of New Hampshire
Mathematics Education

Dmitri Nikshych
PhD, University of California at Los Angeles
Algebra, Representation theory

Eric A. Nordgren, emeritus
PhD, University of Michigan
Operator Theory

Sheree Sharpe
Ph. D., University of Miami
Mathematics Education

Junhao Shen

PhD, University of Pennsylvania
Functional analysis, operator algebra and operator theory

Samuel D. Shore
PhD, Pennsylvania State University
General Topology

Kevin M. Short
PhD, Imperial College
Applied Nonlinear Dynamics

Marianna Shubov
PhD, St. Petersburg (Leningrad) State University
Applied mathematics, mathematical analysis

Donovan H. Van Osdol, emeritus
PhD, University of Illinois
Categorical Algebra

Haiying Wang
Ph. D.,
Statistics

3. GRADUATE COURSES

This section includes the Graduate Catalog descriptions for all courses currently being offered by the Department and numbered 931 or above -- as well as more detailed (in-house Department of Mathematics) course details for the required courses MATH 951-955. Course details similar to these are written for all courses and published in a separate volume, entitled **Graduate Courses in Mathematics**. This volume is on file in the Department Office and in the Graduate Student Study (Kingsbury 306); you are encouraged to refer to this information when you are planning your program and selecting the courses to include in your program. Note that topics courses that have been offered in recent years are also described there.

In general,

MATH 95N is intended to be a basic first- or second-year graduate course.

MATH 96N is intended to be a deeper study in an area that has the potential to become a minor area of study or a dissertation area of study.

MATH 97N will usually be a more specialized area that has **MATH 96N** as a prerequisite. Thus, this could either complete the minor area of study or lead to further reading courses that lead to a dissertation.

Courses numbered 931 through 959 are introductory courses for the MS degree in mathematics and the PhD degrees in mathematics and mathematics education.

Courses numbered 961 through 979 are more specialized topics courses that are offered periodically in response to faculty and student interests. Content may vary from year to year. With the permission of the instructor, these courses may be taken more than once.

INTRODUCTORY COURSES

MATH 931-932. Mathematical Physics

Complex variables, differential equations, asymptotic methods, integral transforms, special functions, linear vectors spaces and matrices, Green's functions, and additional topics selected from integral equations, variational methods, numerical methods, tensor analysis, and group theory.
Prereq: Differential equations, linear algebra, multi-dimensional calculus
(Also offered as PHYS 931-932.) 3 cr.

MATH 951. Algebra I

Groups and their homomorphisms, products and sums, structure of groups; rings and their homomorphisms, ideals, factorization properties.
Prereq: MATH 861. 3 cr.

MATH 952. Algebra II

Field extensions; Galois theory; module theory.
Prereq: MATH 951. 3 cr.

MATH 953. Analysis I

Measurable spaces and functions, measures, Lebesgue integrals, convergence theorems.
Prereq: MATH 867. 3 cr.

MATH 954. Analysis II

Cauchy theory and local properties of analytic functions, Riemann mapping theorem, representation theorems, harmonic functions.
Prereq: MATH 888. 3 cr.

MATH 955. Topology I

Subspace, product, and quotient topologies; embedding; separation and countability axioms; connectedness; compactness and compactifications; paracompactness, metrization, and metric completions.
Prereq: MATH 884. 3 cr.

MATH 956. Topology II

Chain complexes; homology of simplicial complexes; singular homology and cohomology; axiomatic homology.
Prereq: MATH 861, MATH 884. 3 cr.

[H]*MATH 957. Introduction to Applied Mathematics*

MATH 958. Introduction to Mathematics Education

Topics will include: major issues, trends, and programs in mathematics education research, the research process, theoretical perspectives to guide research, the profession and infrastructure of mathematics education, cultural and historical aspects of mathematics education, and the research-practice interface. Examples will span the K-16 spectrum.
Prereq: permission. 3 cr.

[H]*MATH 959. Introduction to Graduate Probability and Statistics*

[H]Courses listed in italics are planned for, but not currently listed in, the Graduate Catalog.

