THE UNIVERSITY OF ARIZONA
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Mathematics

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Mathematics Graduate Program At the University of Arizona

Photo by the University of Arizona

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About Our Department

Members of the department create, communicate, and apply mathematics of the highest caliber through activities such as internationally recognized research and graduate education, award winning undergraduate programs, and extensive outreach to local schools.

The department's faculty includes two Regents' Professors, three University Distinguished Professors, and numerous recipients of national and international awards. A large percentage of the faculty has been awarded grants and contracts from external funding agencies, with total awards averaging about $2 million per year.

The department offers PhD, MS, and MA programs in Mathematics and Mathematics Education, and it provides major contributions to the Graduate Interdisciplinary Degree Programs in Applied Mathematics and Statistics. It also offers many postdoctoral opportunities for recent PhDs planning careers in research and education.

At the undergraduate level, the department provides more than 46,000 credit hours of instruction per year and offers its more than 600 majors and more than 800 minors unparalleled opportunities for research, tutoring experiences, and internships.

The department has a long and excellent tradition of outreach to schools in Tucson, ranging from programs supporting high school teachers to a research center focusing on improving the mathematics education of low-income Latino students.

Through the breadth and quality of its programs, the Department of Mathematics makes major contributions to the mission of the University of Arizona and to the quality of life in Tucson and beyond.

The central goal of the Department of Mathematics at the University of Arizona is to provide intellectual leadership in the mathematical sciences that is of direct benefit to the state and its citizens and commands national and international respect for its depth of scholarship.

Department Mission Statement

Specifically our goals are:

- to communicate the beauty, utility, and excitement of mathematics and to be at the frontiers of new discoveries;
- to prime the pipeline pump and prepare a broad and ethnically diverse spectrum of entering students, enabling them to meet the challenges of University programs whose quality will continue to climb;
- to build a first-rate, enthusiastic and vigorous faculty blending youth and maturity in a variety of overlapping fields across the broad spectrum of mathematical sciences with the dual aims that each individual is internationally recognized for the depth and originality of his or her contributions and that the collaborations lead to an environment in which the whole is greater than the sum of the parts;
- not to do all things, but to do well those things we do;
- to provide flexible yet solid undergraduate and graduate programs which challenge the intellect, cater to the diverse interests of our majors and which complement, particularly at the graduate level, our internationally recognized Interdisciplinary Program in Applied Mathematics;
- to encourage and foster creativity and scholarship in their broadest possible interpretations;
- to encourage students in the belief that they gain most from the university experience by developing self-discipline, self-reliance and, under appropriately supervised conditions, by giving full rein to their own creativity;
- to embrace the notion that change such as is manifested in computer technology and educational reform can be beneficial, enhance learning and enrich the intellectual environment;
- to be a resource in the mathematical sciences for other disciplines whose own activities have an ever-increasing need for the power of mathematics;
- to work closely, not only with colleagues from other disciplines within the University, but also with colleagues from the local schools and community colleges who share the responsibility of ensuring the flow of a mathematically literate and confident generation of new Students;
- to be part of a University which aspires to be the best and which pursues policies compatible with this goal.

What Constitutes a Rigorous Undergraduate Mathematics Major

Here is a list of topics from various areas of mathematics that we believe describes a basis for a complete, rigorous undergraduate mathematics major. At University of Arizona, this essentially consists of the content of the courses Math 413 (Linear Algebra), Math 415A (Introduction to Abstract Algebra), Math 415B (A Second Course in Abstract Algebra), Math 424 (Theory of Complex Variables), Math 425A (Real Analysis of One Variable), Math 425B (Real Analysis of Several Variables), Math 432 (Topological Spaces).

Students are generally expected to take similar such courses or learn this material on their own. We have included this list so that students can see if their background meets these expectations, or if some of these courses will need to be taken prior to taking the graduate core courses as described in the next section. We strongly encourage each entering student to review (or learn) this material, using the references mentioned or other similar ones.

We note that the phrase "know" in the first sentence above does not mean *have seen*. Rather, we expect that students will know the definitions, the main examples and major theorems and how these fit together, and also that they can solve interesting problems using these concepts. The best way to test your level of understanding is to get a book on the subject and go directly to the exercises. If you can do most of them without breaking a sweat, then you *know* the topic. If not, be sure to go back and see that you understand the basics, not just how to do those exercises.

