UVM
Handbook
for Graduate Studies
in Mathematics
2016-2017

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This Handbook contains information about the Graduate Program in Mathematics at the University of Vermont. It is useful for potential students, current students, advisors and professors. Comments or suggestions may be relayed to Dr. Christopher Danforth, the Director of the Mathematics Graduate Program, Department of Mathematics and Statistics, University of Vermont, Burlington, VT 05401. Questions about the graduate program can be sent to Dr. Danforth at chris.danforth@uvm.edu. The department phone number is (802) 656-2940. Information can be found on the internet at www.uvm.edu/math.

Department Information

The Department of Mathematics and Statistics offers programs towards the Master of Science (M.S.), Master of Science in Teaching (M.S.T.), and Doctor of Philosophy in the Mathematical Sciences (Ph.D.) degrees. The M.S.T. degree is for licensed teachers only. We also offer an Accelerated Master's Program (A.M.P.) which combines studies towards the Bachelor of Science (B.S.) and Master of Science degrees into one 5-year program. The Statistics Program also offers Master's Degrees in Biostatistics and Statistics. This handbook does not cover those

degrees. Statistics students should contact Professor Ruth Mickey. The curriculum for all degrees has two main streams: pure mathematics and applied mathematics. Students are encouraged to take courses common to both areas, enabling them to gain an appreciation of the problems and techniques in each, an understanding of the connections between them, and the common role of scientific computation.

The department is located in the historic Henry Marcus Lord building on the north edge of campus, at 16 Colchester Avenue, with additional offices in nearby Mansfield House and Pearl House. Professor Jeff Buzas is the Department Chair, as well as the Director of the Statistics Program. Professor Gregory Warrington is the Associate Department Chair. Professor Chris Danforth is Director of the Mathematics Graduate Program. Professor Ruth Mickey is the Director of the Graduate Program in Statistics.

There is also a standing departmental Mathematics Graduate Committee in charge of overseeing the Mathematics Graduate Program. Any of the people listed above are more than willing to answer your questions about the department. Some relevant e-mail addresses are:

Jeff Buzas	Jeff.Buzas@uvm.edu
Greg Warrington	Greg.Warrington@uvm.edu
Chris Danforth	Chris.Danforth@uvm.edu
Ruth Mickey	Ruth.Mickey@uvm.edu

We want to help. Students with a question or a problem are encouraged to ask someone for help. Meghan Kelly, our department secretary, is always a good person to start with.

New graduate students will need to see Meghan for their office keys and for course materials including a textbook if they are teaching a course. She can also point out where the mailboxes and graduate student offices are located. She is available to take phone messages and in general helps keep the department running smoothly.

Networked computers are available in the graduate student offices and at many locations around campus. All graduate students have accounts on the UVM network. These accounts are maintained by the University's Information Technology department. They provide access to the Internet, a variety of installed software, and extensive computing power. Students are encouraged to acquaint themselves with the system and its capabilities. For example, one can access computer algebra systems (Mathematica, MATLAB), packages for mathematical computing (PARI, SAGE, MATLAB), mathematical typesetting software (LaTeX), and various tools for doing mathematical research.

Each graduate student receives both a postal and an electronic mailbox provided by the College of Engineering and Mathematical Sciences. These are used for Department, College, and University communications.

The department sponsors several social events of note. On a weekend close to Labor Day we have our annual fall picnic. This gathering of department members, friends, and family features

a potluck picnic, outdoor games, and just plain lazing in the sun (or rain, depending).

We hit the trails for a local day-hike and "leaf-peeping" sometime around the end of September or beginning of October. Mathematics and statistics undergraduate students, graduate students, and faculty members have formed volleyball, basketball, and softball teams. Students traditionally challenge the faculty to a spring softball game. Both Henry Marcus Lord House and the Mansfield House have ping-pong tables.

The University of Vermont (UVM) is located in Burlington, a city of about 50,000 located on the shores of Lake Champlain, with views of Vermont's Green Mountains to the east and New York's Adirondack Mountains to the west. Burlington is 90 miles south of Montreal, 200 miles northwest of Boston and 300 miles north of New York City. This location affords many intellectual, cultural and recreational opportunities. Popular outdoor activities include hiking, climbing, bicycling, in-line skating, mountain-biking, sailing, skateboarding, skiing and snowboarding.

Mathematics Graduate Faculty and Students

The mathematics faculty at UVM has strengths in several areas (see below), and members are actively involved in research in their areas of expertise. The department and university have a friendly, collegial atmosphere in which students have ample opportunity to talk with professors on an informal basis. We strive to offer an education that is comprehensive, yet tailored to the individual needs of our students. Students are invited to participate in the ongoing research seminars in number theory, applied mathematics, complex systems and combinatorics. These include participants from St. Michael's College, Middlebury, and other institutions.

A list of all mathematics and statistics faculty members is available from the department's home page. There you will also find links to personal web pages of individual faculty members and graduate students. These web pages contain much more information about the individuals including, in many cases, complete copies of their recent publications.

The Graduate Faculty and Their Interests

Daniel E. Bentil	Applied Mathematics, Modeling, Biomathematics
James Bagrow	Complex Systems and Networks, Statistical Physics, Optimization
Chris Danforth	Chaos, Mathematical Modeling, Complex Systems, Applied Mathematics
Jeffrey H. Dinitz	Combinatorics
Peter Sheridan Dodds	Applied Mathematics, Complex Systems & Networks, Contagion, Modeling

Richard M. Foote	Finite Group Theory and its Applications, Algebra
Taras I. Lakoba	Applied Mathematics, Modeling
Jonathan W. Sands	Algebraic Number Theory
Samuel Scarpino	Mathematical Biology, Public Health, Epidemiology
Christelle Vincent	Number Theory, Geometry
Gregory Warrington	Algebraic Combinatorics
J. Michael Wilson	Fourier Analysis
Jianke Yang	Applied Mathematics, Nonlinear PDEs
Jun Yu	Applied Mathematics, Modeling, Biomathematics

In addition to the mathematics faculty listed above, students may draw upon the statistics faculty: Taka Ashikaga, Jeff Buzas, Peter Callas, Bernard (Chip) Cole, Ruth Mickey, Rich Single, and Mun Son.

Faculty with secondary appointments in our department are: Alan Ling (Computer Science: Combinatorial Design Theory and Coding Theory), Kurt Oughstun (Electrical and Computer Engineering: Electromagnetic and Optical Field Theory), George Pinder (Civil and Environmental Engineering: Groundwater Behavior, Numerical Modeling), and Robert Snapp (Computer Science: Neural Networks, Image Processing).

University Information

The Department of Mathematics and Statistics (656-2940) is situated administratively in the College of Engineering and Mathematical Sciences. College offices are located in Votey Hall. The Dean is Dr. Luis Garcia. The Assistant Dean is Doug Dickey. The administrative assistant is Sharon Sylvester.