INTRODUCTORY TOPICS COURSES

MATH 961. Topics in Algebra I
An introduction to topics chosen from algebra and number theory.
Prereq: MATH 951-952. 3 cr.

MATH 963. Functional Analysis
Banach and Hilbert spaces, Hahn-Banach theorem, open mapping and closed graph theorems, dual spaces, topological vector spaces.
Prereq: MATH 953. 3 cr.

MATH 964. Topics in Analysis I
An introduction to topics in analysis.
Prereq: permission. 3 cr.

MATH 965. Topics in General Topology I
An introduction to topics in general topology.
Prereq: MATH 955. 3 cr.

MATH 966. Topics in Algebraic Topology I
An introduction to topics in algebraic topology.
Prereq: MATH 956. 3 cr.

MATH 967. Topics in Applied Mathematics I
An introduction to topics in applied mathematics.
Prereq: permission. 3 cr.

MATH 968. Topics in Mathematics Education I
A) The Teaching and Learning of Mathematics;
B) Curriculum and History in Mathematics Education.
Topics will be selected from: epistemologies of knowledge applied to mathematics; theories of learning and teaching mathematics; theoretical perspectives in research; mathematics education research programs K-16; research methods for studying mathematics teaching, learning, and curricula; theoretical frameworks for curriculum development, implementation of new curricula, and research on curricula; historical perspectives of research in mathematics education; the evolution and history of K-16 mathematics curricula both in the United States and internationally.
Versions A and B offered alternately.
Prereq: MATH 958 or permission. 3 cr.

MATH 969. Topics in Probability and Statistics I
Time series analysis; analysis of variance; stochastic processes; probability; design of experiments; nonparametric statistics.
Prereq: permission. 3 cr.

ADVANCED TOPICS AND READING COURSES

MATH 971. Topics in Algebra II
An introduction to advanced topics chosen from algebra and number theory.
Prereq: MATH 951-952 and permission. 3 cr.

MATH 973. Topics in Operator Theory
Selected topics in operator theory.
Prereq: MATH 963. 3 cr.

MATH 977. Topics in Applied Mathematics II
An exploration of an area of research in applied mathematics.
Prereq: permission. 3 cr.

MATH 978. Topics in Mathematics Education I
An exploration of an area of research in mathematics education.
Prereq: permission. 3 cr.

MATH 998. Reading Courses

A) Algebra;
B) Analysis;
C) Operator Theory;
D) Geometry;
E) General Topology;
F) Algebraic Topology;
G) Applied Mathematics;
H) Mathematics Education;
I) Probability and Statistics.

Prereq: permission. 1-6 cr.

MATH 999. Doctoral Research

COURSE DESCRIPTIONS

FOR

REQUIRED COURSES

MATH 951. Algebra I

MATH 952. Algebra II

MATH 953. Analysis I

MATH 954. Analysis II

MATH 955. Topology I

Similar course descriptions for all graduate courses are published in a separate volume and located in the Department of Mathematics Office (Kingsbury M312) and in the Graduate Student Study (Kingsbury 306).

Mathematics 951. Algebra I (Old MATH 933)

Purpose. To introduce the basic results of group and ring theory.

Audience. First-year graduate students in mathematics.

Prerequisite. MATH 861.

Follow-up Courses.
MATH 932, MATH 961, MATH 971.

Possible Texts.
Hungerford, **Algebra**,
Springer-Verlag.

Minimal Content.
Groups;
Homomorphisms and normal subgroups;
Permutation groups;
Sylow theorems;
Finitely generated abelian groups;
Products and coproducts;
Rings, homomorphisms and ideals;
Quotient rings;
Factorization.

Possible Additional Content, time permitting.
Free groups;
Nilpotent and solvable groups;
Notherian and Artinean rings.

Remarks.
This course is required in all graduate programs, and is usually taken in preparation for the Algebra Comprehensive Exam. More advanced topics in this course may appear in the Advanced Algebra Comprehensive Exam. Depending on the instructor(s), there may be some exchange of topics between this course and MATH 952.