A. Linear Algebra

1. Vector spaces and linear transformations. subspaces, quotient spaces, and direct sums. Kernel and image of a linear transformation.
2. Bases in a linear space. The matrix of a linear transformation with respect to two bases. Change of basis formula.
3. Gaussian elimination ("row reduction") and applications to systems of equations, ranks.
4. The dual space and the transpose of a linear transformation.
5. Determinants, traces, characteristic and minimal polynomials.
6. Eigenvectors and eigenvalues. Generalized eigenvectors. Various normal forms, especially the Jordan form. The determinant, trace, and characteristic polynomial in terms of the eigenvalues.
7. Scalar products (both complex and real). Matrix of a scalar product and change of basis formula. Orthonormal bases and the Gram-Schmidt process.
8. Self-adjoint and symmetric operators. Unitary and orthogonal operators. Spectral theorems.

References

Axler *Linear Algebra Done Right* is well-written and accurately titled. Hoffman and Kunze *Linear Algebra* is a standard reference which is a bit more high-brow.

B. Vector Calculus and Differential Equations

1. The derivative of a function f: $\mathbf{R}^n \to \mathbf{R}^m$. Linear approximation.
2. Line integrals. The multidimensional Riemann integral. Change of variables formula.
3. Div, grad, curl. Divergence theorem, Stokes' theorem, Green's theorem.
4. Existence and uniqueness of solutions to a first order ODE.
5. First and second order linear ODEs with constant coefficients.
6. Higher order linear ODEs and systems of first order ODEs.

References

Courant *Differential and Integral Calculus* is a classic. Another option is Apostol's two-volume *Calculus* (Wiley). You might supplement either with the differential equations books by Boyce and DiPrima or Edwards and Penney.

C. Complex Analysis

1. Holomorphic (analytic) functions.
2. Elementary functions and the mappings that they define.
3. Conformal mappings. Problems such as finding a conformal mapping from a quadrant to a disc.
4. The Taylor series of a holomorphic function.
5. Contour integrals. Cauchy's theorem. The Cauchy formula.
6. Poles. Meromorphic functions. Laurent series. Residues.
7. Evaluating contour integrals of meromorphic functions.
8. Using complex integration for evaluating some improper integrals.

References
Churchhill and Brown *Complex Variables and Applications*. Two more advanced references are Ahlfors *Complex Analysis*, and Conway *Functions of One Complex Variable*.

D. Algebra

1. Groups and homomorphisms of groups. Basic examples: permutation groups, alternating groups, cyclic groups, dihedral groups, linear groups.
2. Subgroups, normal subgroups, quotient groups, product groups.
3. Group actions on sets. Orbits and stabilizers.
4. Structure of finitely generated abelian groups.
5. Rings, ideals, quotient rings. Prime ideals and maximal ideals.
6. Principal ideals and principal ideal domains (PIDs). Examples of PIDs (integers, polynomial rings). Division algorithm and factorization in PIDs.
7. Modules. Structure of finitely generated modules over a PID.
8. Basic field theory. Finite fields.

References
Two we like are Artin *Algebra*, and Dummitt and Foote *Abstract Algebra*.

E. Real Analysis

1. Improper integrals. Convergence tests.
2. Sequences and series. Taylor series. Radius of convergence.
3. Series of functions. Uniform convergence.
4. Exchanging the order of summation and limit.
5. Differentiation and integration of series of functions.
6. Countable and uncountable sets. Axiom of choice and Zorn's lemma.
7. Axioms for **R**.

References
Most of this is in Courant *Differential and Integral Calculus*. Two other classics are Spivak *Calculus* and Apostol *Calculus*.

F. Point Set Topology

1. Open, closed, connected, and compact subsets of $\mathbf{R}^n$. Heine-Borel theorem.
2. Topological spaces and Hausdorff spaces.
3. Metric spaces as topological spaces.
4. Continuous functions.
5. Compact sets. Images of compact sets are compact. Continuous functions achieve their maximum on compact sets.
6. Connected sets. Images of connected sets are connected.

References
Munkres *Topology: A First Course* or the first two chapters of Singer and Thorpe *Lecture Notes on Topology and Geometry*. See also your real analysis references.

Selecting Your First-Year Classes

The primary learning goals of the first year or two of your graduate career are:

1) Demonstrate knowledge in a broad range of fundamental undergraduate level mathematics.
2) Demonstrate basic knowledge in a broad range of fundamental graduate level mathematics.

Students who need to cover some of the material in an Rigorous Undergraduate Mathematics Major (see above) may need to take some of the corresponding courses with a graduate number (e.g., Math 513 is co-convened with Math 413 and covers roughly the same material). Those who have completed a rigorous undergraduate mathematics major will be prepared to take the graduate *core courses*:

- MATH 511A (Algebra)
- MATH 523A (Real Analysis)
- MATH 534A (Topology-Geometry)

Before the start of the Fall semester you will have the opportunity to discuss the best set of courses for the first year with the Associate Head for the graduate program and other faculty and make changes as needed. Part of this process will be to determine a plan for completing all of the necessary coursework and taking qualifying exams.