The Graduate College (656-3160), located in the Waterman building, coordinates graduate studies across the University. Its staff can help resolve difficulties that cannot be managed within our department. Administrative Assistants Kimberly Hess and Sean Milnamow oversee admissions and all program related functions for the College of Engineering and Mathematical Sciences. Along with the Mathematics Graduate Director, they will be able to help you with such things as: format of theses and dissertations, your progress through the program requirements as you near graduation, changes in your program, transfer credits, and academic standing. We encourage you to familiarize yourself with their timeline for graduation.

The Graduate College also hosts a Graduate Student Orientation at the beginning of the semester and sponsors a Graduate Teaching Assistant of the year competition. They administer Summer Research Fellowships, and Travel Mini-Grants for students to present research at professional meetings.

The Center for Teaching and Learning offers workshops on various aspects of teaching, grading and the Blackboard course management software used at UVM. These are open to teaching assistants.

A majority of our students, and about half of our undergraduate majors, are from the College of Arts and Sciences (CAS), also located in Waterman.

The Office of International Educational Services (656-4296) coordinates programs, events, and services of special interest to international students. This includes Language and Writing Workshops, assistance in academic and cultural adjustment, and immigration and employment help. Much valuable information can be found online at http://www.uvm.edu/oie/. They also assist applicants and new students with obtaining I-20 forms, Statements of Support, etc.

The *Graduate Catalogue* contains a wealth of essential information, such as degree requirements, university policies, and student rights and responsibilities. The latter includes academic honesty, sexual harassment, and grievance procedures. The catalogue is linked to the Graduate College website at http://www.uvm.edu/~gradcoll. For another view of departmental services and of our undergraduate programs you may wish to consult a copy of our Handbook for Majors, which can be found on the department website.

Information for Applicants

The Application Process

A student interested in graduate studies in mathematics should contact the Director of the Mathematics Graduate Program, Chris Danforth; his e-mail address is Chris.Danforth@uvm.edu, and his office phone is (802) 656-3032. Students interested in statistics should contact the Director of the Statistics Graduate Program, Ruth Mickey; her email address is rmickey@uvm.edu. Complete applications include a statement of purpose, three reference letters, GRE scores, and college transcripts. International students whose native language is not English must take the Test of English as a Foreign Language (TOEFL) exam. A TOEFL score of 90 is required for admission and 100 for Teaching Assistantship consideration.

Application forms may be found on the Graduate College's web pages at: http://www.uvm.edu/~gradcoll.

The Mathematics & Statistics Department has no specified minimum cutoff for applicants with low GRE scores, but instead evaluates each applicant based on overall documentation. Applicants with low GRE scores are examined carefully for mitigating circumstances.

Students with prior graduate study may, with the permission of the Graduate College, transfer up to 9 hours of credit from another university, or apply up to 9 hours of UVM graduate credit towards the degree. In addition, the student may apply up to 6 extra hours for courses taken during the semester in which we act upon their application.

Decisions on admissions to both the Masters and Ph.D. Programs are made on a continuing basis; students may be admitted for the fall semester during the summer just preceding it. Students may also apply to be admitted at the beginning of a spring semester. (See the subsequent section on Funding for Graduate Students for information about applying for GTA

support.)

Applying to the Ph.D. Program

Only exceptional applicants with a bachelor's degree are admitted directly into the Ph.D. program. More commonly, students are admitted into the Masters program. Due to the size of our graduate program, we suggest that applicants to the Ph.D. contact potential thesis advisors in the department during the application process. Applicants wishing to be admitted directly into the Ph.D. program should work closely with the Graduate Director to ensure that this contact is well established before admission decisions are made. (See also the subsequent section on Concurrent Credit for M.S. and Ph.D. programs.)

Protocol for Review of Current M.S. Students Who Apply to the Ph.D. Program

Students currently enrolled in the M.S. program who wish to apply for admission to the Ph.D. program must communicate this in writing to the Director of the Mathematics Graduate Program by January 15 of their final year in the M.S. program.

The letter of application must contain the names of at least three faculty members who may be contacted for letters of recommendation. These three references should include an individual who potentially may serve as the student's doctoral advisor. (The faculty members need not all be members of the department or UVM.)

The application letter must contain a preliminary plan and timetable for completing the Ph.D., including a possible research area, a potential thesis advisor, and course work (including reading courses) that might be needed to carry out the plan.

Admission criteria will include: the quality and level of graduate work done at UVM or other institutions, fit of the applicant's research plan within the areas of expertise of the UVM faculty, prognosis for completion of the applicant's plan, consideration of funding for the student (where applicable) during his/her doctoral studies, and comparisons with the pool of external applicants (who are also subject to these criteria). Students accepted to the doctoral program do not need to retake any Ph.D. qualifying exams they have already passed; however, they may take each exam at most two times, including attempts during the course of their M.S. program.

Applications will be reviewed by the Mathematics Graduate Committee and will informed of their status by no later than April 15 following their application.

Funding for Graduate Students

The Mathematics Graduate Program currently has 15 Graduate Teaching Assistantships (GTAs), and, on average, about 7-8 of these become available to new incoming students each year; most of these are awarded to students applying to the Masters Programs. The stipend for an MS GTA

is approximately $16,000, and for a PhD GTA the stipend is $18,750. These assistantships also carry a scholarship covering up to 9 credit hours of graduate credit per semester during the period of the award.

Graduate Teaching Assistantships are usually awarded (and renewed) for an academic year beginning with the fall semester. *Applicants whose files are complete by January 15 will receive full consideration for a GTA beginning the next fall semester. Applications that become complete after January 15 will be evaluated on a continuing basis for GTA support until all assistantships have been awarded.*

Occasionally, one or more GTA positions will become available at the start of the spring semester. In such a case, all unsupported students currently in Mathematics Graduate Program as well as applicants who have indicated they wish to begin that spring will be considered for the award(s).

Duties of a Teaching Assistant usually involve teaching one section of an elementary mathematics course per semester (normally 3 teaching hours per week), and conducting help sessions (1 to 2 hours per week). Full-time Master's students are commonly supported by a GTA, which is awarded in their first year and renewed for a second year based on good performance as a teacher and a student. Doctoral students are often supported on faculty research grants, although they are occasionally funded for one or two semesters by a GTA position to provide them with important teaching experience. The net amount of support from a grant is usually comparable to that of a GTA.

A limited number of Higher Education and Student Affairs Assistantships, whose recipients supervise residence hall activities, are available from the Student Affairs Division of the University (Nicholson House). The stipend is approximately the same as for a GTA.

Both GTAs and Student Affairs Assistantships are open to all applicants, domestic and international.

Fees for Graduate Students

Graduate students are responsible for certain fees (that are *not* covered by a GTA stipend). These include a Student Health Fee and Student Accident and Sickness Insurance. Complete information about all fees may be obtained from the Graduate College's web pages.

