Mathematics and Statistics

The Department of Mathematics and Statistics offers two master's degrees (one in mathematics and one in statistics) and two doctoral degrees (one in mathematics and one in statistics). The areas of study for mathematics include algebra, algebraic geometry, real and complex analysis, differential geometry, and topology. The areas of study for statistics are mathematical statistics, survival analysis, modeling, statistical computing for massive data, Bayesian regulation, bioinformatics, longitudinal and functional data analysis, statistical computation, asymptotic theory, objective Bayes, bootstrap, post-selection inference, and the application of statistics to medicine. Because it is difficult to make up coherent programs for students entering in the middle of the year, students are ordinarily admitted only in the fall.

When they first arrive, graduate students have the opportunity to share common concerns and to become acquainted. One of the most attractive features of our program is the friendly and supportive atmosphere that develops among our graduate students. Advanced courses in the Washington University mathematics and statistics department can build on the common background shared by all students. As a result, these courses are richer and nearer to the level of PhD work than typical advanced courses.

Students typically complete the PhD program in five years, and those students may expect up to five years of support. Continuation of support each year is dependent upon normal progress toward the degree and the satisfactory performance of duties. A student who comes to Washington University with advanced preparation may finish in less time. On the other hand, some students find that it is advisable for them to take preparatory math courses before attempting the qualifying courses. In special cases, the time schedule may be lengthened accordingly. Each student should plan to develop a close relationship with their thesis advisor so that the advisor may have a realistic idea of the student's progress.

Graduate study in mathematics or statistics is not for everyone. Entering students usually find that the time and effort required to succeed goes well beyond anything they encountered as undergraduates. Success requires both ample mathematical ability and the determination to grapple with a subject for many days or weeks until the light of understanding shines through, and the experience can be daunting. Those who continue in their studies are largely those for whom the pleasure of attaining that understanding more than compensates for the required effort. For such persons, the life of a mathematician can be richly rewarding.

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Algebraic and topological combinatorics

Directors

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Director of Undergraduate Studies
Professor of Mathematics and Statistics
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PhD, University of California, Berkeley
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PhD, Cornell University
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PhD, University of Cambridge
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PhD, University of Wisconsin–Madison
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PhD, Carnegie Mellon University
Statistical network analysis; time series; resampling methods; high-dimensional statistics

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Applications of Lie theory to algebraic geometry and the related combinatorics

Donsub Rim (https://math.wustl.edu/people/donsub-rim/)
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Applied mathematics

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PhD, Pennsylvania State University
Noncommutative geometry; symplectic geometry; representation theory

Professors Emeriti

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PhD, Harvard University
Differential topology

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General topology

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Complex analysis; interpolation theory

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PhD, University of Chicago
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PhD, Washington University
Harmonic analysis; differential geometry

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Affine algebraic geometry; polynomial automorphisms

William Chauvenet Postdoctoral Lecturers

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PhD, Clemson University
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Algebraic and symplectic geometry

Postdoctoral Lecturers

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Hierarchical Bayesian methods; high-dimensional data analysis; network analysis with applications to biomedical datasets such as single-cell RNA sequencing datasets; SNP genotyping datasets

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Gauge theory; low dimensional topology

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Noncommutative geometry

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PhD, Pennsylvania State University
Noncommutative index theory; cyclic cohomology; spin Riemannian geometry, high dimensional gauge theory

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PhD, University of Illinois at Urbana–Champaign
Differential geometry; Poisson geometry; singular spaces

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PhD, Iowa State University
Queueing theory; stochastic control problems; mathematical finance

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Algebraic number theory

Associate Director of Undergraduate Studies

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PhD, University of Utah
Geometric topology

Degree Requirements

Master of Arts in Mathematics

General requirements: There are 36 units of graduate-level course work required, with or without a thesis; 6 units may be for thesis research. The minimum residence requirement is one full academic year of graduate study. If the department consents, a student may transfer up to 6 units from other universities. A grade point average of B (3.0) or better must be maintained in graduate course work.