If you will be a teaching assistant you are required to register for

- MATH 597T (Professional Development Workshop in Teaching Mathematics) when it is offered in the first semester of your second year.

Ph. D. Requirements

This section describes the requirements for completing the Ph.D. degree. Information about satisfactory progress through the program is in a separate section entitled "Satisfactory Progress,"

Students should refer to the graduate catalog, available on the Graduate College web site, for more details on graduate college requirements for PhD candidates.

A. Course Requirements

Students are required to complete 36 units of graduate credit in the major and 9 to 12 units in a supporting minor (as determined by the minor program), which may be declared in Mathematics, although outside minors are encouraged. In addition, 18 units of dissertation (Math 920) must be completed. Students cannot register for 920 until they have passed their oral comprehensive exam. This rule can be waived by the Director of Graduate Studies in exceptional circumstances.

Traditional Core Courses

For each of the traditional core courses, Algebra (MATH 511A-B), Real Analysis (MATH 523A-B), and Geometry–Topology (MATH 534A-B), students must either take the course and receive a grade of B or better in both semesters or earn a high pass on the corresponding written qualifying exam. The material in these courses is essential knowledge for all mathematicians, and it is assumed in all further advanced coursework in the department.

Further Mathematics Coursework

Two year-long Mathematics course sequences that are not co-convened and are not part of the required core of algebra, real analysis, and geometry-topology are required. Students should seek advice on appropriate courses from their advisor (if they have one already), faculty in the area in which they plan to do research or the director of the graduate program. For many students Complex Analysis (MATH 520A-B) is a good choice for one of these sequences.

Outside of Department Courses or Internship

Students must take two courses (6 units) outside the mathematics department. These may be applied toward the minor, if appropriate. The spirit of the outside course requirement is that students should learn to communicate with and appreciate the perspectives of users and producers of mathematics in other disciplines. Courses which fulfill this requirement should (a) have significant content in mathematics or mathematics education; and (b) not be substantially equivalent to courses in the mathematics department. We maintain a list of a priori acceptable courses. A priori unacceptable courses include those cross-listed in mathematics or taught by a mathematics faculty member. An exception is that courses offered by the mathematics department in mathematics education may be used by students in mathematics proper (i.e., not students pursuing the mathematics education options) to satisfy the outside course requirement.

Students may also satisfy this requirement by doing an internship during the summer or during the year. The student's internship supervisor is required to write a brief letter detailing the work done by the student and the internship must be approved by the Director of Graduate Studies.

Minor

The University requires that PhD students declare a minor. PhD students in Mathematics may declare their minor in mathematics or in a supporting discipline. Requirements for the minor are determined by the minor department, but usually entail a program of 9 to 12 units. Students contemplating a minor other than Mathematics should consult with the Director of Graduate Studies and their thesis advisor regarding the suitability of their plans. Typical minors include Statistics, Computer Science, Education, Physics, and Applied Mathematics, though others may be considered.

Program of Study

Each student must present a coherent collection of courses in which the work outside of Mathematics is related to part of the studies in Mathematics. There are many such possibilities, including: algebra, and computer science or discrete methods in operations research; probability, and statistics or reliability/quality control; numerical mathematics, and computer science or computational science; mathematical foundations and history, and education; analysis, and physics or optics; etc.

B. Graduate Faculty Advisor

All students in the Mathematics Ph.D. program are required to have a Graduate Faculty Advisor (also called Major Professor) in order to maintain Satisfactory Progress. First year students should select a faculty advisor and have it approved by the Director of Graduate Studies (DGS). If the student cannot find an advisor, the DGS will work with the student to appoint one. Students may change their advisor in consultation with the DGS at any time. Once an advisor is chosen, the student will inform the Graduate Coordinator. By the time a student starts to prepare for their Comprehensive Exam, it is expected that the chair of Comprehensive Committee will take over the role of Graduate Faculty Advisor will It is typical for the Dissertation Advisor to serve as Graduate Faculty Advisor once the research area is selected.

The primary responsibilities of a Graduate Faculty Advisor include:

1. Be a source of academic information for their graduate students.

2. Provide assistance with details in determining the Plan of Study.

3. Be proficient in inputting, managing, and approving forms in GradPath as needed to assure smooth progression to final degree.

4. Meet periodically with their students and provide regular, timely input to determine academic progress. This may include review of Plan of Study and Prospectus as prepared by the student.