Information for New Students

The department runs an orientation for new students during the week before fall classes begin. Students are strongly encouraged to attend, and new recipients of Graduate Teaching Assistantships are required to attend.

During the orientation, you will learn your way around the department and meet the faculty, staff, and other graduate students. You will be given office assignments, computer accounts, and

Student Identification cards. We will help you to register for your courses and give you an introduction to the University computing system, including how to use UVM e-mail.

Graduate Teaching Assistants (GTAs) will find out their teaching assignments by the week before classes at the latest, with the goal of scheduling the assignment around courses the GTAs will enroll in themselves. Course syllabi and teaching methodology will be discussed during orientation. Generally, GTAs teach one course per semester. GTAs control their own course, planning and giving lectures, designing and grading examinations, and assigning the final grade. In some multi-section courses there are common syllabi and exams, supervised by a course leader. Usually GTAs teach an entry-level course. Typical topics involve elementary algebra, trigonometry, finite mathematics, and an introduction to calculus. We provide a sample syllabus and a textbook. GTAs must attend our teacher-training sessions during orientation. These sessions include delivering practice lectures and discussing common issues that arise.

We hope to have one to two classes available each summer for graduate students to teach. There is no guarantee that these classes will have sufficient enrollment to be offered, and cancellations can occur. Ph.D. students doing research towards their dissertation get priority for summer teaching assignments. We generally do not offer graduate-level classes in the summer.

GTAs should be aware that the first paycheck does not arrive until the middle of September (the last paycheck is at the end of May, after the end of spring semester). Students may request an advance on their salary under extreme circumstances. For more information please see Karen Wright.

Graduate Student Responsibilities

As Students

Graduate students are strongly encouraged to attend the department colloquia. Invited speakers make presentations on topics of current interest in mathematics, and often provide introductory talks especially suited for graduate students. Watch for the announcements! Also, students are encouraged to participate in seminars in various research areas. Graduate students should attend the department meeting at the beginning of each semester so that they can be introduced to the rest of the department.

The University community will not tolerate discrimination or sexual harassment. Both the *Graduate Catalogue* and the *Cat's Tale* contain information about these policies. Any student who has a complaint should notify the Office of Affirmative Action, Equal Opportunity, and Diversity Programs. Likewise, academic dishonesty will not be tolerated, and policies are described in the same sources.

As Teachers

Attend the training sessions offered by the department for first-time GTAs, and perform your teaching duties responsibly. In particular, hand out a syllabus the first day of classes detailing what material will be covered, the exam schedule, and the criteria for grading. A special rule here at UVM: you may not schedule an exam during the last 5 days of classes, so plan ahead. A

very helpful listing of standard teaching practices at UVM is available on the department website.

TAs should not cancel classes without first making every effort to find a substitute teacher. The Graduate Director should be notified of all substitute teaching and any required class cancellations. TAs need to hold regularly scheduled office hours, a total of approximately 3 hours per week, and inform the department of when they are (forms for this purpose are distributed at the beginning of each term). These hours should also be posted on course websites and on office doors.

Graduate Teaching Assistants are required to staff the Help Sessions. This responsibility is just as important as classroom teaching. Any TA who cannot be present must find a substitute. TAs should encourage their students to visit the Help Sessions for help outside of classes.

The graduate director, the course coordinators, and other mentors will be closely monitoring and evaluating TAs' teaching effectiveness. They are available to help TAs if any questions related to teaching should arise.

Department and University Awards

There are several awards programs in the department and university for graduate students.

Each year at Honors Day, the department gives the John F. Kenney Award to the outstanding graduate student in mathematics. The department also gives the Sang Kil Nam Scholarship Award to an outstanding undergraduate or graduate student in mathematics and statistics.

The department has one free one-year membership in the Mathematical Association of America and several one-year memberships in the American Mathematical Society. The Director of the Mathematics Graduate Program awards these to the most qualified eligible graduate students. Priority goes to second-year M.S. students. No student will receive the award more than once.

Each year, the Graduate College holds a university-wide competition for the Graduate Teaching Assistant of the Year. The department may nominate up to three students for this award (two in mathematics, one in statistics).

Each summer, the Graduate College offers a number of Graduate Student Summer Research Fellowships. For details, please contact the Graduate College.

Each fall, the university initiates a *Student-Faculty Research Program*. Students (junior/senior undergraduates and first year graduates) may apply for funding of a joint research project with a faculty member. Funding - including a stipend and supplies - is given for either the spring or summer. Application to this program is competitive, and requires submission of a proposal for review by a faculty panel. More information, including deadlines, application forms, etc.is available from UVM's Office of Sponsored Programs (on their web site as well).

Each April, the Graduate College and other offices on campus host the *UVM Student Research Conference*. Students engaged in research projects are strongly encouraged to participate.

Master's and Doctoral Degree Requirements

The following description of our degree requirements is included for your information. The online Graduate Catalogue contains the formal requirements including rules and regulations, e.g. those concerning residency for in-state tuition.

Doctor of Philosophy in the Mathematical Sciences

The Ph.D. degree requires 75 semester hours in coursework and dissertation research. Students must maintain a 3.0 GPA. Students are required to pass two qualifying exams and an oral examination; for details see the subsequent section on Doctor of Philosophy Qualifying Exams. Following successful completion of these exams, the student is admitted to candidacy for the degree. The candidate must then write a doctoral dissertation and pass a final oral defense of that dissertation. At least one semesters of college teaching experience is required.

Master of Science Degree Requirements

Each student must complete one of the following options:
a. Twenty-four hours of acceptable graduate credits in advanced mathematics courses; six hours of thesis research culminating in a master's thesis, or

b. Thirty semester hours of acceptable graduate credits in advanced mathematics courses; no thesis required.

Under either option, students must take, or acquire the knowledge of the content in, the courses Math 331 and 333, and must satisfactorily complete at least four 300-level mathematics courses and the seminar 382. In both options, students must select a *major concentration* from among the areas: Analysis, Algebra, Applied Mathematics, or Discrete Mathematics. The concentration shall consist of at least nine approved credit hours in advanced mathematics courses in the respective area, three of which must be at the 300-level; students in option a. may count the six hours of thesis credit towards these nine hours. (More detailed descriptions of the major concentration areas appear in the next section of this *Handbook*.) With approval of the student's advisor, up to six credit hours of courses outside mathematics may be used to fulfill the major or degree requirements.

Students must maintain a 3.0 cumulative GPA. Students must complete an oral comprehensive examination. This program usually requires two years (full-time) to complete.

Master of Science in Teaching

The M.S.T. degree is intended for people who are licensed teachers. The requirements are 30 hours of study in mathematics and completion of an oral comprehensive examination. Students must maintain a 3.0 GPA. This program usually requires two years to complete.

The M.S.T. degree specifically allows more than one 100 level course to count towards the degree.