Course requirements: There are four basic graduate course sequences in pure mathematics: Math 5021 Complex Analysis I–Math 5022 Complex Analysis II, Math 5031 Algebra I–Math 5032 Algebra II, Math 5045 Geometry/Topology I: Algebraic Topology–Math 5046 Geometry/Topology II: Differential Topology or Math 5047 Geometry/Topology III: Differential Geometry, and Math 5051 Measure Theory and Functional Analysis I–Math 5052 Measure Theory and Functional Analysis II. A candidate for the AM in Mathematics must include two of these sequences (12 units) in the required 36 units. Each student, in consultation with their advisor, selects the remaining 24 units according to the student's interests and needs.

Master of Arts in Statistics

General requirements: There are 36 units of course work required and an optional thesis; 3 units may be for thesis research. The minimum residence requirement is one full academic year of graduate study. A GPA of B (3.0) or better must be maintained in graduate courses.

Optional thesis requirements: To be eligible for the thesis option, a student must maintain a cumulative GPA of 3.5 or higher in the first 18 units of courses satisfying the program requirements.

Course requirements: The student must take (or have taken) the following six required courses in mathematics or their equivalents:

One of the following two sequences:

Required	Units
Probability; Mathematical Statistics	6
or Theory of Statistics I & II	

plus:

Required	Units
Linear Statistical Models	3
Bayesian Statistics	3
Statistical Computation or a suitable substitute elective approved by the department	3
Practical Training	3

If an equivalent course has been taken and proficiency in the course material has been demonstrated, other 500-level and above electives may be substituted in consultation with the advisor. Additional 500-level or higher electives will be chosen by the student in consultation with their advisor to make up the 36 units.

Master’s Degree in Statistics for Political Science PhD Students

General requirements: This program is a tailored master’s degree in statistics for graduate students in political science. Note that, while the program is designed to serve political science graduate students, it is run by the Department of Mathematics and Statistics. Students interested in this program will need to begin their additional course work during their third year of study (or before). Students are encouraged to apply for the program in their third year, but they may prefer to try the additional courses first.

Requirements for admission:

- To be eligible for this program, students must have already passed Pol Sci 5052 Mathematical Modeling in Political Science, Pol Sci 581 Quantitative Political Methodology I, and Pol Sci 582 Quantitative Political Methodology II and earned a grade of A- or A in these courses. Although exceptions have been made in the grade requirements at the request of political science faculty, this decision is up to the Department of Mathematics and Statistics.
- Students must obtain permission from the methodology field committee in the Department of Political Science.
- Students must formally apply to the Department of Mathematics and Statistics Master of Arts program.

Modified course requirements for the degree: Students must meet the core course requirements for the traditional Master of Arts in Statistics (typically five courses), with two exceptions:

- Math 5130 Linear Statistical Models may be replaced with Pol Sci 581 Quantitative Political Methodology I and Pol Sci 582 Quantitative Political Methodology II, with 3 additional credits produced.
- Math 591 Practical Training in Statistics is not required.

There are three political science courses that count toward this master's degree in statistics that are required of all political science graduate students:

- Pol Sci 506 Theories of Individual and Collective Choice II
- Pol Sci 581 Quantitative Political Methodology I
- Pol Sci 582 Quantitative Political Methodology II

These additioinal details make a total 21 credits: 15 required credits from statistics courses, plus 3 additional credits from substituting Pol Sci 581 and Pol Sci 582 for Math 5130 Linear Statistical Models, plus 3 credits from Pol Sci 506. Outstanding students who wish to not make the substitution can take Math 5130 Linear Statistical Models and one additional math elective, but only with permission. The remaining 15 credits are completed through electives and an optional thesis.

Students may choose any electives acceptable for the traditional Master of Arts in Statistics. The following additional electives are also available for students in this program:

- Pol Sci 5024 Causal Inference
- Pol Sci 5625 Applied Statistical Programming
- Pol Sci 583 Topics in Quantitative Political Methodology: Computational Social Science

Thesis: To be eligible for the thesis option, a student must maintain a cumulative grade point average of 3.5 or above in the first two semesters (or 18 units) of course work satisfying the program requirements. A maximum of 3 units may be used for thesis research. The thesis must be supervised by faculty with an appointment in Mathematics and Statistics (e.g., a faculty member with a joint appointment in Political Science and Mathematics and Statistics).

PhD in Mathematics

No one can earn a doctorate merely by completing specified courses of study. The doctoral candidate must demonstrate high scholarship and the ability to perform significant original research in mathematics.