When selecting the Graduate Faculty Advisor, the student should contact the faculty member to discuss expectations for both the faculty member and the student. The two shall meet throughout the academic year and at the end of each semester the student will complete the end of year conversation form to discuss with the advisor. After the meeting a signed copy of this form will be submitted to the Graduate Coordinator for placement in the student's file.

C. Research Tutorial Groups

Students must enroll in MATH 596G and complete a research tutorial group (RTG) project starting in the spring semester of their first or second year of enrollment. In the spring, MATH 596G is a one-unit course in which faculty members present short lecture series on research topics of current interest. In the following fall, students choose one of the proposed topics and work with the corresponding faculty member on a research project. This project and a presentation of it at the end of the fall semester is the basis for three more units of credit in MATH 596G. The RTG project is meant to be an early introduction to research in mathematics and forms part of the evaluation of the qualifying exam.

D. Qualifying Examination

The qualifying examination is based on the following assessment options:

- A written exam in algebra
- A written exam in analysis
- A written exam in geometry and topology
- An MS thesis

Students must attempt at least three assessment options. Two of the assessments must be chosen from the traditional core exams (the first three options). Each written exam is offered in August and January. There is no limit to the number of attempts for the written exams. Students may attempt more than three assessment options. Students with prior preparation may attempt the examinations upon entrance to the program, or after one semester.

Each of the options has three possible grades: fail, pass, and high pass. In general, a grade of high pass indicates the student is ready to go on to advanced course work and to prepare the comprehensive exam. For the MS thesis option the meaning of pass is that the thesis is acceptable for the MS degree. The meaning of high pass is that the quality of the thesis indicates the student is capable of PhD level work. The thesis need not contain original work, but the quality should indicate that the student has the potential for such work. The grade for the MS thesis is determined by the thesis committee. Prior to scheduling your thesis defense, you will need to get your MS committee approved by submitting the Committee Approval form to the Graduate Office. Once your committee is approved, you will need to print out the Results of the MS thesis form and take this to your thesis defense for a final grade. Both forms can be found on the forms page on our website.

The written exams in algebra, analysis and geometry/topology cover material from the traditional core courses, Algebra (MATH 511A-B), Real Analysis (MATH 523A-B), and Topology–Geometry (MATH 534A-B). They also include a small amount of undergraduate level material. For the algebra exam this undergraduate material is from linear algebra. For the analysis exam it is from rigorous advanced calculus. For the geometry/topology exam it is from undergraduate complex analysis. Short lists of topics on the exams and copies of recent examinations are available on the web.

To successfully complete the Ph.D. qualifying examination, a student is expected to obtain a result of high pass in two of the assessment options and a result of pass or high pass in a third. The Graduate Committee will be responsible for making the final determination as to whether the student has successfully completed the Ph.D. qualifying examination and may take into account all factors relating to the student's work.

Students must successfully complete the qualifying exams before the end of their sixth semester to continue in the PhD program. Students who fail to do so will be ineligible for funding and will be recommended for disqualification from the program. For appeals, see the section on Appeals Procedure in the Satisfactory Progress section.

E. Comprehensive Examination

The purpose of the comprehensive examination is to determine whether the student has mastered the necessary general and specialized knowledge required to carry out dissertation research. The comprehensive exam has written and oral parts. To complete the written part, students write a short paper which may give an account of a research problem of interest, a significant example, or significant computations. An updated CV must also be submitted. The written part must be approved by the examining committee, which consists of a minimum of 4 tenured or tenure-track faculty, at least two weeks before the oral examination. The oral examination consists of a talk by the student, typically lasting one hour, followed by questions from the examining committee.

The Oral Comprehensive Examination is primarily, but not exclusively, on material in the area of concentration. The examination covers background material for the general area together with advanced references in a more specific sub-specialty.

F. Prospectus

After completing the comprehensive exam, students are expected to prepare a prospectus in consultation with their advisor. The prospectus is a detailed plan for the last years of their program. This plan should include a discussion of the research being undertaken as well as courses to take, seminars to participate in, faculty beyond the dissertation advisor to interact with, and possibly conferences to attend and professional development activities to undertake. Students must complete a departmental approval form.

G. Professional Development Requirements

PhD students must complete two professional development requirements chosen from this list:

- a foreign language requirement,
- a computing requirement, and
- a communication skills requirement.

Details of each requirement are given below. The requirements have been designed so that to a great extent they should be satisfied by activities that would normally be undertaken by any good PhD student. The need for foreign language and computing skills varies considerably among fields of mathematics and so students should consult with their advisors on which requirements would be the best choice. Advisors may also suggest that students complete more than the minimum of two of these requirements. Students are urged to complete the professional development requirements as early in their programs as possible. In all cases, they must be completed before advancement to candidacy. Failure to do so will delay advancement to candidacy and may delay the dissertation defense.

