MATHEMATICAL SCIENCES,
BACHELOR OF SCIENCE (B.S.)
WITH A CONCENTRATION IN
APPLIED MATHEMATICS

The curriculum in mathematical sciences promotes understanding of the mathematical sciences and their structures, uses and relationships to other disciplines. To this end, the scholarly growth of the faculty and students in the mathematical sciences is nurtured through study, research and a high standard of teaching. The curriculum provides a sound foundation for the student seeking to enter a career with a technological orientation or for the student who wishes to pursue graduate study in applied mathematics, biomathematics, mathematics, operations research, statistics, teaching mathematics in secondary schools or related fields.

A Bachelor of Science is offered jointly by the Department of Mathematics and Applied Mathematics and the Department of Statistical Sciences and Operations Research. In the Department of Mathematics and Applied Mathematics, students pursuing the Bachelor of Science in Mathematical Sciences can choose a concentration of applied mathematics, which focuses on the analytical and computational techniques necessary to solve many of today's problems. These methods traditionally had been applied in such areas as chemistry and physics, but now are applied in many other areas.

Student learning outcomes

Upon completing this program, students will know how to do the following:

Bachelor of Science in Mathematical Sciences core outcomes

- Solve mathematical problems
- Solve and interpret mathematical problems which originate from applications outside of mathematics
- Use technology to solve and/or explore mathematics problems

Applied mathematics concentration-specific outcomes

- Write mathematics (not including mathematical proofs) clearly, concisely and correctly
- Write mathematical proofs clearly, concisely and correctly
- Read and comprehend mathematical works
- Collaborate in projects
- Make effective presentations to demonstrate their understanding of mathematical ideas
- Write prose about mathematics
- Use appropriate mathematical methods to investigate mathematical models of real-world problems

Special requirements

The B.S. in Mathematical Sciences requires a minimum of 120 credits. Along with the general education requirements of the College of Humanities and Sciences and the undergraduate degree requirements, students are required to take core courses and fulfill specific requirements for the degree.

Based on the results of the Mathematics Placement Test, students may be required to take MATH 151. No more than one course in mathematics (MATH) at the 100 level can count for the general requirements toward the degree. Credit for 100-level mathematical sciences courses cannot be applied toward the mathematical sciences courses required for the major in mathematical sciences.

Double major

Students who meet the requirements for two of the concentrations within the mathematical sciences curriculum can receive a double major. To initiate a double major, students must obtain the appropriate form from the Office of Records and Registration.

Second baccalaureate degree

For students possessing a bachelor's degree and wishing to gain undergraduate preparation in an area of mathematical sciences, second baccalaureate degrees are offered through the department. For detailed information about these programs, refer to the "Academic regulations and general degree requirement" section of this bulletin.

Degree requirements for Mathematical Sciences, Bachelor of Science (B.S.) with a concentration in applied mathematics

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH 201</td>
<td>Calculus with Analytic Geometry II</td>
<td>4</td>
</tr>
<tr>
<td>MATH 307</td>
<td>Multivariate Calculus</td>
<td>4</td>
</tr>
<tr>
<td>MATH 310</td>
<td>Linear Algebra</td>
<td>3</td>
</tr>
<tr>
<td>MATH 255</td>
<td>Introduction to Computational Mathematics</td>
<td>3</td>
</tr>
<tr>
<td>or CMSC 245</td>
<td>Introduction to Programming Using C++</td>
<td></td>
</tr>
<tr>
<td>or EGRE 245</td>
<td>Engineering Programming</td>
<td></td>
</tr>
<tr>
<td>MATH 300</td>
<td>Introduction to Mathematical Reasoning</td>
<td>3</td>
</tr>
<tr>
<td>MATH 407</td>
<td>Real Analysis</td>
<td>3</td>
</tr>
<tr>
<td>MATH 490</td>
<td>Mathematical Expositions</td>
<td>3</td>
</tr>
<tr>
<td>MATH 301</td>
<td>Differential Equations</td>
<td>3</td>
</tr>
<tr>
<td>MATH 415</td>
<td>Numerical Methods</td>
<td>3</td>
</tr>
<tr>
<td>MATH 435</td>
<td>Mathematical and Computational Modeling</td>
<td>3</td>
</tr>
</tbody>
</table>

Select two from:

- MATH 432 Ordinary Differential Equations
- MATH 433 Partial Differential Equations
- MATH 434 Discrete Dynamical Systems

Concentration electives | 0-6

Ancillary requirements
### Mathematical Sciences, Bachelor of Science (B.S.) with a concentration in applied mathematics