Catalog Description.
Groups and their homomorphisms, products and sums, structure of groups; rings and their homomorphisms, ideals, factorization properties.
Prereq: MATH 861. 3 cr.

Mathematics 952. Algebra II (Old MATH 934)

Purpose. To introduce the basic results of field and in module theory.

Audience. First-year graduate students in mathematics and mathematics education.

Prerequisite. MATH 951.

Follow-up Courses. MATH 961, MATH 971.

Possible Texts.
Hungerford, **Algebra**,
Springer-Verlag.

Minimal Content.
Polynomial rings;
Field extensions;
Galois theory;
Finite fields;
Radical extensions;
Modules and their homomorphisms;
Free modules;
Modules over principal ideal domains.

Possible Additional Content, time permitting.
Transcendence bases;
Linear disjointness;
Projective and injective modules;
Tensor products;
Algebras;
Wedderburn-Artin Theorem.

Remarks.
This course is required in all graduate programs, and is usually taken in preparation for the Algebra Comprehensive Exam. More advanced topics in this course may appear in the Advanced Algebra Comprehensive Exam. Depending on the instructor(s), there may be some exchange of topics between this course and MATH 951.

Catalog Description.
Field extensions; Galois theory; module theory.
Prereq: MATH 951. 3 cr.

Mathematics 953. Analysis I (Old MATH 935)

Purpose. To introduce the Lebesgue integral in order to provide a basis for further work in analysis.

Audience. First-year graduate students in mathematics.

Prerequisite. MATH 867.
(Knowledge of undergraduate linear algebra and complex analysis is useful.)

Follow-up Courses.
MATH 963 (Functional Analysis), MATH 973 (Topics in Operator Theory);
MATH 964, (Topics in Analysis.)

Possible Texts.
Walter Rudin, **Real and Complex Analysis**,
McGraw-Hill, 1974.

Minimal Content.
Measurable spaces, measures and outer measures;
Lebesgue measure on Euclidean spaces;
Measurable functions;
Lebesgue integral and convergence theorems;
L^p spaces;
Product measures and Fubini theorems;
Absolute continuity and Radon-Nikodyn theorem;
Riemann integrability.

Possible Additional Content, time permitting.
Complex measures, monotone functions on **R**.

Remarks.
Most students take this course in preparation for the comprehensive examination.

Catalog Description.
Measurable spaces and functions, measures, Lebesgue integrals, convergence theorems.
Prereq: MATH 867. 3 cr.

Mathematics 954. Analysis II (Old MATH 937)

Purpose. To study analytic function theory.

Audience. First-year graduate students in mathematics.

Prerequisite. MATH 888.

Follow-up Courses. MATH 964 (Topics in Analysis I).

Possible Texts.

John B. Conway, **Functions of One Complex Variable**, Springer-Verlag, 1975.

Walter Rudin, **Real and Complex Analysis**, McGraw-Hill, 1974.

Minimal Content.

Review of fundamentals, including power series and Cauchy theory, isolated singularities, residue calculus;

Open mapping theorem;

Maximum modulus theorem;

Rouche's theorem;

Schwarz's lemma;

Riemann mapping theorem;

Harmonic functions;

Representation theorems.

Possible Additional Content, time permitting.

Riemann surfaces.

Remarks.

Most students take this course in preparation for the comprehensive examination.

Catalog Description.

Cauchy theory and local properties of analytic functions, Riemann mapping theorem, representation theorems, harmonic functions.

Prereq: MATH 888. 3 cr.

Mathematics 955. Topology I. (Old MATH 939)

Purpose. To introduce the fundamental ideas and results of general topology.

Audience. First-year graduate students in mathematics.

Prerequisite. MATH 884.

Follow-up Courses. MATH 945. (Topics in General Topology I.)

Possible Texts.
John L. Kelley, **General Topology**,
Springer-Verlag, 19??.
James R. Munkres, **Topology**,
Prentice-Hall, 1975.
Stephen Willard, **General Topology**,
Addison-Wesley, 1970 (out of print).