Foreign Language Requirement

A substantial portion of the mathematical literature is written in languages other than English, principally French, German, and Russian. Knowledge of Spanish is important for some fields of Mathematics Education. Being able to read and accurately translate these texts is a valuable skill in Mathematics and Mathematics Education research.

In order to fulfill the foreign language requirement, students will demonstrate their abilities to read and accurately translate mathematical texts in French, German, or Russian, (or, for students in Mathematics Education, texts relevant to that field in Spanish) by passing an examination given by a faculty member approved by the graduate committee. The student will prepare a careful, written translation of a text

chosen by the examining faculty member (typically 5–10 pages) in a limited amount of time (typically 48–72 hours), with the aid of a dictionary and language reference works, but without the assistance of computers or other people. As a minimum standard, the translation must be mathematically accurate. We maintain a list of approved examiners.

Grading of language examinations is a significant burden on faculty and students should not make frivolous attempts to pass the examination without sufficient preparation. Faculty members may administer an oral "pre-test" to gauge whether the student appears to be prepared for the examination.

Results of foreign language examinations should be communicated to the graduate office by the examining faculty member using the language examination form.

Computing Requirement

Machine computation is an increasingly important component of mathematical research. Students for whom such computation will be relevant should master the needed programming skills and software packages during their graduate careers.

To fulfill the computing requirement, students should demonstrate their mastery of the relevant skills by carrying out a significant computing project under the supervision of a mathematics faculty member. This project might be tied to course work, the student's MS thesis, or his or her dissertation research. The precise nature of the project will be determined by the student and the sponsoring faculty member, but projects must have substantial mathematical content and should typically involve the following aspects of computing:

- formatted input and output
- appropriate use of data structures and algorithms
- use of structured programming techniques, possibly including calls to externally provided subroutines or functions.

Projects may be written in a standard programming language such as Python, Java, C, or Fortran, or may use software packages such as Matlab, Maple, R, Mathematica, SAS, GAP, or Pari.

At the conclusion of the project, working code and documentation must be made available on the department's web site. The completion of the requirement should be communicated to the graduate office by the sponsoring faculty member using the computing examination form.

Communication Skills Requirement

The ability to communicate effectively, both verbally and in writing and to audiences of varying levels of sophistication, is essential to a successful career in industry, research, or teaching. The communication skills requirement gives students an opportunity to develop their capabilities in a variety of directions. To complete the requirement students must:

- prepare a basic web page containing information on the student's research, teaching, and other professional activities and make this page available on the department's web site
- prepare a professional CV and post it on the web site
- write articles or proposals and give lectures or presentations for audiences of various levels of sophistication so that at least one activity occurs in each row and column of the following table of examples:

	Verbal	Written
non-mathematical audience	• HS visit • Galileo circle talk • Math Inst Colloq	• CATTS or space grant • Dept newsletter article • An essay, intended for undergraduates on your research
general mathematical audience	• Colloquium talk • MS thesis defense • poster session	• grant proposal • survey article
specialist audience	• seminar talk • conference talk • poster session	• research paper • MS thesis • Math review article • paper for a course

The entries in the table are meant to be illustrative and do not exhaust the possibilities. Written components should use TeX or other scientific text processing software. Verbal components may involve the use of such technologies as overhead transparencies or presentation software. Each component must be sponsored by a faculty member who will review the text or presentation and provide constructive feedback. When the sponsoring faculty member is satisfied with a student's performance on a component of the requirement, this fact should be communicated to the graduate office using the communication skills progress form.

H. Advancement to Candidacy

A student may advance to candidacy once they have completed all program requirements other than the dissertation. Students must advance to candidacy at least one semester prior to their dissertation defense. Failure to do so will delay the date of the dissertation defense.

I. Dissertation

The dissertation is a polished written account of a substantial new contribution to the mathematical sciences, publishable in a reputable journal. It is evaluated by an internal committee of at least 4 members who must be tenured or tenure-track faculty members or approved as equivalent by the Graduate College. One member may come from the minor department. Otherwise the members must be from the Mathematics Department. (Exceptions to this last rule may be granted by the Graduate Committee.) The dissertation committee approves the dissertation after a final oral defense. An updated CV must also be submitted. Students have the option of also including an external reviewer who is not on the faculty of the University of Arizona. The inclusion of such an outside reviewer can provide the student with valuable feedback as well as help make the student's research known outside the local community. Students should register for Math 920 while working on their dissertation. The Graduate College requires 18 units of Math 920.

The dissertation is by far the most important component of the PhD program and its quality and originality will have a major impact on the beginning of the student's professional career. Writing a quality dissertation should be the student's top priority.