<table>
<thead>
<tr>
<th>Course</th>
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<th>Hours</th>
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<tbody>
<tr>
<td>MATH 200</td>
<td>Calculus with Analytic Geometry I (satisfies general education quantitative foundations)</td>
<td>4</td>
</tr>
<tr>
<td>STAT 212</td>
<td>Concepts of Statistics</td>
<td>3</td>
</tr>
<tr>
<td>HUMS 202</td>
<td>Choices in a Consumer Society</td>
<td>1</td>
</tr>
</tbody>
</table>

#### Experiential fine arts

0-6

#### Foreign language through the 102 level (by course or placement)

0-6

#### Natural science sequence:
Select one sequence from list below (satisfies general education BOK for natural sciences and AOI for scientific and logical reasoning)

- **Sequence 1**
  - BIOL 151: Introduction to Biological Sciences I (satisfies general education BOK for natural sciences and AOI for scientific and logical reasoning)
  - BIOL 152: Introduction to Biological Sciences II
  - BIOZ 152: Introduction to Biological Science Laboratory II

- **Sequence 2**
  - CHEM 101: General Chemistry I (satisfies general education BOK for natural sciences and AOI for scientific and logical reasoning)
  - CHEZ 101: General Chemistry Laboratory I (satisfies general education AOI for scientific and logical reasoning)
  - CHEM 102: General Chemistry II
  - CHEZ 102: General Chemistry Laboratory II

- **Sequence 3**
  - PHYS 201: General Physics I (satisfies general education BOK for natural sciences and AOI for scientific and logical reasoning)
  - PHYS 202: General Physics II

- **Sequence 4**
  - PHYS 207: University Physics I (satisfies general education quantitative foundations)
  - PHYS 208: University Physics II

#### Natural science elective (different from chosen science sequence)

3-5

#### Open electives

Select any course.

21-39

**Total Hours**: 120

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1. These courses/credits require a minimum grade of C.

2. Six additional upper-level credits in the mathematical sciences (MATH, STAT, OPER, CMSC) or the completion of a minor or a double major.

3. Course offered by the School of the Arts

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The minimum number of credit hours required for this degree is 120.

### Natural science sequence

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIOL 151</td>
<td>Introduction to Biological Sciences I (satisfies general education BOK for natural sciences and AOI for scientific and logical reasoning)</td>
<td>3</td>
</tr>
<tr>
<td>BIOZ 151</td>
<td>Introduction to Biological Science Laboratory I</td>
<td>1</td>
</tr>
<tr>
<td>BIOL 152</td>
<td>Introduction to Biological Sciences II</td>
<td>3</td>
</tr>
<tr>
<td>BIOZ 152</td>
<td>Introduction to Biological Science Laboratory II</td>
<td>1</td>
</tr>
</tbody>
</table>

#### Fall semester

**Term Hours**: 14

- MATH 200: Calculus with Analytic Geometry I (satisfies general education quantitative foundations)
- UNIV 101: Introduction to the University
- UNIV 111: Focused Inquiry I (satisfies general education UNIV foundations)
- Foreign language 101

**General education course (select AOI in consultation with adviser)**

3

**Term Hours**: 15-17

### Spring semester

**Term Hours**: 16

- MATH 201: Calculus with Analytic Geometry II
- STAT 212: Concepts of Statistics
- UNIV 112: Focused Inquiry II (satisfies general education UNIV foundations)
- Foreign language 101

**General education course (select BOK to complete breadth of knowledge requirement)**

3
Mathematical Sciences, Bachelor of Science (B.S.) with a concentration in applied mathematics

General education course (select BOK to complete breadth of knowledge requirement) 3

Term Hours: 15

Junior year

Fall semester

MATH 407  Real Analysis 3

Concentration elective (upper level) 3

Natural sciences sequence (select one of the following) 4-5
(satisfies general education BOK for natural sciences and A0I for scientific and logical reasoning)

BIOL 151  Introduction to Biological Sciences I 3
& BIOZ 151  - 3
and Introduction to Biological Science Laboratory I

CHEM 101  General Chemistry I 3
& CHEZ 101 and General Chemistry Laboratory I 3

PHYS 201  General Physics I 3

PHYS 207  University Physics I 3

Open electives 6

Term Hours: 16-17

Spring semester

MATH 415  Numerical Methods 3

Concentration elective (upper level) 3

Natural sciences sequence (Select one of the following with appropriate matching course.) 4-5

BIOL 152  Introduction to Biological Sciences II 3
& BIOZ 152 and Introduction to Biological Science Laboratory II 3

CHEM 102  General Chemistry II 3
& CHEZ 102 and General Chemistry Laboratory II 3