More extensive references:
Ryszard Engelking, **General Topology** (revised edition),
Heldermann Verlag, Berlin, 1989.
Jun-iti Nagata, **Modern General Topology** (revised second edition),
Elsevier Science Publishers, 1985.

Minimal Content.
Basic topological context;
Separation properties (Hausdorff, regular and normal);
Countability conditions (first and second countability, separability);
Covering properties (compact, Lindelöf, paracompact);
Compactifications;
Metrizability;
Metrization theorems (including the Nagata-Smirnov-Bing theorem);
Connectedness.

Possible Additional Content, time permitting.
First and second category; cardinal invariants for topological spaces.

Remarks.
The prerequisite is a necessity in order to develop any depth in the minimal content; most students take this course in preparation for the comprehensive examination. This course serves as a useful resource for analysis courses.

Catalog Description.
Subspace, product, and quotient topologies; embedding; separation and countability axioms; connectedness; compactness and compactifications; paracompactness, metrization, and metric completions.
Prereq: MATH 884. 3 cr.

4. MORE ABOUT THE COMPREHENSIVE EXAM

The parts of the comprehensive exam corresponding roughly to their course- counterparts. However, the content of a course is not intended to completely describe the material that might appear on the exam. It is expected that the Ph.D. student will develop maturity and understanding that runs deeper than reproducing theorems that might have appeared in a course.

ANALYSIS.

Basic Spaces:

Measure spaces, σ-algebras, Borel fields, monotone class lemma.

Measure:

Measures and outer measures, completion; Lebesgue measure on $\mathbf{R}^n$; σ-finite measures, regular measures.

Integral:

Measurable functions, Lusin's theorem, simple functions; Lebesgue integral, absolute continuity, Radon-Nikodym theorem, Lebesgue's decomposition; signed and complex measures, Riesz representation theorem, L^p-spaces; product measures and Fubini's theorem.

Convergence:

Sequences and series of functions of real and complex functions, convergence (uniform, a.e., in mean p, in measure); Fatou's lemma, monotone and dominated convergence theorems; Egoroff's theorem.

Complex Analysis:

Analytic, entire and meromorphic functions; Cauchy-Riemann equations, Cauchy-Goursat theorem, Cauchy integral formula; power series and series representation; isolated singularities, residues and calculus of residues.

Suggested References:

Rudin, **Real and Complex Analysis**, McGraw-Hill, 1974.
Royden, **Real Analysis**, MacMillan, 1968.
Conway, **Functions of One Complex Variable**, Springer, New York, 1973

COMPLEX ANALYSIS.

Analytic Functions:

Cauchy-Riemann equations, Cauchy-Goursat theorem, Cauchy integral formula, poles and essential singularities, meromorphic functions, entire functions.

Limits:

Infinite series, uniform convergence, power series, radius of convergence, equicontinuity, normal families, Arzela-Ascoli theorem, infinite products, Laurent series.

Major Theorems:

Open mapping theorem, Maximum modulus theorem, Schwartz lemma, Riemann mapping theorem, Weierstrass factorization theorem, Mittag-Leffler theorem, Morera theorem, Liouville theorem, Casorati-Weierstrass theorem, argument principle, Rouche's theorem, Weierstrass factorization theorem.

Calculus of Residues:

Residue theorem, contour integration.

Harmonic Functions:

Basic properties, mean-value property, Poisson's integral.

Analytic Continuation:

General analytic functions, Riemann surfaces, monodromy theorem.

Suggested References:

Ahlfors, **Complex Analysis**, McGraw-Hill, 19**
Conway, **Functions of One Complex Variable**, Springer, New York, 1973
Rudin, **Real and Complex Analysis**, McGraw-Hill, 1974
Hille, **Analytic Function Theory**, Vol 1, Ginn, 19**

FUNCTIONAL ANALYSIS.

Topological Vector Spaces:

Locally convex spaces, seminorms and norms, Minkowski functionals, convergence of nets in locally convex spaces, quotient spaces.

Basic Spaces of Functional Analysis:

Fréchet spaces, Banach spaces, Hilbert spaces, sequence spaces, L^p-spaces of functions.