General requirements: Completion of the PhD requires four full years of graduate study (72 units), with at least 48 units completed in residence at Washington University. The student must spend at least one academic year as a full-time student; this requirement cannot be met wholly by summer sessions or part-time study. The student may, with departmental permission, transfer a maximum of 24 graduate credits from other universities. The typical course load is 9 credit units per semester. A GPA of B (3.0) or better is required in graduate course work.

Graduate students in mathematics may ordinarily expect up to five years of support. Continuation of support each year is dependent upon normal progress toward the degree and the satisfactory performance of duties.

For the well-prepared student, "normal progress" usually means the following:

- At the end of the second year, the student has successfully completed the specific course requirements and passed six qualifying exams.
- At the end of the third year, the student has successfully completed the candidacy requirement.
- At the end of the fourth year, the student has completed the 72-unit course requirement and is making substantial progress on a thesis.

Students must also complete the Teaching Seminar course (Math 597 Teaching Seminar). This course prepares them for both Assistant to the Instructor work and academic teaching duties, which are integral to all scholarly activities. For a typical PhD student, the course is taken twice: once in the spring of the first year and again in the fall of the second year. Each student will have departmental duties (e.g., grading, proctoring) of no more than 15 hours per week as Assistant to the Instructor. Students must also complete a Professional Development course (Math 598 Mathematical Professional Development).

Please note that the sequence outlined above is for "well-prepared" students. The exact point at which any student enters the sequence depends on their ability and background. When warranted, deviation from the normal sequence is permissible, and a tailored program that fits the student's ability and background will be followed.

Specific course requirements: The 72 units of course work must include eight of the following nine courses: Math 5031 Algebra I–Math 5032 Algebra II, Math 5051 Measure Theory and Functional Analysis I–Math 5052 Measure Theory and Functional Analysis II, Math 5021 Complex Analysis I–Math 5022 Complex Analysis II, and Math 5045 Geometry/Topology I: Algebraic Topology–Math 5047 Geometry/Topology III: Differential Geometry. Students may omit one of the following courses when satisfying the course requirement: Math 5022 Complex Analysis II, Math 5047 Geometry/Topology III: Differential Geometry, or Math 5052 Measure Theory and Functional Analysis II. To satisfy the breadth requirement, the student must pass the required courses with a B (3.0) or better. The courses are typically offered in the following time frame:

> Fall: Algebra I, Real Analysis, Complex Analysis I, Algebraic Topology, Differential Geometry
>
> Spring: Algebra II, Functional Analysis, Complex Analysis II, Differential Topology

In exceptional circumstances, departmental permission may be requested to replace required courses with suitable alternatives. The student may also petition the department to waive one or more of these courses because of work completed previously.

It is in each student's best interest to take the courses that contain the material covered in the qualifying exams as soon as their individual program allows. Sequels to these courses, at the 500 level, are frequently offered. The qualifying exam courses are generally prerequisites to these 500-level courses.

Language requirement: All students must demonstrate proficiency in English.

If English is not the student's native language, they must pass an oral English proficiency exam with a grade of 3 or better. If the student does not score a 3 the first time they take the exam, the director of English Language Programs for Arts & Sciences will recommend that the student take one or more classes to improve reading, writing, pronunciation, listening, or speaking skills. After the recommended classes have been completed, the student is required to retake the English proficiency exam. Once the student has demonstrated the ability to handle teaching a class (by scoring a 3 or better on the exam), they will qualify for Assistant to the Instructor or Course Instructor duties.

Qualifying examinations and candidacy requirements: The qualifying exam and candidacy requirement constitute two separate requirements. The qualifying exam is a series of six written tests that cover a range of topics; the candidacy requirement is an oral presentation and thesis proposal.

The written tests cover the material in one semester of courses: Math 5021 Complex Analysis I, Math 5022 Complex Analysis II, Math 5031 Algebra I, Math 5032 Algebra II, Math 5045 Geometry/Topology I: Algebraic Topology, Math 5046 Geometry/Topology II: Differential Topology, Math 5047 Geometry/Topology III: Differential Geometry, Math 5051 Measure Theory and Functional Analysis I, and Math 5052 Measure Theory and Functional Analysis II. To satisfy the written exam requirement, the student must pass six out of the nine possible qualification exams, with the requirement that two be from Math 5021 Complex Analysis I, Math 5022 Complex Analysis II, Math 5051 Measure Theory and Functional Analysis I, or Math 5052 Measure Theory and Functional Analysis II; two be from Math 5045 Geometry/Topology I: Algebraic Topology, Math 5046 Geometry/Topology II: Differential Topology, or Math 5047 Geometry/Topology

III: Differential Geometry; and two be from Math 5031 Algebra I and Math 5032 Algebra II. To satisfy the qualification examination requirement, the student must pass the final exam for the course with an A- or better.