PHYS 202  General Physics II 3

PHYS 208  University Physics II 3

Open electives 6

Term Hours: 16-17

Senior year

Fall semester

MATH 432  Ordinary Differential Equations 3
or MATH 433 or Partial Differential Equations 3
or MATH 434 or Discrete Dynamical Systems 3

MATH 435  Mathematical and Computational Modeling 3

Natural sciences elective 1 3-5

Open electives 6

Term Hours: 15-17

Spring semester

MATH 432  Ordinary Differential Equations 3
or MATH 433 or Partial Differential Equations 3
or MATH 434 or Discrete Dynamical Systems 3

MATH 490  Mathematical Expositions 3

Open electives 7-9

Term Hours: 13-15

Total Hours: 120-128

1 Different science than chosen for sequence.

The minimum number of credit hours required for this degree is 120.

Accelerated B.S. and M.S.

The accelerated B.S. and M.S. program allows qualified students in the applied mathematics and biomathematics concentrations to earn both the B.S. in Mathematical Sciences and the M.S. in Mathematical Sciences with a concentration in applied mathematics in a minimum of five years by completing approved graduate courses during the senior year of their undergraduate program. Students in the program may count up to nine hours of graduate courses toward both the B.S. and M.S. degrees. Thus, the two degrees may be earned with a minimum of 141 credits rather than the 150 credits necessary if the two degrees are pursued separately.

Students holding these degrees are better prepared for a career in a technical industry, for a career in teaching and/or for further studies in a quantitative Ph.D. program, such as mathematics, data sciences or statistics. An accelerated B.S. and M.S. degree in Mathematics offers a direct pathway toward high-paying positions in big tech companies and financial institutions. Over the past decade, the increasingly competitive application process for Ph.D. programs in mathematics has made it extremely difficult for students holding only a B.S. degree to be admitted. On the other hand, students graduating from VCU with a master’s in mathematical sciences have a history of getting into highly rated Ph.D. programs, often with generous funding.

Entrance to the accelerated program

Interested undergraduate students should consult with their adviser as early as possible to receive specific information about the accelerated program, determine academic eligibility and submit (no later than two semesters prior to graduating with a baccalaureate degree, that is, before the end of the spring semester of their junior year) an Accelerated Program Declaration Form to be approved by the graduate program director. Limited spaces may be available in the accelerated program. Academically qualified students may not receive approval if capacity has been reached.

Minimum qualifications for entrance to this accelerated program include completion of 90 undergraduate credit hours, including STAT 212, MATH 255, MATH 301, MATH 307, MATH 310, MATH 380 (this course for the biomathematics concentration only) and MATH 407; an overall GPA of 3.0, and a GPA of 3.0 in mathematics course work. Students who do not meet the minimum GPA requirements may submit general GRE scores to receive further consideration. Students who are interested in the accelerated program should consult with the faculty adviser to the Mathematical Sciences M.S. program before they have completed 90 credits. Successful applicants would enter the program in the fall semester of their senior year.

Once enrolled in the accelerated program, students must meet the standards of performance applicable to graduate students as described in the “Satisfactory academic progress” section of the Graduate Bulletin, including maintaining a 3.0 GPA. Guidance to students admitted to the accelerated program is provided by both the undergraduate mathematics adviser and the faculty adviser to the graduate program.
Admission to the graduate program

Entrance to the accelerated program enables the student to take the approved shared courses that will apply to the undergraduate and graduate degrees. However, entry into an accelerated program via an approved Accelerated Program Declaration Form does not constitute application or admission into the graduate program. Admission to the graduate program requires a separate step that occurs through a formal application to the master's program, which is submitted through Graduate Admissions no later than a semester prior to graduation with the baccalaureate degree, that is, before the end of the fall semester of the senior year. In order to continue pursuing the master's degree after the baccalaureate degree is conferred, accelerated students must follow the admission to graduate study requirements outlined in the VCU Bulletin. One of the three required reference letters must come from a Department of Mathematics and Applied Mathematics faculty member.

Degree requirements

The Bachelor of Science in Mathematical Sciences degree (with a concentration in either applied mathematics or biomathematics) will be awarded upon completion of a minimum of 120 credits in undergraduate program credits and the satisfactory completion of all undergraduate degree requirements as stated in the Undergraduate Bulletin.

Students must pass a comprehensive exam in the core courses and selected elective courses determined by the Department of Mathematics and Applied Mathematics.

A maximum of 12 graduate credits may be taken prior to completion of the baccalaureate degree. These graduate credits substitute for major requirements and required major electives for the undergraduate degree and are shared with the graduate program, meaning that they will be applied to both undergraduate and graduate degree requirements.