Fundamental Theorems:

Baire category theorem, uniform boundedness principle, open mapping and closed graph theorems, Hahn-Banach theorems, Tychonoff's theorem; Alaogul's theorem, Krein-Milman theorem, Krein-Shmulyan theorem.

Duality Theory:

Dual spaces and their representations, weak and weak*-topologies and convergence, polars.

Linearity:

Basic properties of continuous linear transformations, adjoints, sums and products.

Suggested References:

Dunford and Schwartz, **Linear Operators, Part I**, Wiley, 1963.
Rudin, **Real and Complex Analysis**, McGraw-Hill, 1974.
Rudin, **Functional Analysis**, McGraw-Hill, 1973.
Conway, **A Course in Functional Analysis**, Springer-Verlag, 1985.
Robertson and Robertson, **Topological Vector Spaces**, Cambridge, 1973.

ALGEBRA.

Group Theory:

Elementary properties; normal subgroups; quotient groups; isomorphism theorems; (direct) products and sums; Sylow theorems and applications; *p*-groups; finitely generated abelian groups.

Ring Theory:

Elementary properties; ideals (prime, maximal, et al.); quotient rings; isomorphism theorems; divisibility; (unique) factorization; euclidean and principal ideal domains; polynomial rings.

Module Theory:

Elementary properties; homomorphisms and sequences, exactness; free modules; rank.

Suggested References:

Hungerford, **Algebra**,
Graduate Texts in Mathematics, No. 73, Springer-Verlag, 1974.
MacLane and Birkoff, **Algebra**,
MacMillan, 1967.

Other references of a comparable nature certainly may be used. If in doubt, please inquire as to its suitability.

ADVANCED ALGEBRA.

Categories:

Definitions and examples; products and coproducts; free objects.

Groups:

Free groups; products and coproducts of groups; generators and relations; subnormal series; nilpotent and solvable groups; composition series.

Rings:

Power series rings; irreducibility of polynomials; fields of quotients; localizations.

Modules:

Exact sequences (short and other); splitting of short exact sequences; invariant basis property; projective and injective modules; projective modules over PIDs.

Fields:

Field extensions; Galois groups of extensions; Galois correspondence; algebraic and transcendental extensions; (finite-dimensional) Galois Theory; separable extensions; splitting fields of (sets of) polynomials; algebraically closed fields; algebraic closures; finite fields.

Suggested References:

Hungerford, **Algebra**,
Graduate Texts in Mathematics, No. 73, Springer-Verlag, 1974.
MacLane and Birkoff, **Algebra**,
MacMillan, 1967.

Others as indicated in Algebra Exam description.

TOPOLOGY.

Basic Topological Context:

Base, closure, interior; subspace, product and quotient topology; topological properties preserved by subspace, products and continuous maps; embedding theorem; convergence; examples and counterexamples.

Separation and Countability:

Hausdorff, regular and normal spaces;
Urysohn's Lemma, Urysohn-Tietze Extension theorem;
first and second countability, separability.

Covering Properties:

Compactness, Lindelöf, paracompact;
Tychonoff product theorem, Stone's theorem;
compactifications; local compactness.

Metrizability and Metrization:

Separation, covering and countability properties;
Tychonoff-Urysohn metrization theorem, Nagata-Smirnov-Bing metrization theorem.

Connectedness and Local Connectedness:

Suggested References:

Kelley, **General Topology**,
Springer-Verlag, 19??.
Munkres, **Topology**,
Prentice-Hall, 1975.
Willard, **General Topology**,
Addison-Wesley, Reading, 1970. (out of print)
Steen and Seebach, **Counterexamples in Topology**,
(out of print) Holt, Rinehart and Winston, Inc., 1970.

ALGEBRAIC TOPOLOGY.

Preliminaries: categories and functors.

Definition of singular hormology, basic properties, homology of a point, Ho (X), homotophy, excision.

Exact sequences, basic applications.

Eilenberg-Steenrod axioms.

CW complexes.

Homology, cohomology and product spaces.