Because each course varies somewhat in content from year to year, it is recommended that the student take the exams at the conclusion of the course in which they are enrolled. No advantage is gained by delaying the exam. It is required to finish all six qualification exams by the end of the second year of study.

Some students will enter the PhD program with previously acquired expertise in one or more of the required courses. This situation sometimes happens with students who transfer from other PhD programs or who come from certain foreign countries. Such students may formally petition the chair of the graduate committee to be exempted from the appropriate course and its qualifying exam. The petition must be accompanied by hard evidence (e.g., published research, written testimony from experts, records of equivalent courses, examinations and the grades achieved on them). The graduate committee will make the final judgment on all exemption requests.

Once the written phase of the qualifying process is complete, the student is ready to begin specialized study. By the third year of study, the student must complete the candidacy requirement. The student must form a preliminary thesis committee called a *Research Advisory Committee* that includes their advisor and at least two other faculty members. In discussion with the advisor and the preliminary thesis committee, the student will select a topic and a body of literature related to this topic. The student will prepare a one-hour oral presentation related to the topic and a two-page thesis proposal that demonstrates mastery of the selected topic. The oral presentation is designed to expedite specialized study and to provide guidance toward the thesis. The preparatory work for the thesis proposal often becomes the foundation on which the thesis is constructed.

After the student completes the candidacy requirement, work on the thesis begins.

The dissertation and thesis defense: The student's dissertation is the single most important requirement for the PhD degree. It must be an original contribution to mathematical knowledge and is the student's opportunity to conduct significant independent research.

It is the student's responsibility to find a thesis advisor who is willing to guide their research. Since the advisor should be part of the candidacy requirement, the student should have engaged an advisor by the beginning of the third year of study.

Once the department has accepted the dissertation (on the recommendation of the thesis advisor), the student is required to defend their thesis through a presentation accompanied by a question-and-answer period.

For information about preparing the thesis and its abstract as well as the deadlines involved, including the creation of the Research Advisory Committee and the Dissertation Defense Committee, please consult the Office of Graduate Studies, Arts & Sciences. Please use these additional relevant resources: the Doctoral Dissertation Guide (https://gradstudies.artsci.wustl.edu/dissertation/), the Forms page (https://gradstudies.artsci.wustl.edu/forms/), and the Policies and Procedures page (https://gradstudies.artsci.wustl.edu/graduate-school-policies-and-procedures/).

PhD in Statistics

Degree Requirements Summary

A total of 72 graduate units are required, consisting of the following:

- 24 required course work units in fundamental topics and exam fields
- 12 elective course work units
- Three qualifying exams: two in statistics, one in mathematics
- Teaching Requirement for PhD Students from the Office of Graduate Studies, Arts & Sciences
- Oral presentation
- Dissertation research, thesis preparation, and defense (30 course work units)

General requirements: Completion of the PhD requires four full years of graduate study (72 units), with at least 48 units completed in residence at Washington University. The student must spend at least one academic year as a full-time student; this requirement cannot be met wholly by summer sessions or part-time study. The student may, with departmental permission, transfer a maximum of 24 graduate credits from other universities. The typical course load is 9 credit units per semester. A GPA of B (3.0) or better is required in graduate course work.

Graduate students in statistics may ordinarily expect up to five years of support. Continuation of support each year is dependent upon normal progress toward the degree and the satisfactory performance of duties. Teaching experience is an increasingly important component of graduate education for students who seek academic employment. The PhD in statistics program provides the opportunity for students to work as Assistants to the Instructor and to learn how to teach technical topics to students with a wide range of backgrounds.