Concurrent Credit for M.S. and Ph.D. Programs

Up to 30 credit hours of course work for which graduate credit is earned at UVM in a masters degree program, whether a masters degree is received or not, may be applied toward a Ph.D. at UVM, provided they are appropriate for the Ph.D. program. A student may thus potentially complete both the M.S. and Ph.D. degrees with a minimum of 75 credit hours of course and thesis work.

Note that an M.S. in statistics or biostatistics can be earned with the Ph.D. in mathematical science. Advising for the M.S. would be arranged through Professor Jeff Buzas in close coordination with the student's Ph.D. advisor.

Major Concentration Areas for the M.S. Degree Program

Each of the four major concentration areas is described, and pre-approved course sequences together with non-thesis sample programs are listed in each area. *Note that alternate courses may be used to fulfill the Major Concentration requirement, with the approval of the student's advisor.*

Major Concentration in Algebra

Students with a major concentration in Algebra must acquire a solid foundation in the fundamentals of abstract algebra, as covered in Math 251 and Math 252. Students are expected to go beyond this foundation by achieving some degree of depth in a more specialized area, as is normally treated in Math 351, Topics in Algebra.

Students wishing to pursue a major concentration in applied (or numerical) algebra may do so under the rubric of Applied Mathematics.

Pre-approved Course Requirements: the knowledge of Math 251, 252, and either 351 or an approved 395 course in algebra.

Sample Program with a Major Concentration in Algebra

First Year, fall:	Math 241 & 251 & XXX	(9 cr hrs)
First Year, spring:	Math 242 & 252 & 331	(10 cr hrs)
Second Year, fall:	Math 333 & 351	(7 cr hrs)
Second Year, spring:	Math XXX & XXX & 382	(7 cr hrs)

A third course in the fall of the Second Year could be taken in place of, or in addition to, the Third course in the fall of the First Year.

Major Concentration in Analysis

The student must acquire a firm knowledge of undergraduate analysis (Math 241 and 242), the basics of measure theory and the Lebesgue integral (Math 333), and the theory of functions of a complex variable (Math 331). The student should then build on this foundation to acquire a deeper knowledge and expertise in a more specialized area, such as functional analysis (Math 335, Math 336), differential equations (Math 330, Math 339), or Fourier analysis (Math 395: Special topics).

Pre-approved Course Requirements: the knowledge of Math 335, plus 330 or 339, and either 240 or an approved 395 course in analysis.

Sample Program with a Major Concentration in Analysis

First Year, fall:	Math 241 & 251 & one of 237,330,332,339	(9 cr hrs)
First Year, spring:	Math 242 & 252& 331	(10 cr hrs)
Second Year, fall:	Math 333 & one of 332,330,339	(7 cr hrs)
Second Year, spring:	Math 335,& XXX & 382	(7 cr hrs)

Major Concentration in Applied Mathematics

In tandem with taking the common core of courses in real and complex analysis, students with a major concentration in Applied Mathematics must acquire a rigorous knowledge of foundational areas of applied mathematics such as numerical analysis (Math 237, 238) and differential equations (Math 330, 339). In addition, students must gain an in-depth experience involving the application of mathematics to real-world problems; such experience may be obtained through mathematics courses (eg., Math 266, Math 268, Math 300, Math 303), or through appropriate graduate level courses outside the Mathematics Program. In the latter case, students must obtain prior written approval from their advisor to ensure that the courses outside the Mathematics Program appropriately supplement the applied mathematics courses to form a cohesive, in-depth major concentration.

Alternatively, students may pursue an applied mathematics concentration with a focus in appropriate areas of algebra, analysis, or discrete mathematics. In such areas the mathematical foundation component may be different (eg., Math 274 may be appropriate), and again courses outside the Mathematics Program may be utilized or even required (in CS, for example).

However, the fundamental stricture – that students must gain a solid mathematical foundation coupled with significant in-depth experiences in an applications area – must be met through a carefully advised, pre-approved program.

Pre-Approved Course Requirements: the knowledge of Math 237 and 268, and either 330 or 339.

Sample Program with a Major Concentration in Applied Math

First Year, fall:	Math 237 & 241 & 330	(9 cr hrs)
First Year, spring:	Math 337 & 242 & 331	(10 cr hrs)
Second Year, fall:	Math 333 & 268 & XXX	(10 cr hrs)
Second Year, spring:	Math 339 & XXX & 382	(7 cr hrs)

Major Concentration in Discrete Mathematics

Students with a major concentration in Discrete Mathematics must acquire a solid foundation in the fundamentals of abstract algebra, as covered in Math 251 and they must also acquire a working knowledge of graph theory (Math 273). Further, students are expected to go beyond this foundation by achieving some degree of depth in a more specialized area, as is normally treated in Math 373, Topics in Combinatorics

Pre-approved Course Requirements: the knowledge of Math 251 and 273, and either 373 or an approved 395 course in combinatorics or related area of theoretical computer science.

Sample Program with a Major Concentration in Discrete Math

First Year, fall:	Math 241 & 251	(6 cr hrs)
First Year, spring:	Math 242 & 252 & 273	(9 cr hrs)
Second Year, fall:	Math 333 & 3xx & 373	(10 cr hrs)
Second Year, spring:	Math 331 & 2xx & 382	(8 cr hrs)

It is essential that students interested in pursuing the major concentration in Discrete Mathematics discuss their plan of study with an advisor as there are many possibilities for the program.

Oral and Written Examinations

The nature and timing of the written and oral examinations depend on your degree objective and whether you've concentrated on pure or applied mathematics.

Master's Oral Examinations

All students for the M.S. or M.S.T. degree are required to pass an oral comprehensive examination. There is no written exam for the M.S. or M.S.T. degree. Generally the oral exams are given in March of the student's second year. The department requires exams to be finished by the beginning of April; the Graduate College has an absolute deadline in late April.

Any student taking an oral examination should contact the Director of the Mathematics Graduate Program at the beginning of the semester. In consultation with the Graduate Committee, the Director will appoint a committee of at least three people. The chair of this committee must be a member of the Graduate Faculty. Generally, each member of the committee assumes responsibility for questions in one of the primary areas. However, any member is free to ask questions in any area. The exam generally requires two hours. On occasion an examining committee may require the student to retest in one or more areas before making a final decision.

For M.S. students with any major concentration the final oral exam will cover three areas: Real Analysis (Math 241, 242, 333; approximately 30 min.), Complex Analysis (Math 331; approximately 30 min), and the major concentration area (approximately 40 min. Students completing the thesis option will be examined in their major concentration as part of their (required) thesis defense; therefore in their regular oral exam these students will only be examined in Real Analysis and Complex Analysis.