J. Final Oral Examination

The final oral examination is a presentation and defense of the student's dissertation; the first part of the exam is open to the public.

Ph.D. Degree Requirements: MATHEMATICS EDUCATION OPTION

A. Course Requirements

The course requirements are 36 units of graduate credit in the major and a minor in Education (or related field).

Courses in Mathematics

Students will take graduate core courses in Algebra (MATH 511A-B), Real Analysis (MATH 523A-B), and Topology–Geometry (MATH 534A-B), and take Qualifying Examinations as described in Ph.D. program in Mathematics. The remaining 18 units will be chosen in consultation with an advisor. These remaining units will include one year-long Mathematics course sequence that is not co-convened and is not part of the required core of algebra, real analysis, and topology-geometry. Some of the units will include relevant courses in Mathematics Education research (to be discussed with an advisor).

Courses in Education (or related field)

The 12 units in Education (or related) will be chosen in consultation with an advisor to ensure a coherent program of study. The courses will primarily be in Education. Courses in psychology, anthropology, sociology, women's studies, etc., may also be appropriate, depending on the student's research focus. Some suggested Education courses are listed below. EDUC 500, 501, 600, 601, 602; TTE 521, 524, 532, 545, 621, 640. Two courses in research design and methods (e.g., EDUC 600, 601, 602, or appropriate research methods courses in other fields such as sociology, anthropology, agriculture, ...) are required.

Teaching Experience or Practicum

Two or more years of pre-college teaching experience are required. Students can fulfill this requirement through 9 units of practicum in local schools. Such students will take 3 units per semester to complete one practicum at the elementary school level, one at the middle school level, and one at the high school level. (Note: these 9 units do not apply toward the required 36 units of mathematics nor the 12 minor units.)

B. Graduate Faculty Advisor

The same stipulations as given for the Ph.D. program in Mathematics

C. Program of Study

The same stipulations as given for the Ph.D. program in Mathematics.

D. Qualifying Examination

Same as for the Ph.D. program in Mathematics.

E. Comprehensive Examination

Similar guidelines to those for the Ph.D. program in Mathematics, but the area of concentration will be in Mathematics Education.

F. Prospectus

The same stipulations as given for the Ph.D. program in Mathematics.

G. Professional Development Requirements

Same as for the Ph.D. program in Mathematics except that the foreign language requirement may be satisfied in Spanish or American Sign Language as well as French, German, or Russian.

H. Advancement to Candidacy

The same stipulations as given for the Ph.D. program in Mathematics.

I. Dissertation

Same guidelines as for the Ph.D. program in Mathematics. The dissertation will be in Mathematics Education.

J. Final Oral Examination

Same as for the Ph.D. program in Mathematics.

Satisfactory Progress - Ph.D. program

Variations

The following discussion is a template which assumes the student enters in the fall semester and does not already have a Master's degree in Mathematics. Satisfactory progress policies for students in unusual situations, for example those entering in the spring semester or those entering with a Master's degree, will be decided on an individual basis and agreed upon in writing at the time of entrance to the program.

Progress in the first three years

Admission to the PhD program implies a three-year initial commitment by the department, provided that satisfactory academic progress is made and teaching obligations are met. Satisfactory progress is defined as being enrolled for at least 9 units of graduate or approved credit in each semester, maintaining a GPA of at least 3.0 in each semester, and meeting the following expectations.

Students are expected to complete the core courses and qualifying exams as expeditiously as possible. They are encouraged to attempt any part of the qualifying exam for which they may be ready in August before the first semester of enrollment. A failure on such an attempt will not prejudice any future evaluation of qualifying exam results.

It is expected that students will enroll in at least one of the traditional core courses during the first year and attempt the corresponding part of the qualifying exam in August following the first year of enrollment. Students are expected to have passed at least one part of the qualifying exam at the “high pass” level by January of the second year of enrollment and to have completed the core courses and attempted all three parts of the qualifying exam by August before the third year of enrollment. Students must successfully complete the qualifying exams by the start of their sixth semester to continue in the PhD program.

Progress in later years

Continuation in the PhD program beyond the third year implies a commitment on the part of the department to two, or possibly three, more years of support, provided that satisfactory academic progress is made and teaching obligations are met. Satisfactory progress is defined as being enrolled for at least 6 units of graduate or approved credit in each semester, maintaining a GPA of at least 3.0 in each semester, and making adequate progress toward the dissertation as determined by the faculty.

Students are encouraged to complete the written and oral comprehensive examination as early as possible. In all cases, this exam must be complete by the end of February of the fourth year of enrollment. Failure to meet this deadline would be a violation of the “adequate progress” requirement in the preceding paragraph.

