Mathematics and Statistics

The Department of Mathematics and Statistics offers two master's degrees, one in Mathematics and the other in Statistics, and two doctoral degrees, one in Mathematics and one in Statistics. 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 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.

Graduate students have an opportunity when they first arrive to share common concerns and to become acquainted. One of the most attractive features of our program is the friendly and supportive atmosphere among 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. A student who comes here 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. Students should plan to develop a close relationship with their thesis advisers so that they may have a realistic idea of their 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. The experience can be daunting. Those who continue in their studies are largely those for whom the pleasure in 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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PhD, University of California, Berkeley
Analysis; operator theory; one and several complex variables

Directors
Brett Wick (https://math.wustl.edu/people/brett-wick)
Director of Graduate Studies; Professor of Mathematics
PhD, Brown University
Complex analysis, harmonic analysis, operator theory, and several complex variables

John Shareshian (https://math.wustl.edu/people/john-shareshian)
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Algebraic and topological combinatorics

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Brett Wick (https://math.wustl.edu/people/brett-wick)
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Todd Kuffner (https://math.wustl.edu/people/todd-kuffner)
PhD, Imperial College London
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Martha Precup (https://math.wustl.edu/people/martha-precup)
PhD, University of Notre Dame
Applications of Lie theory to algebraic geometry and the related combinatorics

Yanli Song (https://math.wustl.edu/people/yanli-song)
PhD, Pennsylvania State University
Noncommutative geometry, symplectic geometry and representation theory

Visiting Assistant Professor
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Shape analysis, face recognition

Professors Emeriti
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PhD, Harvard University
Differential topology

Ron Freiwald (https://math.wustl.edu/people/ron-freiwald)
PhD, University of Rochester
General topology

Gary R. Jensen (https://math.wustl.edu/people/gary-r-jensen)
PhD, University of California, Berkeley
Differential geometry

Robert McDowell (https://math.wustl.edu/people/robert-mcdowell)
PhD, Purdue University
General topology

Richard Rochberg
PhD, Harvard University
Complex analysis, interpolation theory
Degree Requirements

Master of Arts (AM) in Mathematics

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

Course requirements: There are four basic graduate course sequences in pure mathematics: Math 5021–5022, 5031–5032, 5041–5042 or 5043, and 5051–5052. A candidate for the AM in Mathematics must include two of these sequences (12 hours) in the required 36 hours. The student, in consultation with their advisor, selects the remaining 24 hours according to the student's interests and needs.

The AM examination: Candidates for the AM degree must pass at least four of the nine semester-long PhD qualifying exams. Under exceptional circumstances, the graduate committee may allow the student to substitute the PhD qualifying exams mentioned above with a comprehensive examination on the contents of Math 411–412, 417–418, and 429–430.

Master of Arts (AM) in Statistics

General requirements: 36 units of courses and an optional thesis. 3 units may be for thesis research. The minimum residence requirement is one full academic year of graduate study. A grade point average of B or better must be maintained in graduate courses.

Optional thesis requirements: To be eligible for the thesis option, a student must maintain a cumulative grade point average 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:

<table>
<thead>
<tr>
<th>Required</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probability; Mathematical Statistics</td>
<td>6</td>
</tr>
<tr>
<td>or Theory of Statistics I &amp; II</td>
<td></td>
</tr>
<tr>
<td>plus:</td>
<td></td>
</tr>
<tr>
<td>Required</td>
<td>Units</td>
</tr>
<tr>
<td>Linear Statistical Models</td>
<td>3</td>
</tr>
<tr>
<td>Advanced Linear Statistical Models</td>
<td>3</td>
</tr>
<tr>
<td>Bayesian Statistics</td>
<td>3</td>
</tr>
<tr>
<td>Statistical Computation</td>
<td>3</td>
</tr>
</tbody>
</table>
or a suitable substitute elective approved by the department

In the case that an equivalent course has been taken and also proficiency in the course material has been demonstrated, other 400-level and above electives may be substituted in consultation with the adviser. Additional 400-level or higher electives will be chosen by the student in consultation with their adviser to make up the 36 units.