The guidelines for the M.S. ORAL EXAMINATION only require that the student *has knowledge of* the material; it does not require that the student has taken the corresponding courses. Thus a student who has entered the program with a strong background may not need to take the courses listed above. *Students taking this exam are encouraged to get a Study Guide from the Director of the Mathematics Graduate Program.* The study guide includes sample M.S. oral exam questions.

Students pursuing the M.S.T. degree may not have taken the full complement of courses covering the required topics for the M.S. oral examination. Nevertheless, the student is still responsible for some knowledge in each area. These students and their advisors should carefully prepare a plan of study in preparation for the exam. The student should arrange with their advisor, the Director of the Mathematics Graduate Program, and the Chair of the Examining Committee for the exact syllabus on the oral exam.

Doctor of Philosophy Qualifying Examinations

Doctoral candidates are required to pass three qualifying exams (two written and one oral):

Students will take written examinations in a total of two areas (in no particular order). Students with a concentration in Pure Mathematics will take exams in

1. Real & Complex Analysis (331 and 333),
2. Algebra (251 and 252).

Students with a concentration in Applied Mathematics will take exams in

1. Numerical Analysis (237 and 337),
2. Differential Equations (330 and 339).

In addition, all students will take a 2-hour oral qualifying exam in a topic chosen in consultation with their research studies committee whose members will be present for the examination. Topics currently offered include

3a. Number Theory (255 and 351 as appropriate)
3b. Combinatorics (273 and 373 as appropriate)
3c. Functional Analysis (335)
3d. Methods of Applied Mathematics (395)
3e. Complex Systems (266 and 300)
3f. Nonlinear PDEs (395)
3g. Mathematical Biology and Ecology (268)

Students interested in taking an oral exam in a topic not found in the above list are encouraged to contact the Graduate Director regarding other possible exam topics.

Note that it is only required that a student acquire a knowledge of the material in these areas; it is not required that they take the corresponding courses. A student who enters the program with an exceptionally strong background may attempt the exams without the coursework.

These exams are offered twice a year: at the start of the spring semester (the middle of January), and after the end of the academic year (the end of May).

Students are encouraged to try their first exam by the end of the first year of study. They must pass at least one exam by January of their second year of study, and pass all three exams by September of the third year. Students are allowed two chances to pass each exam.

One to two months in advance of the exam date, the graduate director will send out an email reminder, which will give a deadline for students to inform the director of their intention to take an exam. The Graduate Committee will prepare, administer, and grade the exams. Students can expect to hear the results two weeks after taking the exam.

Doctoral students taking a written exam are encouraged to get a syllabus from the Director of the Mathematics Graduate Program. Separate syllabi are available in each area. Some previous exams with solution sets are posted on the "Graduate Programs" section of the departmental website.

Master Degrees and Advancement to Candidacy for Doctoral Students

After successful completion of the qualifying exams a doctoral candidate can petition for awarding of the M.S. degree and advance to candidacy for the Ph.D. degree. A student may be awarded the M.S. degree but not be admitted to candidacy for the Ph.D. if the student fails a particular examination twice, but is deemed to have done sufficiently well in their coursework and examinations.

Advising and Program Requirements

All graduate students should periodically check the Graduate College's web pages for Current Students (http://www.uvm.edu/~gradcoll) for relevant information. The director of the Mathematics Graduate Program will pair each student with an advisor from among the Graduate Faculty. Students are welcome to change advisors in accord with their interests.

Because of the size of the graduate program and the need to provide funding for students, applicants to the Ph.D. program are generally not admitted without their first identifying a suitable research and dissertation advisor (or advisors). As soon as possible after matriculation, the student should, in consultation with the Graduate Program Director and identified faculty advisor, establish a Studies Committee. It is the responsibility of the Studies Committee to supervise the graduate student's program and to review progress at regular intervals. The Studies Committee consisting of at least three members of the Graduate Faculty is appointed by the Graduate Program Director and approved by the Dean of the Graduate College. The student's academic/dissertation advisor serves as the Chairperson of the Studies Committee. On occasion, it may be appropriate for a professional other than a member of the Graduate Faculty to serve as a member of the Studies Committee, and in this case written approval must be obtained from the Dean of the Graduate College prior to the student's beginning dissertation research.

The Studies Committee must meet with the student at least annually, and more frequent consultation is both highly recommended and encouraged. A brief report from these meetings certifying appropriate progress toward completion of the degree (e.g., timely completion of required Qualifying Exams) and indicating any items of importance (e.g., agreed-upon timelines for completion of thesis work) appropriate for the record should be prepared for the Graduate Program Director. These reports will be forwarded to the Graduate College and placed in the candidate's graduate record.

The graduate students play an important role in the shaping of our curriculum. The graduate committee welcomes suggestions on course offerings. If a number of students would like to take a particular course they should contact the Director of the Mathematics Graduate Program or a professor with interests in that area. This is especially important for topics courses in areas where students want to do thesis research.

Most 200 level courses are available for both undergraduate and graduate credit. In these courses students attend common lectures. Usually, however, the graduate students may be given

additional homework assignments and different exams, and held to higher grading standards. Please note that credit for Math 230 does not apply towards a degree in Mathematics. Math 230 is considered elementary material which a student should have had as an undergraduate. A student who needs to review this material may sit in on this course without credit, or study the material independently. If they do take the course for credit the tuition will be covered under a Graduate Teaching Assistantship, but the credits earned will *not* count towards the degree.

Master's students are required to take Math 382 (Graduate Seminar). Master's students choosing the thesis option may sign up for Math 391, Master's Thesis Research. Doctoral students may sign up for Math 491, Doctoral Dissertation Research. All students are recommended to take Math 330, Advanced Ordinary Differential Equations, but this course is not required.

Students and advisors should carefully read the section on oral and written examinations in this handbook for information on the scheduling, topics, and structure of these exams.

Advisors should note that GTA students carry a tuition waiver covering up to 9 credits per semester. A minimum of 6 credits per semester is needed to maintain full-time graduate student status. Credits above the 9 credit remission per semester are charged to the student on a per-credit basis. However, with the approval of the Graduate College and the student's advisor, it may be possible to waive this extra fee, provided that a student takes at most 24 credits per year. Students interested in this possibility should ask the Graduate College.

Depending on the degree option, a student may be required to pass a thesis defense (applicable to all doctoral candidates, and to those masters candidates writing a thesis) depending on the program of study. A student writing a thesis or dissertation should consult the Thesis and Dissertation information linked to the Graduate College webpage under "Policies and Procedures."

On occasion a graduate student may desire to postpone or suspend studies for a period of time. Students may apply for up to one year's leave of absence, a semester at a time. Application forms are available at the Graduate College.

A student who has finished all coursework but not yet graduated can sign up for Continuous Registration. This option maintains one's full-time student status while minimizing tuition costs. This is done by registering for a semester of GRAD 903 at a cost of $300 per semester.