Funding and continuation in the program for a sixth year will be determined by the graduate committee, based on the sense of the faculty regarding the student's progress. Funding and continuation in the program beyond the sixth year will be possible only in some circumstances, as determined by the Graduate Committee. Examples of such circumstances may include leave of absence, maternity/paternity leave, or health problems. For appeals, see the section on Appeal Procedure.

Appeals Procedure

If a student wishes to appeal any of the requirements mentioned above, the appeal should be made in writing to the Director of Graduate Studies. The appeal will be reviewed by the Graduate Committee and requires a majority vote to succeed. The Committee may place additional requirements/deadlines on the student as a prerequisite for continuing in the program.

Students who wish to appeal the decision of the Graduate Committee must submit an appeal in writing to Head of the Mathematics Department, who will make a decision in consultation with other faculty, as appropriate.

M.A./M.S. Requirements

Course Requirements

MA Degree: 30 units of approved graduate credit, including up to 6 units of thesis credit; 9 to 12 units must be in courses from departments other than Mathematics. At least one year-long course sequence in mathematics which is not dual-numbered must be included.

MA Degree (Teaching Option): 30 units of approved graduate credit, including up to 6 units of thesis credit; 9 to 12 units should be outside the Department of Mathematics or from the following list of graduate mathematics courses: Math 504, 530, and 596E (Topics in Mathematics for Secondary Teachers – contents will vary, the course may be repeated). At least 12 units of mathematics should not be from that list, and should include a year long course sequence which is not co-convened. Each candidate's course of study should be established in consultation with a member of the Mathematics Education Committee. Please consult the Mathematics Education Research website.

MS Degree: 30 units of approved graduate credit, including up to 6 units of thesis credit. The 30 units must include at least 18 units of courses that are not co-convened, including a year long course sequence in mathematics. The 30 units must also include 6 units in courses from departments other than Mathematics. As with the PhD degree, the requirement of 6 units from outside the Mathematics Department may also be satisfied with an internship. See the "Outside of Department Courses or Internship" section of the PhD requirements for more details.

Program of Study

Each student must present a coherent collection of courses in which the work outside of Mathematics is related to part of the studies in Mathematics. There are many such possibilities, including: algebra, and computer science or discrete methods in operations research; probability, and statistics or reliability/quality control; numerical mathematics, and computer science or computational science; mathematical foundations and history, and education; analysis, and physics or optics; etc.

Thesis

A Master's thesis is required for which students may receive up to 6 units of graduate credit. PhD candidates may substitute successful completion of the Comprehensive Examination for the Master's thesis. The thesis is evaluated by an internal committee of at least 4 members who must be tenured or tenure-track faculty members or approved as equivalent by the Graduate College.

Professional Development Requirements

MA and MS students must complete one professional development requirement chosen from this list:

- foreign language requirement
- computing requirement
- communication skills requirement

The details of each requirement are the same as for the PhD program and may be found here. Students should consult with their advisors on which requirement would be the best choice given their area of study and career plans. Advisors may also suggest that students complete more than one of these requirements. Students are urged to complete the professional development requirement as early in their programs as possible.

Examinations

Successful performance is required of all MA and MS recipients on either a Final Oral Examination which covers work presented for the Master's Degree and defense of the thesis, or the Comprehensive Oral Examination for the PhD degree.

Graduate Courses in Mathematics

This page explains the various types of graduate courses in mathematics at the University of Arizona.

Core courses and regular courses

The core courses (511AB—Algebra, 523AB—Real Analysis, and 534AB—Topology-Geometry) constitute the foundation on which the rest of the program is built. These courses are normally taken in the first year and cover the material to be mastered for the qualifying exams.

"Regular courses" are by definition the more advanced courses taught for the most part in the traditional lecture format. These courses serve to take the student from the foundation provided by the core courses to more specialized knowledge required for dissertation research.

RTGs

"Research Tutorial Groups" introduce graduate students to mathematical research training at the end of the first year and beginning of the second year, typically well in advance of formal dissertation research. In the spring of the first year, students listen to short lecture series on topics of current interest. In the following fall, students choose one of the topics and work on a research training project with the sponsoring faculty member, and possibly a small group of fellow students, as part of a three credit RTG course. The spring lecture series is one credit hour while the fall research group is three credit hours.

Co-convened courses

"Co-convened" courses are advanced undergraduate courses (400 level) which are also given a 500 level number. (E.g., Symbolic Logic is both Math 401A and Math 501A.) The point is that graduate students may take these courses for graduate credit. They are mainly populated by senior level undergraduates and graduate students from other departments, but mathematics graduate students sometimes take these courses to fill in missing background or in Masters level coursework. A limited number of dual-numbered credits are applicable to the PhD.

