Mathematics

Degrees Offered

- Master of Science
- Doctor of Philosophy

Programs

The Department of Mathematics offers graduate programs leading to the Master of Science (M.S.) and Doctor of Philosophy (Ph.D.) degrees. The master's degree program offers specializations in pure mathematics, applied mathematics, industrial/applied/interdisciplinary mathematics, and mathematics for secondary educators. The Ph.D. program provides for a common core of fundamental mathematics followed by specialized studies culminating in an original research dissertation directed by a faculty advisor. Depending on the student's program and interests, there are diverse career opportunities available in education, government, and industry.

Financial Support

Many graduate students receive financial support in the form of a graduate teaching assistantship, which provides a stipend and a full waiver of university tuition. These are awarded taking into account primarily the student's academic record along with the letters of recommendation and any supplementary information reflecting on the student's potential for success in the program. In some cases, teaching experience and/or the potential for outstanding teaching can be a consideration. Teaching assistants have the opportunity to work with the mathematics education faculty of the Department's Institute for Mathematics Learning (IML). A small number of research assistantships are also available. Applications from students requesting financial aid should be received no later than February 15 to ensure full consideration for the subsequent fall semester. Late applications are accepted, but students are advised to check with the graduate director as to the availability of assistantships. Applications from students requesting financial aid should be received no later than February 15 to ensure full consideration for the subsequent fall semester. Late applications are accepted, but students are advised to check with the graduate director as to the availability of assistantships. Applications for admission (alone) can also be considered at other times, but for best consideration, particularly for the Ph.D. program, students should adhere to the February 15 deadline. Other financial aid includes partial university tuition waivers and part-time positions assisting in the instructional computer labs. TOEFL scores are required for international students whose native language is not English, with a university requirement of a 550 minimum score for admission.

Doctor of Philosophy

The doctor of philosophy is a research program in which the final product is an original, publishable research thesis. For students entering with regular admission status, the program requires a minimum of twenty-four hours of approved coursework along with research and graduate seminar requirements. As reflected in the interests and expertise of the faculty, students may specialize in a variety of areas of pure, applied, and discrete mathematics as well as research in undergraduate mathematics education.

EXAMINATIONS AND DISSERTATION

The student must pass the Department's Ph.D. Entrance Examination within two years: a student enrolling in a given calendar year must pass by the end of the spring semester two years after. The examination is over two subjects selected from the four areas of algebra, real analysis, differential equations, and topology.

Within three years of enrolling, the student is expected to pass a qualifying oral and written examination on the major and minor areas of study and present an approved dissertation prospectus. A minor examination is waived if the student has obtained at least a 3.5 GPA in the corresponding courses. If the qualifying examination results are unsatisfactory (U), the dissertation committee may reexamine the student once.

A Ph.D. candidate must complete a dissertation, representing at least twenty-four hours of 700-level research credit, under the supervision of a dissertation advisor. The research upon which the dissertation is based must conform to scholastic standards and constitute an original and publishable contribution to mathematics.

COMBINATORIAL COMPUTING AND DISCRETE MATHEMATICS (C.C.D.M.)

This is an option within the mathematics Ph.D. program, emphasizing interdisciplinary research at the intersection of computer science, statistics, and discrete mathematics. A minimum of thirty-three credit hours of coursework is required and includes designated core courses in discrete mathematics, statistics, and computer science. Students may undertake mathematics research of an interdisciplinary nature among these three areas.

LANGUAGE REQUIREMENT

Each Ph.D. student must demonstrate a reading knowledge of French, German, or Russian. The Graduate Programs Committee may approve the substitution of a different foreign language or a computer language for fulfillment of this requirement.