**PhD in Mathematics**

No one can earn a doctorate merely by completing a specified course 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 hours), with at least 48 hours spent 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 hours per semester. A grade point average of B 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-hour course requirement and is making substantial progress on a thesis.

Students must also complete the Teaching Seminar course (L24 597). This course prepares them for both Assistant to the Instructor work and academic teaching duties, which are integral to all scholarly activities. The course spans three semesters, usually starting in the second semester. Each student will have departmental duties (e.g., grading, proctoring) of no more than 12 hours per week as Assistant to the Instructor.

Please note that the sequence outlined above is for “well-prepared” students. The exact point at which any student enters the sequence depends upon 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 hours of course work must include eight of the following nine courses: Math 5031–5032 (Algebra I and Algebra II), Math 5051–5052 (Real Analysis and Functional Analysis), Math 5021–5022 (Complex Analysis I & II), Math 5041–5042 (Smooth Manifolds and Differential Geometry), and Math 5043 (Algebraic Topology). Students may omit one of the following classes when satisfying the course requirement: Math 5022, 5042, or 5052. To satisfy the breadth requirement, the student must pass the required courses with a B or better. The classes are typically offered in the following time frame:

- **Fall:** Algebra I, Real Analysis, Complex Analysis I, Algebraic Topology, Smooth Manifolds
- **Spring:** Algebra II, Functional Analysis, Complex Analysis II, Differential Geometry

In exceptional circumstances, departmental permission may be requested to replace a required course with a suitable alternative. The student may also petition the department to waive one or more of these courses because of work done 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 the English Language Program at the International Office will recommend taking 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 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: 5021, 5022, 5031, 5032, 5041, 5042, 5043, 5051 and 5052. 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, 5022, 5051 or 5052; two be from Math 5041, 5042 or 5043; and two be for Math 5031 and 5032.
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 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 body of literature related to this topic. The student will prepare a one-hour oral presentation related to the topics 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. This 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, please consult the following items from the Graduate School of Arts and Sciences: the Doctoral Dissertation Guide (https://graduateschool.wustl.edu/), the Forms (https://graduateschool.wustl.edu/forms) page, and the Policies and Procedures (https://graduateschool.wustl.edu/policies-procedures) page.

PhD in Statistics

Degree Requirements Summary

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

- 24 required course work units total in fundamental topics and exam fields
- 12 elective course work units
- 3 qualifying exams: 2 in statistics, 1 in mathematics
- Graduate School Teaching Requirement for PhD Students
- 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 hours), with at least 48 hours spent 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 hours per semester. A grade point average of B 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 5061–5062 and Math 439–4392 as well as the mathematical qualifying exam associated with Math 5051–5052. They have also completed the courses Math 459 and Math 475.
- 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-hour course requirement and is making substantial progress on a thesis.

Students must also complete the Teaching Seminar course (L24 597). This course prepares them for both Assistant to the
Instructor work and academic teaching duties, which are integral to all scholarly activities. The course spans three semesters, usually starting in the second semester. Students will have departmental duties (e.g., grading, proctoring) of no more than 12 hours per week as Assistant to the Instructor.

Please note that the sequence outlined above is for "well-prepared" students. The exact point at which any student enters the sequence depends upon 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 hours 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 439 Linear Statistical Models–Math 4392 Advanced Linear Models; the following statistics courses: Math 459 Bayesian Statistics and Math 475 Statistical Computation; and the following graduate-level mathematics sequence: Math 5051–5052. 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 done 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 400- and 500-level statistics electives, and they may also take reading courses with statistics faculty members (Math 500/Math 590). Statistics electives offered by the department include the following:

<table>
<thead>
<tr>
<th>Code</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Math 420</td>
<td>Experimental Design</td>
<td>3</td>
</tr>
<tr>
<td>Math 434</td>
<td>Survival Analysis</td>
<td>3</td>
</tr>
<tr>
<td>Math 449</td>
<td>Numerical Applied Mathematics</td>
<td>3</td>
</tr>
<tr>
<td>Math 456</td>
<td>Financial Mathematics</td>
<td>3</td>
</tr>
<tr>
<td>Math 459</td>
<td>Bayesian Statistics</td>
<td>3</td>
</tr>
<tr>
<td>Math 460</td>
<td>Multivariate Statistical Analysis</td>
<td>3</td>
</tr>
<tr>
<td>Math 461</td>
<td>Time Series Analysis</td>
<td>3</td>
</tr>
<tr>
<td>Math 462</td>
<td>Mathematical Foundations of Big Data</td>
<td>3</td>
</tr>
<tr>
<td>Math 475</td>
<td>Statistical Computation</td>
<td>3</td>
</tr>
<tr>
<td>Math 495</td>
<td>Stochastic Processes</td>
<td>3</td>
</tr>
<tr>
<td>Math 551</td>
<td>Advanced Probability I</td>
<td>3</td>
</tr>
<tr>
<td>Math 552</td>
<td>Advanced Probability II</td>
<td>3</td>
</tr>
<tr>
<td>Math 523C</td>
<td>Information Theory and Statistics (ESE 523)</td>
<td>3</td>
</tr>
</tbody>
</table>

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 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 coursework with other topics that may be helpful for their research and professional development. Some popular elective courses offered by other departments include the following:

<table>
<thead>
<tr>
<th>Code</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESE 405</td>
<td>Reliability and Quality Control</td>
<td>3</td>
</tr>
<tr>
<td>ESE 407</td>
<td>Analysis and Simulation of Discrete Event Systems</td>
<td>3</td>
</tr>
<tr>
<td>ESE 415</td>
<td>Optimization</td>
<td>3</td>
</tr>
<tr>
<td>ESE 425</td>
<td>Random Processes and Kalman Filtering</td>
<td>3</td>
</tr>
<tr>
<td>ESE 428</td>
<td>Probability</td>
<td>3</td>
</tr>
<tr>
<td>ESE 520</td>
<td>Probability and Stochastic Processes</td>
<td>3</td>
</tr>
<tr>
<td>ESE 521</td>
<td>Random Variables and Stochastic Processes I</td>
<td>3</td>
</tr>
<tr>
<td>ESE 522</td>
<td>Random Variables and Stochastic Processes II</td>
<td>3</td>
</tr>
<tr>
<td>ESE 523</td>
<td>Information Theory</td>
<td>3</td>
</tr>
<tr>
<td>CSE 511A</td>
<td>Introduction to Artificial Intelligence</td>
<td>3</td>
</tr>
<tr>
<td>CSE 514A</td>
<td>Data Mining</td>
<td>3</td>
</tr>
<tr>
<td>CSE 517A</td>
<td>Machine Learning</td>
<td>3</td>
</tr>
<tr>
<td>CSE 519T</td>
<td>Advanced Machine Learning</td>
<td>3</td>
</tr>
<tr>
<td>CSE 541T</td>
<td>Advanced Algorithms</td>
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</tr>
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<td>MSB M19-550</td>
<td>Randomized Controlled Trials</td>
<td>3</td>
</tr>
<tr>
<td>MSB M21-623</td>
<td>Advanced Topics in Biostatistics</td>
<td>3</td>
</tr>
<tr>
<td>Econ 5145</td>
<td>Advanced Theoretical Econometrics</td>
<td>3</td>
</tr>
</tbody>
</table>

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 the English Language Program at the International Office will recommend taking 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 5061–5062 and Math 439–4392, and in the mathematics sequence Math 5051–5052. Each spring, at the end of the Math 5061–5062 and Math 439–4392 sequences, all students enrolled in the course 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 5051–5052 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 sometimes happens with students who transfer from other PhD programs or who come from certain foreign countries. Such students may formally petition the chairman 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. The candidacy requirement is designed to expedite this process. Along with a committee of at least two faculty members, the student selects one major and one minor topic and a body of literature dealing with each. The student then usually spends a semester studying the selected material. At the end of this period, the student demonstrates mastery of the two selected topics by means of satisfactory oral expositions to a faculty committee. One member of this committee will in all likelihood become the student's thesis advisor and may have already agreed to be the advisor. The preparatory work for the presentation 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. This 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.