Topics courses, seminar courses, and independent studies

Special topics courses are offered each term by faculty, usually in areas of particular expertise (although sometimes the inspiration is that the subject is hot and the faculty member wants to learn about it as well). They are typically one-time only offerings and may lead to dissertation topics.

Graduate students may also get credit for participation in research seminars. The courses Math 596 and Math 697 are a frequently used formal mechanism for this to come about.

Independent studies are arranged between faculty and students at the discretion of the faculty member. In a typical such course, the student would study a book or paper and meet weekly with the faculty member to discuss the work and related problems.

Identifying Special Topics courses

The following university course catalog numbers are reserved for Special Topics courses: 518, 519, 529, 538, 577, 588.

When a Special Topics course is announced, it will be open but with the designation TBA. If there is sufficient student demand for the course, and the department has the resources to cover all its other teaching obligations, the course will be properly scheduled. Otherwise the course will be cancelled.

Outside department courses

Not surprisingly, these are courses offered by other departments. Graduate degrees in mathematics all have requirements for a certain number of courses outside the department. The outside course page explains the philosophy behind the requirement and lists some courses that fulfill it.

Graduate Assistant/Associate Guidelines

GA Classifications, Salary, and Promotion

Graduate Assistants/Associates in Teaching & Research (GAs) are officially classified into four categories:

Category	**Academic year pay (0.50 Appointment)**
Level I Graduate Assistant	$18,900
Level II Graduate Assistant	$19,320
Graduate Associate	$19,740

The pay rates given here are current. Increases correspond to annual University budgetary guidelines.

Graduate Assistant I

New GAs start as Graduate Assistant I.

Graduate Assistant II

To be promoted to Graduate Assistant II, a student must both

1. complete the Qualifying Exam portion of the Ph.D. program and

2. have satisfactory teaching or research performance.

Satisfactory teaching performance means that the GA received positive evaluations in all aspects of teaching responsibility. All teaching activities of GAs are under the supervision of an assigned member of the department. The supervisor will evaluate the performance of the GA and will submit a written report to the Graduate Committee and to the Undergraduate Committee. The evaluation is not considered confidential and may be discussed with the GA.

Satisfactory research performance is determined by the professor with whom the GA worked. We have additional information on *satisfactory progress*.

Graduate Associate

To be promoted to Graduate Associate, a student must both

3. pass the comprehensive exam, and
4. have satisfactory teaching or research performance.

Promotions will normally take place in August following achievement of milestones.

Appeals

Appeals will follow the same procedure as outlined in the Satisfactory Progress section.

Duties of a Half-Time (50%) Graduate Assistant or Associate in Teaching (GA):

1. First-year Graduate Assistant duties will include:
    1. Teaching four (4) units per semester or equivalent time spent on tutoring, grading, or proctoring examinations.
    2. Mandatory completion of the University's Title IV, Conflict of Interest, Teaching Assistant/Associate Training Online (TATO) and FERPA training;
    3. Mandatory attendance of the Mathematics Department orientation of three half-days.
    4. Mandatory enrollment in MATH 596T.
2. For Graduate Assistants/Associates in their second or later years, duties will include:
    1. Teaching nine (9) units per year or equivalent time spent on tutoring, grading, or proctoring examinations.

Units of Teaching are determined as follows:

1. If the teaching assistant/associate has total responsibility for a class then each hour per week of teaching counts as one unit.
2. Each hour per week spent in the tutoring room counts as 2/5 unit.
3. Each hour per week spent grading counts as 1/3 unit for undergraduate courses, or 2/5 unit for graduate courses.
4. For a student holding a Graduate Assistantship/Associateship in Teaching for a percentage of time other than 50%, the duties are assigned proportionately (e.g., the work load for a 25% GTA is half of that for a 50% GTA).

Conditions for a Graduate Assistant or Associate in Teaching (GA):

Employment as a GA is contingent upon the following:

1. Maintaining at least a 3.0 grade point average in your graduate courses;
2. Successful completion of at least nine units of credit towards your degree program during each semester of this appointment;
3. Satisfactory evaluation of your performance as a teaching assistant;
4. If you have passed the Qualifying Examination at the PhD level, that you make satisfactory progress towards identifying an advisor, forming your Oral Comprehensive Examination Committee, and preparing for your Oral Comprehensive Exam;
5. If you have already completed your Oral Comprehensive Exam, that you have identified a dissertation topic and are making good progress on your dissertation research;
6. While employed as a GA, students may not hold other employment at the University of Arizona or elsewhere which involves 10 hours per week or more without prior, written approval from the Director of Graduate Studies.