Suggested References:

Spanier, **Algebraic Topology**, McGraw Hill, 1966.

Vick, **Homology Theory**, Academic Press, 1973.

Artin and Braun, **Introduction to Algebraic Topology**, Merrill, 1969.

Greenberg, **Lectures on Algebraic Topology**, Benjamin, 1967.

Dold, **Lectures on Algebraic Topology**, Springer, 1972.

MATHEMATICS EDUCATION.

History of Mathematics Education and Curriculum:

Evolution of the field of mathematics education, major trends and developments in mathematics curriculum, including the present reform initiatives and organizations involving in promoting and supporting mathematics education.

Theory and Research About Learning and Teaching Mathematics:

Theories of mathematics learning, theoretical perspectives that guide mathematics education research and practice, knowledge base about student learning of mathematics K-14, theories of knowledge, and theories of teaching and teacher development.

Current Areas of Research and Research Methodology:

Current areas of research in mathematics education, including trends and new directions, and basic research methodologies and issues relevant to those methodologies.

Suggested References:

NCTM History of Mathematics Education Yearbook.
Grouws, D. **Handbook of Research on Mathematics Teaching and Learning**.
NCTM Standards documents.
1992-93 and 1993-94 volumes of the **Journal for Research in Mathematics Education**.
Lesh and Landau, **Acquisition of Mathematics Concepts and Processes**.
Appropriate readings in research design and qualitative methodology, such as Campbell & Stanley, Miles & Huberman.

5. PLANNING YOUR PROGRAM

Advising. The graduate program coordinator serves as the advisor to students in the MS and PhD degree in mathematics programs until a major advisor is appointed.

A graduate faculty member in mathematics education serves in the same capacity for the PhD degree students in mathematics education. Advisors for MST degree students are appointed by the Director of the MST program.

FOUR-YEAR GRADUATE COURSE SCHEDULING

	Fa 95	Sp 96	Fa 96	Sp 97	Fa 97	Sp 98	Fa 98	Sp 99
Probability & Statistics	835	836	835	836	835	836	835	836
	839	840	839	840	839	840	839	840
		842		842		842		842
Applied Mathematics	847		845	846				
	853	854	853	854	853	954	853	854
Algebra	861	861	861	861	861	861	861	861
		862		862		862		862
Analysis	867	867	867	867	867	867	867	867
		888		888		888		888
Set Theory and Topology	883	884	876	884	883	884	876	884
Algebra I, II	951	952	951	952	951	952	951	952
Topics in Algebra		961		961		961		961
Measure; Complex	954	953	954	953	954	953	954	953
Functional; Topics	963	973	963	964	963	973	963	964
Topology I, II	965		955	956	955	965	955	956
Applied Math I, II	931	932	931	932	931	932	931	932
Topics Applied Math		967		967		967		967
Mathematics Education	968	968	978		958	968	978	
Probability & Statistics		969	969		969		969	

Sample Scheduling. The following samples indicate sequences of courses that are designed to prepare a student for taking the required Comprehensive Examinations in the summer after the second year of graduate student and to have completed the optional comprehensive as soon as possible.

The student would begin a sequence at various places in each row depending on the preparation of the student.

	Fall	Spring	Fall	Spring	Fall	Spring
Algebra	861	862	951	952		
or, entering Sp		861,862	951	852		
Optional Topics		864			961	
Analysis	867	888,935	954			
or	867	888	954	953		
or, entering Sp		867,888	954	953		
Optional Topics					963	964/973
Topology		884	955			
Optional Topics	883		876	956/965		
Applied Mathematics	853	854	931	932		
Optional Topics	847				967	
Mathematics Education	958	968	978		958	968
or		968	958,978			
Probability & Statistics	835	836	839	842,969		

Changing Majors. A student who is enrolled in the MS degree program in mathematics at UNH and wishes to pursue the Ph.D. degree at UNH is required to file a "Change of Major"' form with the Graduate School. If the student has already graduated, then an entirely new application must be submitted. In either case the usual admission procedure of the Graduate School is invoked.