The graduate mathematics courses that may be taken as an undergraduate once a student is admitted to the program are below.

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH 507</td>
<td>Bridge to Modern Analysis (may count as undergraduate major elective)</td>
<td>3</td>
</tr>
<tr>
<td>MATH 515</td>
<td>Numerical Analysis (may count as undergraduate major requirement or open elective)</td>
<td>3</td>
</tr>
<tr>
<td>MATH 535</td>
<td>Introduction to Dynamical Systems (may count as undergraduate major elective)</td>
<td>3</td>
</tr>
<tr>
<td>MATH 610</td>
<td>Advanced Linear Algebra</td>
<td>3</td>
</tr>
</tbody>
</table>

Recommended course sequence/plan of study

What follows is the recommended plan of study for students interested in the accelerated program beginning in the fall of the junior year prior to admission to the accelerated program in the senior year.

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH 407</td>
<td>Real Analysis</td>
<td>3</td>
</tr>
<tr>
<td>MATH 432</td>
<td>Ordinary Differential Equations</td>
<td>3</td>
</tr>
<tr>
<td>Experiential fine arts</td>
<td></td>
<td>1-3</td>
</tr>
<tr>
<td>General education course</td>
<td></td>
<td>3</td>
</tr>
</tbody>
</table>

| Natural science sequence | 4-5 |
| Term Hours: | 14-17  |
| Spring semester |
| MATH 433 | Partial Differential Equations                                     | 3     |
| MATH 435 | Mathematical and Computational Modeling                             | 3     |

General education course | 3
Natural science sequence | 4-5
Open elective | 3
Term Hours: | 16-17

Senior year

Fall semester
<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Hours</th>
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</thead>
<tbody>
<tr>
<td>MATH 507</td>
<td>Bridge to Modern Analysis</td>
<td>3</td>
</tr>
<tr>
<td>MATH 535</td>
<td>Introduction to Dynamical Systems</td>
<td>3</td>
</tr>
<tr>
<td>MATH 585</td>
<td>Biomathematics Seminar (biomathematics concentration only)</td>
<td>1</td>
</tr>
<tr>
<td>MATH 610</td>
<td>Advanced Linear Algebra</td>
<td>3</td>
</tr>
</tbody>
</table>

| Term Hours: | 16-17  |
| Spring semester |
| MATH 490 | Mathematical Expositions                                              | 3     |
| MATH 515 | Numerical Analysis                                                   | 3     |

Concentration elective (appropriate to applied mathematics or biomathematics) | 3
Open electives | 6
Term Hours: | 15

Fifth year

Fall semester
<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH 615</td>
<td>Iterative Numerical Methods</td>
<td>3</td>
</tr>
<tr>
<td>MATH 769</td>
<td>Topics in Applied Mathematics: ____</td>
<td>3</td>
</tr>
</tbody>
</table>

Graduate math elective | 3
Term Hours: | 9

Spring semester
<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH 632</td>
<td>Ordinary Differential Equations I or MATH 633 Partial Differential Equations</td>
<td>3</td>
</tr>
<tr>
<td>MATH 690</td>
<td>Research Seminar</td>
<td>2</td>
</tr>
<tr>
<td>Math electives (600- to 700-level)</td>
<td></td>
<td>6</td>
</tr>
</tbody>
</table>

Term Hours: | 11

Students registering for.

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMSC 255</td>
<td>Introduction to Programming</td>
<td>4</td>
</tr>
<tr>
<td>MATH 131</td>
<td>Introduction to Contemporary Mathematics</td>
<td>3</td>
</tr>
<tr>
<td>MATH 141</td>
<td>Algebra with Applications</td>
<td>4</td>
</tr>
<tr>
<td>MATH 151</td>
<td>Precalculus Mathematics</td>
<td>4</td>
</tr>
<tr>
<td>MATH 200</td>
<td>Calculus with Analytic Geometry I</td>
<td>4</td>
</tr>
<tr>
<td>MATH 211</td>
<td>Mathematical Structures</td>
<td>3</td>
</tr>
<tr>
<td>MATH 300</td>
<td>Introduction to Mathematical Reasoning</td>
<td>3</td>
</tr>
</tbody>
</table>
must place into these courses either from receiving VCU credit for stated prerequisite courses (for instance, MATH 151 is a stated prerequisite course for MATH 200) or from a satisfactory score (within a 39-month period immediately preceding the beginning of the course) on the VCU Mathematics Placement Test.