Further information may be obtained from the department's website at http://www.math.wvu.edu or by contacting the graduate director at gradprog@math.wvu.edu. Details on program requirements can be found in the Department’s Graduate Handbook, available at http://www.math.wvu.edu/graduate_handbook.
FACULTY

CHAIR

- Edgar Fuller - Ph.D. (University of Georgia)

PROFESSORS

- Ian Christie - Ph.D. (University of Dundee)
  Emeritus, Numerical Partial Differential Equations
- Krzysztof Ciesielski
  Analysis, Topology, Set Theory
- Harvey Diamond - Ph.D. (MIT)
  Approximation Theory, Applied Mathematics
- Edgar Fuller - Ph.D. (University of Georgia)
  Geometric Knot Theory, Mathematics Education
- Harry Gingold - D.Sc. (Israel Institute of Technology)
  Differential Equations, Asymptotic Methods
- John Goldwasser
  Combinatorics, Graph Theory
- Henry W. Gould - M.A. (University of Virginia)
  Emeritus, Combinatorics, Number Theory, Special Functions
- Harumi Hattori - Ph.D. (Rensselaer Polytechnic Institute)
  Differential Equations, Continuum Mechanics
- Hong-Jian Lai
  Associate Chair, Graph Theory, Matroid Theory
- Dening Li
  Partial Differential Equations
- Rong Luo - Ph.D. (West Virginia University)
  Discrete Mathematics
- Laura Pyzdrowski - Ed.D. (West Virginia University)
  Mathematics Education, Instructional Technology
- Michael E. Mays - Ph.D. (Penn. State University)
  Director of the Institute for Mathematics Learning, Number Theory
- Sherman D. Riemenschneider - Ph.D. (Syracuse University)
  Emeritus, Approximation Theory, Wavelet Theory
- Jerzy Wojciechowski - Ph.D. (University of Cambridge)
  Combinatorics, Graph Theory
- Cun-Quan Zhang
  Graph Theory, Combinatorics

ASSOCIATE PROFESSOR

- Marjorie Darrah - Ph.D. (WVU)
  Educational Technology, Algorithm Development, K-12 Outreach
- Jessica Deshler - Ph.D. (University of New Mexico)
  Undergraduate Mathematics Education
- Gary H. Ganser
  Applied Mathematics, Fluid Mechanics, Numerical Analysis
- Adam Halasz - Ph.D. (State University of New York at Stony Brook)
  Mathematical Biology, Swarm Robotics
- David Miller - Ph.D. (Oklahoma State University)
  Undergraduate Mathematics Education, Cognitive Science
- James E. Moseley
  Partial Differential Equations, Modeling
- Vicki Sealey - Ph.D. (Arizona State University)
  Mathematics Education
- Adrian Tudorascu - Ph.D. (Carnegie Mellon University)
  Partial Differential Equations
Master's Admission Information

Admission to the M.S. program requires a WVU admission application and submission of applicable transcripts. International students must supply a passing TOEFL score or other acceptable evidence of English proficiency. Students seeking financial aid should also supply an assistantship application and three letters of recommendation. GRE scores are not required.

Programs are available for students to study applied mathematics, pure mathematics, industrial/applied/interdisciplinary mathematics, or mathematics for secondary educators. For regular admission to the M.S. program, students should have the equivalent of an undergraduate major in mathematics, including at least one semester of advanced calculus (Math 451 or equivalent) and courses in linear algebra and modern algebra. Students with deficiencies may be admitted provisionally; deficiencies are expected to be made up in the first year of study. A minimum of three semesters of calculus is normally required for such admission, but students can often complete their remaining calculus courses during the summer prior to full-time enrollment. To be in good standing, a student is expected to maintain at least a 3.0 average (B) in mathematics courses and to present at least a 3.0 average in all work offered in fulfillment of the degree program.

ADVISORY COMMITTEE

Each student will be assigned an advisory committee consisting of at least three members of the graduate faculty. This committee will assist the student in designing a written plan of study that takes into account the student's interests and needs as well as the aims of the department's graduate programs. Later changes in the plan are possible only through mutual agreement of the student and the committee.

PROGRAMS

The student's plan of study is developed in one of these programs: applied mathematics, pure mathematics, industrial/applied/interdisciplinary mathematics, or mathematics for secondary educators. The programs are designed either for students who intend to pursue a doctor of philosophy in mathematics or the mathematical sciences or for those planning to seek employment in education, government, or industry. Depending upon the program selected, thirty to thirty-three semester hours of approved coursework are required.