Sample Schedule for the Doctoral Program

	Pure	Applied
Fall Year 1:	241 & 251 elective	241 & 237 elective
Spring Year 1:	242 & 252 & 331	242 & 339 & 331

1st Ph.D. Written Exam		
Fall Year 2:	333 & first topic elective	330 & first topic elective
2nd Ph.D. Written Exam		
Spring Year 2:	second topic elective & elective	second topic elective & elective
3rd Ph.D. Written Exam		
Subsequent Years:	elective & 491	elective & 491

Accelerated Master's Program

The Accelerated Master's Program (AMP) in mathematics is designed so that students with strong ability and motivation can complete a bachelor's degree in mathematics, science or engineering, as well as a master's degree in mathematics at UVM within five years. Interested students should also see the general description of Accelerated Master's Programs on the Graduate College web pages.

The first four years consist of an undergraduate program that includes the core requirements for a minor in mathematics together with other courses that lay a solid mathematical foundation; this portion culminates in a bachelor's degree. During the fifth year, students take courses that complete the requirements for the master's degree in mathematics.

The AMP in mathematics integrates the undergraduate and graduate experiences so that students receive both the breadth and depth they would achieve had they completed the two degrees separately.

Requirements for Admission

The Accelerated Master's Program in mathematics is designed for students who are mathematics majors, or who are majors in science or engineering with a minor in mathematics. A student who is enrolled in this AMP may count 6 credits of Mathematics coursework at or above the 200-level for both the undergraduate and the graduate degrees. If interested in the AMP in Mathematics, a student declares this interest in writing to the Director of the Mathematics Graduate Program before taking any courses that he or she would like to count towards both degrees. The student should also be sure to inform the course instructors that he or she wishes to participate in these courses at the graduate level.

Formal application for the Accelerated Master's Program in mathematics is made during the spring pre-registration period of the student's junior year. The student carries out the usual procedure for admission to the M.S. Program in mathematics, including submission of letters of

recommendation. Application forms are available online. *The student's admissions essay must specifically address why the student wishes to enter the Accelerated Master's Program*. GREs need not be completed until the fall semester of the applicant's senior year.

Applicants must achieve the following by the end of their junior year:

1. Completion of Math 21, 22, 52, 121, and 124 with an overall GPA of 3.0 or higher,

2. Completion of Math 241 and Math 242 with grades of B+ or better in each, and

3. Completion of a least two additional 200-level mathematics or statistics courses with grades of B+ or better in each.

Requirements for Advancement to Candidacy in the AMP

Students who have been admitted to the Accelerated Master's Program in mathematics normally advance to candidacy in this program at the end of their senior year. This marks the end of their undergraduate curriculum and the beginning of their graduate curriculum. The criteria for advancement to candidacy are:

1. Completion of a bachelor's program in mathematics at UVM, or completion of a bachelor's program in science or engineering at UVM with a minor in mathematics;

2. Satisfactory performance on the general GRE exam (to be taken by the fall semester of the applicant's senior year);

3. Completion of at least two additional mathematics or statistics courses at the 200-level with grades of B or better in each (these are in addition to Math 241, 242 and the two 200-level courses required for admission to the program); and

4. Completion of a 300-level course in Mathematics with a grade of B or better. This course may not be counted towards the student's undergraduate degree or GPA, and so must be taken as an overload.

Students who have been admitted to the AMP on the completion of their junior year but who fail to meet the requirements for advancement to candidacy for the M.S. degree will only be permitted to continue towards their M.S. degree after review by the Graduate Program Committee and with the written approval of the Director of the Graduate Program in Mathematics.

Requirements for Completion of the Master's Degree Portion of the Program

A total of 30 total credits are required for the Master's degree, of which 6 may be in

Mathematics courses at the 200-level or above that were counted towards the Bachelor's degree, and 3 or 4 may come from a 300-level course taken as an overload in the undergraduate years. Fulfilling the M.S. degree requirements then calls for the completing the remaining credit hours, including the Math 382 seminar and two other 300-level mathematics courses. The course of study must include either 6 credits of thesis work or 9 credits in an approved major subject featuring a 300-level course. Students must pass the M.S. oral exams covering real analysis and complex analysis. These exams will also cover the major subject unless the student has chosen the thesis option, in which case there will be a thesis defense. For more details, see the section of the Handbook for Graduate Studies in Mathematics that is devoted to Master of Science Degree Requirements.

Sample AMP Schedule

First Year, fall:	Math 21 (4 hrs) & CS 21 & 3 electives	(16 hrs)
First Year, spring:	Math 22 (4 hrs) & Math 52 & 3 electives	(16 hrs)
Second Year, fall:	Math 121 (4 hrs) & (Math 141, 151 or 1XX) & 3 electives	(16 hrs)
Second Year, spring:	Math 124 & (Math 1XX or 2XX) & 3 electives	(15 hrs)
Third Year, fall	Math 241 & (Math 230 or 2XX) & 3 electives	(15 hrs)
Third Year, spring	Math 242 & Math 2XX & 3 electives	(15 hrs)
Fourth Year, fall	Math 333 (4 hrs) & Math 251 & 3 electives	(16 hrs)
Fourth Year, spring	(Math 252 or 2XX) & (Math 2XX or 3XX) & 3 electives	(15 hrs)
Fifth Year, fall	Math 2XX & 2XX & 3XX & 3XX	(12 hrs)
Fifth Year, spring	Math 331 (4 hrs) & Math 382 (1 hr) & 3XX	(8 hrs)

For more information and a formal list of requirements please contact the Director of the Mathematics Graduate Program.

Course Descriptions

The following informal course descriptions are included for your information. The catalogue contains the formal course descriptions, credit hours, and prerequisites.

Mathematics Courses

Math 230 *Ordinary Differential Equations* Solutions of ordinary differential equations, the Laplace transformations, series solutions of differential equations. *This course is available for*

graduate credit for students in other areas, but credit for this course will not count towards a mathematics graduate degree.

Math 231 *Real Analysis in One Variable* This course is intended to be a terminal course in real analysis. *It is not available for graduate credit*. Graduate students should take Math 241 in its place.

Math 236 *Calculus of Variations* Basic theory: first and second variations; Euler-Lagrange equation for extremals; isoperimetric problems; Hamilton's principle. Emphasis on classical examples and applications.

Math 237 *Introduction to Numerical Analysis* This course develops methods for obtaining numerical solutions to problems too difficult to be solved "in closed form." In addition, the course explores the effect of fixed precision arithmetic when using a computer with these methods. Topics include: methods for solving f(x)=0 and a discussion on efficiency of the computations; methods for solving systems of *n* equations with *n* unknowns, and the effect of having nearly duplicate information (ill-conditioned systems); the problem of generating a function or functions to describe a given set of data (interpolation, splines, least squares); and the problem of estimating the value of definite integrals too difficult to find antiderivatives for.