For the well-prepared student, "normal progress" usually means the following:

- At the end of the second year, the student has successfully passed the two statistical qualifying exams associated with Math 5061 Theory of Statistics I–Math 5062 Theory of Statistics II and Math 5071 Linear Statistical Models Grad–Math 5072 Advanced Linear Models II as well as the mathematical qualifying exam associated with Math 5051 Measure Theory and Functional Analysis I–Math 5052 Measure Theory and Functional Analysis II. They have also completed the courses Math 5310 Bayesian Statistics and Math 5210 Statistical Computation).
- At the end of the third year, the student has completed the candidacy requirement.
- At the end of the fourth year, the student has completed the 72-unit course requirement and is making substantial progress on a thesis.

Students must also complete the Teaching Seminar course (Math 597), which prepares them for both Assistant to the Instructor work and academic teaching duties, which are integral to all scholarly activities. For a typical PhD student, the course is taken twice: once in the spring of the first year and again in the fall of the second year. Each student will have departmental duties (e.g., grading, proctoring) of no more than 15 hours per week as Assistant to the Instructor. Students must also complete a Professional Development course (Math 598).

Please note that the sequence outlined above is for "well-prepared" students. The exact point at which any student enters the sequence depends on their ability and background. When warranted, deviation from the normal sequence is permissible, and a tailored program that fits the student's ability and background will be followed.

Specific course requirements: The 72 units of course work must include two basic graduate-level sequences in statistics: Math 5061 Theory of Statistics I–Math 5062 Theory of Statistics II and Math 5071 Linear Statistical Models Grad–Math 5072 Advanced Linear Models II; the following statistics courses: Math 5310 Bayesian Statistics and Math 5210 Statistical Computation; and the following graduate-level mathematics sequence: Math 5051 Measure Theory and Functional Analysis I–Math 5052 Measure Theory and Functional Analysis II. In exceptional circumstances, departmental permission may be requested to replace one of these sequences with a suitable alternative. The student may also petition the department to waive one or more of these sequences because of work completed previously.

Prerequisites, if needed, are advanced undergraduate courses in abstract linear algebra and real analysis. Such courses would count as 0 credits toward the PhD degree.

It is in each student's best interest to take the three sequences that contain the material covered in the qualifying exams as soon as their individual program allows. Sequels to these courses, at the 500 level, are frequently offered. The qualifying exam courses are generally prerequisites to these 500-level courses.

Prior to finding a research advisor, students are welcome to take any of the Department of Mathematics and Statistics 500-level statistics electives, and they may also take reading courses with statistics faculty members (Math 500/Math 590 Research). Statistics electives offered by the department include the following:

Code	Title	Units
Math 5120	Survival Analysis	3
Math 5155	Time Series Analysis	3
Math 5160	Complex Variables	3
Math 5170	Stochastic Processes	3
Math 5210	Statistical Computation	3
Math 523C	Information Theory	3
Math 5310	Bayesian Statistics	3
Math 5430	Multivariate Statistical Analysis	3
Math 5440	Mathematical Foundations of Big Data	3
Math 5501	Numerical Applied Mathematics	3
Math 551	Advanced Probability I	3
Math 552	Advanced Probability II	3
Math 5560	Topics in Financial Mathematics	3

Prior to finding a research advisor, students may submit a request to the graduate committee to take a course outside of the department. A decision on such requests will be made in consultation with statistics faculty members.

Students are encouraged to take reading courses with department faculty to learn about the research interests of potential advisors. After the student has found a research advisor and a research topic, the advisor may suggest that the student take some additional courses from other departments that may be useful for the student's research program.

Elective courses taken in other departments allow students to supplement their statistics course work with other topics that may be helpful for their research and professional development. Some popular elective courses offered by other departments include the following:

Code	Title	Units
CSE 511A	Introduction to Artificial Intelligence	3
CSE 514A	Data Mining	3
CSE 517A	Machine Learning	3
CSE 519T	Advanced Machine Learning	3
CSE 541T	Advanced Algorithms	3
Econ 5145	Advanced Theoretical Econometrics	3
ESE 405	Reliability and Quality Control	3
ESE 407	Analysis and Simulation of Discrete Event Systems	3
ESE 415	Optimization	3
ESE 425	Random Processes and Kalman Filtering	3
ESE 428	Probability	3
ESE 520	Probability and Stochastic Processes	3
ESE 521	Random Variables and Stochastic Processes I	3
ESE 522	Random Variables and Stochastic Processes II	3
ESE 523	Information Theory	3
PHS 550	Randomized Controlled Trials	3
MSB M21-623	Advanced Topics in Biostatistics	3

Language requirement: All students must demonstrate proficiency in English.