MATH 001. Elementary Algebra. 0 Hours.
Semester course; 3 lecture or 3 laboratory/tutorial hours. No credit. Prerequisite: permission of the department chair. The purpose of this course is to provide laboratory and tutorial instruction for those seeking remediation or review of high school algebra. Topics include basic properties of real numbers, operations with algebraic expressions, solution of equations and inequalities, exponents and radicals, introduction to functions and graphing.

MATH 120. Seeing, Playing, Deciding – This is Math?. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Students will learn about the beautiful and often surprising interactions between mathematics and three broad areas: the visual arts, games and public policy. Representative topics include perspective in the visual arts; tessellations; origami; games and strategies in recreational settings and in the social and natural sciences; the often hidden mathematics behind public policy; and assessing quantitative claims in the public arena.

MATH 121. Perspective Geometry. 1 Hour.
Short course (5 weeks); 3 lecture hours. 1 credit. Students will examine ways in which Renaissance artists who developed linear perspective in geometry in order to paint scenes realistically influenced the development of mathematics and geometry. Topics covered will include the foundations of projective geometry. Pascal’s mystic hexagram, Brianchon’s Theorem and duality. A need for higher mathematics will also be introduced and explained. MATH 121-122-123 fulfills the math requirement for art students. The sequence can be taken in any order.

MATH 122. Tessellations. 1 Hour.
Short course (5 weeks); 3 lecture hours. 1 credit. Students will examine ways in which mathematics is rooted in both natural philosophy and art by examining tiling theory. Course topics include Penrose tilings, symmetries and various other tessellations. MATH 121-122-123 fulfills the math requirement for art students. The sequence can be taken in any order.

MATH 123. Visualization. 1 Hour.
Short course (5 weeks); 3 lecture hours. 1 credit. Students will examine ways in which mathematics has been visualized artistically and will develop their own way to express a mathematical idea. Topics covered will include fractals, knots, minimal surfaces, non-Euclidean geometry and the fourth dimension. MATH 121-122-123 fulfills the math requirement for art students. The sequence can be taken in any order.

MATH 129. Introduction to College Algebra. 3 Hours.
Semester course; 3 lecture hours. 3 credits. A study in algebraic functions through graphical, numerical, symbolic and verbal representations. Topics include the exploration of linear, quadratic, polynomial, exponential and logarithmic functions. Real-world applications and the development of algebra skills are an integral part of the course. This course will not satisfy any general education requirements. Students may receive credit toward graduation for only one of MATH 129 and MATH 141.

MATH 131. Introduction to Contemporary Mathematics. 3 Hours.
Semester course; 3 lecture hours (delivered online, face-to-face or hybrid). 3 credits. Topics include optimization problems, data handling, growth and symmetry, and mathematics with applications in areas of social choice. Major emphasis is on the process of taking a real-world situation, converting the situation to an abstract modeling problem, solving the problem and applying what is learned to the original situation. Does not serve as a prerequisite for MATH 151 or other advanced mathematical sciences courses.

MATH 139. College Algebra with Applications. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisite: MATH 129 with a minimum grade of C or placement through the VCU Math Placement Test within the one-year period immediately preceding the beginning of the course. An in-depth exploration of the characteristics, graphs and applications of linear, exponential, logarithmic and power functions. Topics include fundamental concepts of functions, including but not limited to transformations, inverses, arithmetic operations and composition. Opportunities to investigate, analyze and communicate findings from real-world scenarios will be supported by the use of technology. Students may receive credit toward graduation for only one of MATH 139 and MATH 141.

MATH 141. Algebra with Applications. 4 Hours.
Semester course; 4 lecture hours (delivered online, face-to-face or hybrid). 4 credits. Prerequisite: one year of high school algebra and satisfactory score on the VCU Mathematics Placement Test within the one-year period immediately preceding the beginning of the course. Topics include concepts and applications of linear, exponential, logarithmic, power and quadratic functions; graphing; transformations and inverses of functions; algebra and composition of functions. Students may not receive credit toward graduation for both MATH 141 and either MATH 129 or MATH 139.

MATH 151. Precalculus Mathematics. 4 Hours.
Semester course; 3 lecture and 1 mathematics laboratory/recitation hours. 4 credits. Prerequisite: MATH 139 or MATH 141 with a minimum grade of C, or satisfactory score on the VCU Mathematics Placement Test within the one-year period immediately preceding the beginning of the course. An exception to this policy is made in the case where the stated alternative prerequisite course has been completed at VCU. Concepts and applications of algebra and trigonometry. Topics include graphics, transformations and inverses of functions; linear, exponential, logarithmic, power, polynomial, rational and trigonometric functions.