Note: MATH 590/690/696/697/790/797 may not be counted for credit to satisfy graduate course requirements.

EXAMINATIONS/THESES/PROJECTS

Upon beginning graduate study, all M.S. students are given a basic exam in advanced calculus and linear algebra for purposes of course placement. Depending on the program chosen, students must complete examinations, a thesis, or a project as a graduation requirement.

Ph.D. Admission Requirements

For regular admission, applicants for the Ph.D. program must have completed a graduate degree similar to the M.S. in mathematics. Students with an exceptionally strong undergraduate background may sometimes be admitted provisionally, with twelve–eighteen credit hours of additional coursework required.

The following materials should be submitted:

- A WVU admission application
- An application for financial support (optional)
- Official undergraduate and graduate transcripts
- Three letters of recommendation from individuals having experience with the applicant's mathematical ability
- TOEFL or IELTS scores for students whose native language is not English

All doctoral students must demonstrate that they are prepared to undertake doctoral work and research by passing an entrance examination, given each year in April and August, within two years after enrolling. Specifically, students entering the program in a given calendar year must pass the entrance examination by the end of the spring semester in the calendar year two years after. Students must pass examinations in two areas from among the four areas of algebra, real analysis, topology, and differential equations. For students in the CCDM option (see below), one of these area exams is replaced by an examination over the CCDM core curriculum.

Beyond any coursework taken to remove deficiencies while a provisional student, a minimum of twenty-four hours of approved coursework is required of all doctoral students, which must include a major area of four courses and two minor areas of two courses each. Certain level and distribution
requirements apply to a student’s program. In addition, doctoral students must enroll for one credit hour of graduate seminar each semester they are in residence.

Ph.D. students may choose the CCDM option, which requires a minimum of 33 credit hours of coursework and includes designated core courses in discrete mathematics, statistics, and computer science. Students may undertake mathematics research of an interdisciplinary nature among these three areas.

**Dissertation Committee**

After the above requirements are satisfied, a student must request that the Director of Graduate Studies select a dissertation committee of at least five members (with a dissertation advisor as chairperson and one member from outside the department) for them.

**Master of Science**

**MAJOR REQUIREMENTS**

A minimum GPA of 3.0 is required in all courses applied toward the degree. A minimum grade of B or higher is required for Mathematics courses included in the program of study.

<table>
<thead>
<tr>
<th>Select an Area of Emphasis</th>
<th>28-34</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH 543</td>
<td>Linear Algebra</td>
</tr>
<tr>
<td>Real Analysis Requirement</td>
<td>3-6</td>
</tr>
<tr>
<td>MATH 451 &amp; MATH 452</td>
<td>Introduction to Real Analysis 1</td>
</tr>
<tr>
<td>or MATH 551</td>
<td>and Introduction to Real Analysis 2</td>
</tr>
<tr>
<td>Total Hours</td>
<td>34-43</td>
</tr>
</tbody>
</table>

* At most four courses in the plan of study may be from outside mathematics.

**Other Curriculum Requirements:**

Students must also meet these option prerequisites:

- Partial differential equations (MATH 261 or MATH 465) (may be satisfied by taking MATH 522)
- Probability Theory (STAT 215 or STAT 461) (may be satisfied by taking STAT 561)

Students must complete at least two courses from Math 452, Math 541, Math 543, Math 551, Math 555, and Math 581 with a grade of at least B in each. Including required courses above, at least one course from 4 different groups below must be included. Within two different groups there must be a sequence of two suitably linked courses. Overall, at most 4 courses may be taken from outside the Mathematics Department, subject to approval by the Graduate Director.

I. Computation/optimization: MATH 521, MATH 522

II. Probability theory/mathematical statistics: STAT 561-562 (other approved STAT courses provided STAT 562 is taken)

III. Algebra/Discrete Math: MATH 541, MATH 543, MATH 571, MATH 573, MATH 545, MATH 645. CS courses as approved by the advisor and the Graduate Director

IV. Modeling: MATH 563, an approved course involving modeling, possibly outside Mathematics.

V. Mathematical Analysis: MATH 452, MATH 551, MATH 651, MATH 555

VI. Graduate courses (one 400-level possible with permission) from outside MATH/STAT/CS. These are to be approved by the Graduate Director.