If English is not the student's native language, they must pass an oral English proficiency exam with a grade of 3 or better. If the student does not score a 3 the first time they take the exam, the director of English Language Programs for Arts & Sciences will recommend that the student take one or more classes to improve reading, writing, pronunciation, listening or speaking skills. After the recommended classes have been completed, the student is required to retake the

English proficiency exam. Once the student has demonstrated the ability to handle teaching a class (by scoring a 3 or better on the exam), they will qualify for Assistant to the Instructor or Course Instructor duties.

Qualifying examinations and candidacy requirements: The qualifying exam and candidacy requirement constitute two separate requirements. The qualifying exam is a series of three written tests that cover a range of topics; the candidacy requirement is an oral presentation and thesis proposal.

The written tests cover the material in the two basic statistics course sequences, Math 5061 Theory of Statistics I–Math 5062 Theory of Statistics II and Math 5071 Linear Statistical Models Grad–Math 5072 Advanced Linear Models II, and in the mathematics sequence Math 5051 Measure Theory and Functional Analysis I–Math 5052 Measure Theory and Functional Analysis II. Each spring, at the end of the Math 5061 Theory of Statistics I–Math 5062 Theory of Statistics II and Math 5071 Linear Statistical Models Grad–Math 5072 Advanced Linear Models II sequences, all students enrolled in these courses take a two-hour final exam; this exam usually covers the second half of the sequence. Doctoral candidates take an additional one-hour exam that covers the entire sequence. To pass the qualifying exam, the student must pass the three-hour combined exam. In the case of the Math 5051 Measure Theory and Functional Analysis I–Math 5052 Measure Theory and Functional Analysis II sequence, to satisfy the qualification examination requirement, the student must pass the final exam for the course with an A- or better.

Because each sequence varies somewhat in content from year to year, it is recommended that the student take each set of exams at the conclusion of the sequence in which they are enrolled. No advantage is gained by delaying the exam for a year. It is desirable to make every effort to finish all three exams by the end of the second year of study.

Some students will enter the PhD program with previously acquired expertise in one or more of the three basic sequences. This situation sometimes happens with students who transfer from other PhD programs or who come from certain foreign countries. Such students may formally petition the chair of the graduate committee to be exempted from the appropriate course and its qualifying exam. The petition must be accompanied by hard evidence (e.g., published research, written testimony from experts, records of equivalent courses, examinations and the grades achieved on them). The graduate committee will make the final judgment on all exemption requests.

Once the written phase of the qualifying process is complete, the student is ready to begin specialized study. By the third year of study, the student must complete the candidacy requirement. The student must form a preliminary thesis committee called a *Research Advisory Committee* that includes their advisor and at least two other faculty members. In discussion with the advisor and the preliminary thesis committee, the student will select a topic and a body of literature related to this topic. The student will prepare a one-hour oral presentation related to the topic and a two-page thesis proposal that demonstrates mastery of the selected topic. The oral presentation is designed to expedite specialized study and to provide guidance toward the thesis. The preparatory work for the thesis proposal often becomes the foundation on which the thesis is constructed.

After the student completes the oral presentation, work on the thesis begins.

The dissertation and thesis defense: The student's dissertation is the single most important requirement for the PhD degree; it must be an original contribution to the knowledge of statistics, probability, and/or applied probability and is the student's opportunity to conduct significant independent research.

It is the student's responsibility to find a thesis advisor who is willing to guide their research. Since the advisor should be part of the oral presentation committee, the student should have engaged an advisor by the beginning of the third year of study.

Once the department has accepted the dissertation (on the recommendation of the thesis advisor), the student is required to defend their thesis through a presentation accompanied by a question-and-answer period.

For information about preparing the thesis and its abstract as well as the deadlines involved, including the creation of the Research Advisory Committee and the Dissertation Defense Committee, please consult the Office of Graduate Studies, Arts & Sciences. Please use these additional relevant resources: the Doctoral Dissertation Guide (https://gradstudies.artsci.wustl.edu/dissertation/), the Forms page (https://gradstudies.artsci.wustl.edu/forms/), and the Policies and Procedures page (https://gradstudies.artsci.wustl.edu/graduate-school-policies-and-procedures/).