MATH 191. Topics in Mathematics. 1-3 Hours.
Semester course; 1-3 credits. May be repeated for credit. A study of selected topics in mathematics. For a course to meet the general education requirements it must be stated in the Schedule of Classes. See the Schedule of Classes for specific topics to be offered each semester and prerequisites.

MATH 200. Calculus with Analytic Geometry I. 4 Hours.
Semester course; 4 lecture hours. 4 credits. Prerequisite: MATH 151 with a minimum grade of C or satisfactory score on the VCU Mathematics Placement Test within the one-year period immediately preceding the beginning of the course. Limits, continuity, derivatives, differentials, antiderivatives and definite integrals.

MATH 201. Calculus with Analytic Geometry II. 4 Hours.
Semester course; 4 lecture hours. 4 credits. Prerequisite: MATH 200 with a minimum grade of C. Applications of differentiation and integration. Selected topics in analytic geometry. Infinite series.
MATH 211. Mathematical Structures. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisite: MATH 151, MATH 200, MATH 201 or BUSN 212* with a minimum grade of C, or calculus-level placement on the VCU Mathematics Placement Test within the one-year period immediately preceding enrollment in the course. An alternative prerequisite course may be approved at the discretion of the academic adviser. An introduction to mathematical logic and set theory, including applications in Boolean algebras and graph theory. *Previously MGMT 212, SCMA 212.

MATH 230. Mathematics in Civilization. 3 Hours.
Semester course; 3 lecture hours. 3 credits. For Honors College students only. The growth, development and far-reaching applications of trigonometry, navigation, cartography, logarithms and algebra through ancient, medieval, post-Renaissance and modern times are explored. Will include methods to solve mathematical problems using various historical procedures and will involve collaboration through group projects.

MATH 255. Introduction to Computational Mathematics. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisite: MATH 201 with a minimum grade of C. (A core course for mathematics/applied mathematics majors.) An introduction to computer algebra systems (CAS) and their use in mathematical, scientific and engineering investigations/computations. Introductory mathematical computer programming using a CAS, including implementation of problem-specific algorithms.

MATH 291. Topics in Mathematics. 1-3 Hours.
Semester course; 3 lecture hours. 3 credits. May be repeated for credit. A study of selected topics in mathematics. See the Schedule of Classes for specific topics to be offered each semester and prerequisites.

MATH 300. Introduction to Mathematical Reasoning. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisite: MATH 201 with a minimum grade of C. (A core course for mathematics/applied mathematics majors.) An introduction to basic concepts of mathematical reasoning and the writing of proofs in an elementary setting. Direct, indirect and induction proofs. Illustrations of the concepts include basic proofs from mathematical logic, elementary set theory, elementary number theory, number systems, foundations of calculus, relations, equivalence relations, functions and counting with emphasis on combinatorial proofs.

MATH 301. Differential Equations. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisite: MATH 201 with a minimum grade of C. Solutions of ordinary differential equations of first order. Solutions of higher order linear differential equations with constant coefficients and variable coefficients by the methods of undetermined coefficients and variation of parameters, solutions by Laplace transforms and applications.

MATH 302. Numerical Calculus. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisites: MATH 255 (or knowledge of a programming language/mathematical software package) and MATH 201, each with a minimum grade of C, or permission of the instructor. An introduction to numerical algorithms for solving systems of linear equations, finding zeroes, numerical differentiation and definite integration, optimization.

MATH 303. Investigations in Geometry. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisite: MATH 361 with a minimum grade of C. Enrollment is restricted to students majoring in programs to prepare early childhood and elementary teachers (B.S.Ed. in Elementary Education and Teaching and B.S.Ed. in Early Childhood Education and Teaching). A study of topics in Euclidean geometry to include congruence, similarity, measurement, coordinate geometry, symmetry and transformation in both two and three dimensions. These topics will be investigated using manipulatives and computer software.

MATH 305. Elementary Number Theory. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisite: MATH 300 with a minimum grade of C. Divisibility, congruences, Euler phi-function, Fermat's Theorem, primitive roots, Diophantine equations.

MATH 307. Multivariate Calculus. 4 Hours.
Semester course; 4 lecture hours. 4 credits. Prerequisite: MATH 201 with a minimum grade of C. The calculus of vector-valued functions and of functions of more than one variable. Partial derivatives, multiple integrals, line integrals, surface integrals and curvilinear coordinates. Lagrange multipliers; theorems of Green, Gauss and Stokes. Applications.

MATH 310. Linear Algebra. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisite: MATH 201 with a minimum grade of C. Systems of linear equations, vector spaces, linear dependence, bases, dimensions, linear mappings, matrices, determinants, quadratic forms, orthogonal reduction to diagonal form, eigenvalues and geometric applications.