**Doctor of Philosophy**

**MAJOR REQUIREMENTS**

Minimum GPA of 3.0 is required.

<table>
<thead>
<tr>
<th>MATH 694</th>
<th>Seminar</th>
</tr>
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</table>
or MATH 696  Graduate Seminar

Foreign Language Requirement

Complete the following coursework or select an area of emphasis:

<table>
<thead>
<tr>
<th>Course</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH 641 &amp; MATH 747</td>
<td>Modern Algebra 2 and Advanced Topics in Modern Algebra</td>
</tr>
<tr>
<td>MATH 745 &amp; MATH 746</td>
<td>Analytic Number Theory 1 and Analytic Number Theory 2</td>
</tr>
<tr>
<td>MATH 573 &amp; MATH 773</td>
<td>Graph Theory and Advanced Topics in Graph Theory</td>
</tr>
<tr>
<td>MATH 683 &amp; MATH 783</td>
<td>Set Theory and Applications</td>
</tr>
<tr>
<td>MATH 771 &amp; MATH 772</td>
<td>Matroid Theory 1 and Matroid Theory 2</td>
</tr>
</tbody>
</table>

Other electives in Group A as offered

Group B (Analysis/Differential Equations/Numerical Analysis and Computational Mathematics/Topology) Courses and possible minor sequences:

<table>
<thead>
<tr>
<th>Course</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH 751 &amp; MATH 752</td>
<td>Functional Analysis 1 and Functional Analysis 2</td>
</tr>
<tr>
<td>MATH 757 &amp; MATH 758</td>
<td>Theory of Partial Differential Equations 1 and Theory of Partial Differential Equations 2</td>
</tr>
</tbody>
</table>

Other electives in Group B as offered

One minor sequence may be chosen outside Groups A and B with permission of the Graduate Director, including:

<table>
<thead>
<tr>
<th>Course</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH 791</td>
<td>ADTP:Rsrch-Undrgrd Math Ed 4</td>
</tr>
</tbody>
</table>

Research 24

Entrance Examination

Qualifying Examination

Dissertation Proposal

Dissertation

Dissertation Defense

Total Hours 50

LANGUAGE REQUIREMENT

Each Ph.D. student must demonstrate a reading knowledge of French, German, or Russian. The Graduate Programs Committee may approve the substitution of a different foreign language or a computer language for fulfillment of this requirement.

Further information may be obtained from the department's website at http://www.math.wvu.edu or by contacting the graduate director at gradprog@math.wvu.edu. Details on program requirements can be found in the Department's Graduate Handbook, available at http://www.math.wvu.edu/graduate_handbook.

Applied Mathematics Area of Emphasis

Students in this option must complete the four course RUME sequence. Students must also complete six additional mathematics courses, chosen from the areas in Groups A and B above in include at least four courses at the 700-level. At least two courses should be chosen from each group A and B so as to fulfill the requirements of a minor area. The remaining two courses can be used, for instance, to acquire additional breadth in mathematics or to achieve research level depth in an area. Course options are listed above. In cases where RUME 1-2 have been taken in the M.S program, only RUME 3-4 are required.

<table>
<thead>
<tr>
<th>Course</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH 791 RUME 1-4</td>
<td>6-12</td>
</tr>
<tr>
<td>Minor Area 1</td>
<td>6</td>
</tr>
<tr>
<td>Minor Area 2</td>
<td>6</td>
</tr>
<tr>
<td>Electives</td>
<td>6</td>
</tr>
</tbody>
</table>
### Discrete Mathematics Area of Emphasis

This option is provided for students who wish to work in the intersection of computing, discrete mathematics, and data analysis.

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS 520</td>
<td>Advanced Analysis of Algorithms</td>
<td>3</td>
</tr>
<tr>
<td>MATH 571</td>
<td>Combinatorial Analysis 1</td>
<td>3</td>
</tr>
<tr>
<td>MATH 573</td>
<td>Graph Theory</td>
<td>3</td>
</tr>
<tr>
<td>STAT 561</td>
<td>Theory of Statistics 1</td>
<td>3</td>
</tr>
</tbody>
</table>

A major area and minor areas, representing at least 24 hours at the doctoral level must be chosen from at least three of the groups listed below.