Math 240 *Fourier Series and Integral Transforms* The purpose of the course is to study integral operators and related Fourier series expansions which are useful in solving initial and boundary value problems for differential equations. Topics covered include Green's functions for initial and boundary value problems, Laplace transforms, classical and more general Fourier expansions, eigenvalue methods for boundary value problems.

Math 241 *Real Analysis I* Much of mathematics is traditionally divided into the general areas of Abstract Algebra and Analysis. In our curriculum, these topics are introduced in Math 251 and Math 241. Math 241, Real Analysis I, may be viewed as an extension of the main ideas from Calculus: Limits, derivatives, integrals, and convergence of sequences and series. In this course the student studies the basic properties of sets of real numbers, including the topology of Euclidean *n*-space, and analyzes the behavior of real-valued functions defined on such sets. This sets the stage for generalizations such as abstract metric spaces and other more modern notions.

Math 242 *Real Analysis II* This is the spring semester continuation of Math 241. Topics normally include: differentiation in $\mathbf{R}^n$, Riemann-Stieltjes integral, uniform convergence of functions, Inverse and Implicit Function Theorems.

Math 251 *Abstract Algebra I* Basic theory of groups, rings, fields, homomorphisms, and isomorphisms. The course is set at the level of the text *Abstract Algebra, Second Edition* by D. Dummit and R. Foote (John Wiley & Sons, Inc.).

Math 252 *Abstract Algebra II* This is the spring semester continuation of Math 251. Topics include: modules, vector spaces, linear transformations, rational and Jordan canonical forms, finite fields, field extensions, and Galois Theory leading to the insolvability of quintic equations.

Math 255 *Number Theory* Number theory has been called the "Queen of Mathematics", because it involves the development of a wide variety of useful methods and produces beautiful and profound results concerning one of the most basic objects in mathematics: the natural numbers. This course allows one to appreciate the work of many mathematical giants and some of the relationships between geometry, algebra, and analysis. Those interested in the history or teaching of mathematics, or in obtaining a concrete introduction to some of the concepts of abstract algebra will find this to be an attractive course which can be taken early in the major. The ideas found here, originally thought to be purely theoretical, now find applications of critical importance to society.

Math 257 *Topics in Group Theory* Topics may include abstract group theory, representation theory, classical groups, Lie groups.

Math 264 *Vector Analysis* Fundamental algebraic properties of vectors in Euclidean spaces. Applications to geometry and physics. Tensors.

Math 266 *Chaos, Fractals, and Dynamical Systems* Discrete and continuous dynamical systems, Julia sets, the Mandelbrot set, period doubling, renormalization, Henon map, phase plane analysis, and Lorenz equations.

Math 268 *Mathematical Biology and Ecology* Mathematical modeling in the life sciences. Topics include population modeling, dynamics of infectious diseases, reaction kinetics, wave phenomenon in biology, and biological pattern formation.

Math 272 *Applied Analysis* Fourier series; solution of the wave, heat, and Laplace equations by eigenfunction expansions; Fourier-Bessel series; complex variables; conformal mapping; Schwarz-Christoffel mappings.

Math 273 *Combinatorial Graph Theory* A graph is a collection of points together with lines joining pairs of these points. Graphs are used to model a wide variety of situations. For example, the points may represent microprocessors with the lines representing communication channels. When can we lay out the computer circuit without crossing wires? Or perhaps the points of a graph represent people and the lines indicate friendships. When can we pair together the people so that everyone is with a friend? Or perhaps the points are airports and the lines are flights. How can a traveler arrange his or her schedule to minimize the total cost of her trip? These and other topics are explored in Math 273, Combinatorial Graph Theory. The questions above are respectively special cases of graph planarity, matching theory, and the Hamilton cycle problem. You will also study paths and trees in graphs (connection problems), Eulerian cycles (postman problems), and point and line colorings (storage and scheduling). Finally, what does all this have to do with the five Platonic solids and the thirteen semiregular polyhedra? Take the course and find out!

Math 274 *Numerical Linear Algebra* The purpose of the course is to study numerical algorithms for solving systems of linear equations, manipulating matrices, solving least squares problems, determining rank computationally, finding eigenvalues, and determining sensitivity of solutions to perturbations. The course emphasizes the importance of determining numerical stability of algorithms since floating point computation inevitably introduces errors compared with ideal exact computations.

Math 275,276 *Advanced Engineering Analysis I,II* Problems in analysis in engineering, including ordinary and partial differential equations, special functions, matrices, tensor analysis, variational calculus, complex variables, perturbation methods.

Math 295 *Special Topics* Math 295 adds variety to the schedule of course offerings by providing for the study of different topics each semester upon the initiative of students or of faculty members. A student or group of students interested in pursuing a particular topic may request to enroll in one of these courses for this purpose. They may approach a particular faculty member, or ask the chair of the department for assistance in locating a suitable instructor. Faculty members tend to be quite receptive when students come forward with ideas demonstrating a real enthusiasm for mathematics. Another possibility is that a faculty member may announce the intention to teach a Math 295 course on a topic of particular interest to him or her. Watch for these announcements in your mathematics classes or consult your advisor. These courses often involve some independent study and other activities which take advantage of their intimate and informal nature.

Math 300 *Principles of Complex Systems* Introduction to fundamental concepts of complex systems. Topics include: emergence, scaling phenomena, and mechanisms, multi-scale systems, failure, robustness, collective social phenomena, complex networks. Students from all disciplines welcomed. Pre/co-requisites: Calculus and statistics required. Linear Algebra, Differential Equations, and Computer programming recommended but not required. Cross-listing: CSYS 300. Credits: 3

Math 303 *Complex Networks* Detailed exploration of distribution, transportation, small-world, scale-free, social, biological, organizational networks; generative mechanisms; measurement and statistics of network properties; network dynamics; contagion processes. Students from all disciplines welcomed. Pre/co-requisites: Math 300/CSYS 300, Calculus, and Statistics required. Cross-listing: CSYS 303. Credits: 3

Math 330 *Advanced Ordinary Differential Equations* Linear and nonlinear systems, approximate solutions, existence, uniqueness, dependence on initial conditions, stability, asymptotic behavior, singularities, self-adjoint problems.

Math 331 *Theory of Functions of Complex Variables* Differentiation, integration, Cauchy-Riemann equations, infinite series, properties of analytic continuation, Laurent series, calculus of residues, contour integration, meromorphic functions, conformal mappings, Riemann surfaces.

Math 332 *Approximation Theory* Interpolation and approximation by interpolation, uniform approximation in normed linear spaces, spline functions, orthogonal polynomials. Least square, and Chebychev approximations, rational functions.

Math 333 *Theory of Functions of Real Variables* The theory of Lebesgue integration, Lebesgue measure, sequences of functions, absolute continuity, properties of L^p -spaces.