MATH 350. Introductory Combinatorics. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisite: MATH 201 with a minimum grade of C. An introduction to basic combinatorial concepts such as combinations, permutations, binomial coefficients, Fibonacci numbers and Pascal's triangle; basic theorems such as the pigeonhole principle and Newton's binomial theorem; algorithms such as bubble sort and quicksort; and discussion of basic applications such as chessboard problems, combinatorial games, magic squares and Latin squares.

MATH 351. Applied Abstract Algebra. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisite: MATH 201 with a minimum grade of C. A survey of several areas in applied abstract algebra which have applications in computer science such as groups, codes, matrix algebra, finite fields and advanced graph theory.

MATH 353. Experimental Mathematics. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisite: MATH 201 with a minimum grade of C. An introduction to a mathematical computing package, computer manipulation of lists and sets, and symbolic computing. Numerical computation will be used to investigate mathematical objects, such as integers, prime numbers, graphs, matrices and to identify properties and patterns among these objects. Random methods will be used to explore properties and patterns in long sequences and large collections.

MATH 356. Graphs and Algorithms. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisite: MATH 201 with a minimum grade of C. An introduction to basic graph theoretic concepts such as trees, colorings and matchings; basic theorems such as the handshaking lemma and the Gallai identities; algorithms such as Dijkstra's and Kruskal's; and discussion of famous open problems such as finding shortest tours for a traveling salesman.
MATH 361. Numbers and Operations. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisite: TEDU 101 with a minimum grade of C, and either MATH 131 with a minimum grade of C or satisfactory score on the VCU Mathematics Placement Test within the one-year period immediately preceding the beginning of the course. Enrollment is restricted to students majoring in programs to prepare early childhood and elementary teachers (B.S.Ed. in Elementary Education and Teaching and B.S.Ed. in Early Childhood Education and Teaching). Ways of representing numbers, relationships between numbers, number systems, the meanings of operations and how they relate to one another, and computation within the number systems as a foundation for algebra. The course includes structured observations of elementary-level students.

MATH 362. Algebra and Functions. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisite: MATH 361 with a minimum grade of C. Enrollment is restricted to students majoring in programs to prepare early childhood and elementary teachers (B.S.Ed. in Elementary Education and Teaching and B.S.Ed. in Early Childhood Education and Teaching). This course will explore a variety of numerical topics including proportional reasoning, number theory and algebraic concepts. Attention will be given to the transition from arithmetic to algebra, working with quantitative change, and the description and prediction of change. Topics will be investigated through problem-solving and mathematical discourse. The course includes structured observations of elementary-level students.

MATH 380. Introduction to Mathematical Biology. 4 Hours.
Semester course; 3 lecture and 2 laboratory hours. 4 credits. Prerequisites: MATH 200 and BIOL 151, both with a minimum grade of C, or permission of instructor. An introduction to mathematical biology. Various mathematical modeling tools will be covered and implemented in a range of biological areas. Additionally, the collaborative research process will be presented and discussed. Crosslisted as: BINFO 380.

MATH 391. Topics in Mathematics. 1-3 Hours.
Semester course; 1-3 credits. May be repeated for credit. A study of selected topics in mathematics. See the Schedule of Classes for specific topics to be offered each semester and prerequisites.

MATH 401. Introduction to Abstract Algebra. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisites: MATH 300 and MATH 310, each with a minimum grade of C. An introduction to groups, rings and fields from an axiomatic point of view. Coset decomposition and basic morphisms.

MATH 404. Algebraic Structures and Functions. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisites: MATH 300 and MATH 310, each with a minimum grade of C. An introduction to groups, rings and fields from an axiomatic point of view. Exponential, logarithmic and trigonometric functions. Graphing in parametric and polar coordinates. Arithmetic and geometric sequences and series.

MATH 407. Real Analysis. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisite: MATH 300 with a minimum grade of C. Theoretical aspects of calculus. Topics include properties of real numbers, countable and uncountable sets, sequences and series, limits, continuity, derivatives, and Riemann integration.

MATH 409. General Topology. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisite: MATH 407 with a minimum grade of C. Foundations and fundamental concepts of point-set topology. Topological spaces, continuity, convergence, connected sets, compactness, product spaces, quotient spaces, function spaces, separation properties.

MATH 411. Excursions in Geometry. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisites: MATH 300, MATH 307 and MATH 310, each with a minimum grade of C. An introduction to the fundamental concepts of geometry on manifolds. A study of charts and atlases, local and global properties, regular and rational functions and maps, and smoothness and tangent spaces. Other topics may include Riemannian metrics, projective varieties or integration on manifolds.