For CCDM students with mathematics chairs, the major area and one of the minor areas must be taken within the Department of Mathematics.

For CCDM students with mathematics and computer science/statistics co-chairs, either the major area or both of the minor areas must be taken within the Department of Mathematics.

- Group A: Algebra/Number Theory/Discrete Mathematics/Set Theory
- Group B: Analysis/Differential Equations/Numerical Analysis and Computational Mathematics/Topology
- Group C: (CS courses) Algorithms, Automata Theory, Formal Language, Advanced graphics and image processing, Data Mining, Pattern Recognition, Artificial Intelligence
- Group D: (STAT courses) Data Mining, Advanced Statistical Theory, Stochastic Processes, Bioinformatics

<table>
<thead>
<tr>
<th>Area</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major Area</td>
<td>12</td>
</tr>
<tr>
<td>Minor Area</td>
<td>6</td>
</tr>
<tr>
<td>Research</td>
<td>24</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH 797</td>
<td>Research</td>
<td>24</td>
</tr>
</tbody>
</table>

### Major Learning Goals

**MATHEMATICS**

The Department of Mathematics offers the M.S. and Ph.D. degrees and has programs emphasizing pure and applied mathematics (M.S., Ph.D.), mathematics for secondary educators (M.S.) and research in undergraduate mathematics education (Ph.D.). Major goals include the following:

Students in the M.S. program receive broad, rigorous training in areas fundamental to mathematics, with options depending on their post-graduation goals:

- Master's level students planning to continue graduate study will have a solid grounding in mathematics basic to their intended graduate programs.
- Students preparing for industry jobs will possess the breadth of applicable mathematical knowledge and experience needed for the challenges of mathematics in industry.
- Students preparing for secondary education will have a broad based deep appreciation of the core of mathematics and effective pedagogy.

Ph.D. students continue advanced training with the following goals:

- Obtain specialized, advanced training in a major field giving them a research-level background and the ability to contribute in their field.
- Under the mentorship of their thesis supervisor, conduct independent, original research in mathematics leading to a significant contribution in their field of study.
• Become acquainted with mathematical research in a variety of fields through course work, seminars, colloquia, and conference presentations.
• Gain significant experience in teaching at the university level and in communicating mathematics.

M.S. Examinations

Students in the Applied Mathematics area of emphasis must pass the M.S Advanced Exam by passing two subject area exams at the M.S level, taken from among Real Analysis, Algebra, Topology, and Differential Equations. No more than three attempts at any one subject area exam are permitted.

Students in the Pure Mathematics area of emphasis must pass the M.S. Advanced Exam by passing two subject area exams at the MS level, taken from among Real Analysis, Algebra, Topology, and Differential Equations. No more than three attempts at any one subject area exam are permitted.

Students in the Mathematics for Secondary Education area of emphasis must pass a final written examination based on their course work, consisting of four sections: algebra, geometry, applied/discrete mathematics, and probability/statistics. With the approval of the Advisory Committee, the exam may be taken after completion of the required 18 hours of graduate mathematics courses and the core curriculum.

Ph.D. Examinations

1) Students must pass the Ph.D. Entrance Examination by the end of their second year in the program. This entails passing two subject area exams at the Ph.D. level, from among Algebra, Real Analysis, Topology, and Differential equations. Any exam may be taken up to three times.

2) Students must pass the Qualifying Examination by the end of their third year. Students whose dissertation area is Research in Undergraduate Mathematics Education will be provided by their committee with a research assignment, based on content areas and research techniques in the field, to be completed over a four-week period. The results will be presented in written form and orally examined by the student's committee. Second, the student must present a thesis prospectus. The student's committee must approve the outcome of both the exam and the prospectus.

3) For each minor area in which the GPA is not 3.5 or above, as part of the Qualifying Exam, the student must take an exam over the minor area to assess competency.