Math 335, 336 *Advanced Real Analysis* L^2-spaces, L^p-spaces; Hilbert, Banach spaces; linear functionals, linear operators; completely continuous operators (including symmetric); Fredholm alternative; Hilbert-Schmidt theory; unitary operators; Bochner's Theorem; Fourier-Plancherel, Watson transforms.

Math 337 *Numerical Differential Equations* Numerical solution and analysis of differential equations: initial-value and boundary-value problems; finite difference and finite element methods. Prerequisites: MATH 237, either MATH 230 or 271 recommended. Credits: 3

Math 339 *Partial Differential Equations* Classification of equations, linear equations, first order equations, second order elliptic, parabolic, and hyperbolic equations, uniqueness and existence of solutions.

Math 342 *Computability and Recursive Function Theory* Cross-listed as Computer Science 342.

Math 351 *Topics in Algebra* Topics include algebraic number theory, commutative algebra, modular forms, representation theory, algebraic geometry, and the arithmetic of elliptic curves. May be repeated for credit with the permission of the instructor and the advisor.

Math 353 *Point-Set Topology* Topological spaces, closed and open sets, closure operators, separation axioms, continuity, connectedness, compactness, metrization, uniform spaces.

Math 354 *Algebraic Topology* Homotopy, covering spaces, homology and cohomology theories, fixed point theorems.

Math 373 *Topics in Combinatorics* Topics will vary each semester and may include combinatorial designs, coding theory, topological graph theory, cryptography.

Math 382 *Seminar* Topical discussions with assigned reading. This one credit-hour course is required of M.S. candidates.

Math 391 *Master's Thesis Research* Provides up to 6 credits for research and preparation of a M.S. Thesis.

Math 395 *Special Topics* See the description for Math 295. This course is now available for variable credits.

Math 491 *Dissertation Research* This course provides credit for the research and preparation of your Ph.D. dissertation.

Statistics Courses

Stat 200 *Medical Biostatistics* Introductory design and analysis of medical studies. Epidemiological concepts, case-control, and cohort studies, and clinical trials. Students evaluate statistical aspects of published health science studies. (Required for Biostat M.S.)

Stat 211 *Statistical Methods I* Fundamental concepts and techniques for data analysis and experimental design, descriptive and inferential statistics, including classical and nonparametric methods, regression, correlation and analysis of variance. This course is taken as an introduction by graduate students of various disciplines (but would not count as credit for the statistics or biostatistics M.S. degrees).

Stat 221 *Statistical Methods II* Multiple regression and correlation, basic experimental design. analysis of variance (fixed, random and mixed models) and analysis of covariance. Computer software usage. (Required for the stat/biostat M.S.)

Stat 223 *Applied Multivariate Analysis* Analysis methods for categorical and continuous multivariate data, discriminate analysis, logistic regression, canonical correlation, principal components, factor analysis and log linear models, computer software usage. (Required for the stat/biostat M.S.)

Stat 224 *Statistics for Quality and Productivity* Statistical methods for product quality and productivity, statistical process controls Shewhart and CUSUM, contorl charts, acceptance, continuous, sequential sampling. Selected statistical computer programs utilized. (Required for the stat M.S.)

Stat 225 *Applied Regression Analysis* Regression analysis is concerned with how to predict the values of one variable (y) from the given values of other variables (x_1, x_2, …); the simplest example being a straight line (linear) relation $f(x)=ax+b$. With real data collected on y and x the function f never exactly explains y in terms of the $x$values, and so one typically uses a least squares error approach to obtain the best fitting functions to the data. Regression analysis is the basic method used in business, economics and other social/behavioral sciences, health and other biological sciences, and engineering and other physical sciences to fit mathematical models of real data. The standard models and assumptions are reviewed, fitting methods discussed (with software and appropriate matrix methods), and methods of checking the fit (residual analysis) are covered. Linear, multiple, polynomial, logistic, and ridge regressions are included. Important forecasting applications provide some of the examples.

Stat 231 *Experimental Design* Randomization, complete and incomplete blocks, cross-overs, covariance analysis, factorial experiments, confounding, fractional-replication, nesting, split-plots, repeated measures, response surface optimization, Taguchi methods, and optimal designs. (Required for the stat/biostat M.S.)

Stat 233 *Design of Sample Surveys* Design and data analysis for sample surveys. Simple random, stratified, systematic, cluster, multistage sampling. Practical issues in planning and conducting surveys.

Stat 237 *Nonparametric Statistical Methods* Nonparametric and distribution free methods; categorical, ordinal and quantitative data; confidence intervals; rank and Chi-Square hypothesis tests; computer-intensive procedures (Bootstrap, exact tests).

Stat 241 *Statistical Inference* Introduction to statistical theory: related probability fundamentals, derivation of statistical principles and methodology for parameter estimation and hypothesis testing. (Required for biostat M.S.; but mathematics graduates would be recommended to take Stat 261.)

Stat 251 *Probability Theory* Distributions of random variables and functions of random variables. Expectations, stochastic independence, sampling and limiting distributions (central limit theorems). Concepts of random number generation. (Required for stat M.S.)

Stat 253 *Applied Time Series and Forecasting* A fundamental problem in business, economics, engineering and other sciences is providing forecasts for the future values of data collected in time order. Modern statistical models (autoregressive integrated moving average models) are developed in this course, which can be used in the analysis of time series data, fitting models to these data, checking forecast errors, and providing future forecasts. Seasonal effects are considered as well. If information from other series (x) can be used to aid in the forecast of y, then one can use transfer function models for the analysis. You gain practical experience in fitting a variety of real series with the latest software methods.

Stat 261 *Statistical Theory I* Point and interval estimation, hypothesis testing, and decision theory. Applications to areas such as nonparametric tests, sequential analysis and linear models. (Required for stat M.S.)

Stat 287 *Data Science I* Data harvesting, cleaning, and summarizing. Working with non-traditional, non-numeric data (social network, natural language textual data, etc.). Scientific visualization using static and interactive "infographics". A practical focus on real datasets, and developing good habits for rigorous and reproducible computational science.

Stat 330 *Bayesian Statistics* Introduction to Bayesian inference. Posterior inference, predictive distributions, prior distribution selection. MCMC algorithms. Hierarchical models. Model checking and selection. Use of computer software.

Stat 355 *Statistical Pattern Recognition*
Analysis of algorithms used for feature selection, density estimation, and pattern classification, including Bayes classifiers, maximum likelihood, nearest neighbors, kernels, discriminants, neural networks and clustering.

Stat 360 *Linear Models*
Theory of linear models, least squares and maximum likelihood estimation, fixed, random and mixed models, variance component estimation, introduction to generalized linear models, bootstrapping.

Stat 387 *Data Science II* Advanced data analysis, collection, and filtering. Statistical modeling, monte carlo statistical methods, and in particular Bayesian data analysis, including necessary probabilistic background material. A practical focus on real datasets and developing good habits for rigorous and reproducible computational science.