MATH 415. Numerical Methods. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisites: MATH 255, MATH 301 and MATH 310, each with a minimum grade of C. Numerical methods for interpolation, solving systems of linear equations and initial value problems (ordinary differential equations) and the exploration of computational error.

MATH 427. Excursions in Analysis: Real. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisites: MATH 307, MATH 310 and MATH 407, each with a minimum grade of C. May be repeated once for credit with a different emphasis and permission of the instructor. Intensive study of ideas and applications from real analysis.

MATH 428. Excursions in Analysis: Complex. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisites: MATH 307, MATH 310 and MATH 407, each with a minimum grade of C. May be repeated once for credit with a different emphasis and permission of the instructor. Intensive study of ideas and applications from complex analysis.

MATH 429. Excursions in Analysis: Applied. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisites: MATH 301, MATH 307, MATH 310 and MATH 407, each with a minimum grade of C. May be repeated once for credit with a different emphasis and permission of the instructor. Intensive study of ideas and applications from applied analysis.

MATH 430. The History of Mathematics. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisites: MATH 300, MATH 307, MATH 310, and either MATH 301 or OPER 327, all with a minimum grade of C. Surveys major trends in the development of mathematics from ancient times through the 19th century and considers the cultural and social contexts of mathematical activity.

MATH 431. Expositions in Modern Mathematics. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisites: MATH 307, MATH 310 and MATH 407, each with a minimum grade of C. Descriptively studies several major ideas relevant to present-day mathematics, such as the advent of pure abstraction, difficulties in the logical foundations of mathematics, the impact of mathematics and statistics in the 20th century and the computer revolution.

MATH 432. Ordinary Differential Equations. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisites: MATH 300, MATH 307, MATH 310 and either MATH 301 or OPER 327, all with a minimum grade of C. Existence and uniqueness of solutions, linearization and stability analysis, Lyapunov stability theory, periodic solutions, and bifurcations. Applications and simulations are emphasized.
MATH 433. Partial Differential Equations. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisites: MATH 300, MATH 301, MATH 307 and MATH 310, each with a minimum grade of C. Parabolic (heat), hyperbolic (wave) and elliptic (steady-state) partial differential equations are studied. Solution techniques such as separation of variables, reflection methods, integral transform methods and numerical methods are demonstrated. Practical problems and applications are emphasized.

MATH 434. Discrete Dynamical Systems. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisites: MATH 301, MATH 307 and MATH 310, each with a minimum grade of C. Theory and applications of difference equations including existence and uniqueness of solutions, linearization and stability, periodic solutions, and bifurcations.

MATH 435. Mathematical and Computational Modeling. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisites: MATH 301 and MATH 310, each with minimum grade of C. Focuses on general mathematical modeling principles. A variety of application areas are explored through a complete model development cycle. This process involves the theoretical development of a mathematical model, implementation of a computational solution and exploration of the solution within the context of the application area.

MATH 434. Using Technology in the Teaching of Mathematics. 3 Hours.
Semester course; 2 lecture and 2 laboratory hours. 3 credits. Prerequisites: MATH 200 and STAT 212, each with a minimum grade of C; six additional credits in the mathematical sciences; and permission of the instructor. Using graphing calculators, calculator-based labs and computer software packages in teaching topics in algebra, geometry, trigonometry, statistics, finance and calculus.

MATH 480. Methods of Applied Mathematics for the Life Sciences: Discrete. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisites: MATH 301, MATH 307, MATH 310 and MATH 380, each with a minimum grade of C. Focuses on the use of discrete dynamical system models to describe phenomena in biology and medicine. Students will explore the theoretical mathematics necessary to analyze these models. Computational solutions to these models will be developed and implemented to validate the models and to further explore the biological phenomena.

MATH 481. Methods of Applied Mathematics for the Life Sciences: ODE. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisites: MATH 301, MATH 307, MATH 310 and MATH 380, each with a minimum grade of C. Focuses on the use of ordinary differential equation models to describe phenomena in biology and medicine. Students will explore the theoretical mathematics necessary to analyze these models. Computational solutions to these models will be developed and implemented to validate the models and to further explore the biological phenomena.

MATH 482. Methods of Applied Mathematics for the Life Sciences: PDE. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisites: MATH 301, MATH 307, MATH 310 and MATH 380, each with a minimum grade of C. Focuses on the use of partial differential equation models to describe phenomena in biology and medicine. Students will explore the theoretical mathematics necessary to analyze these models. Computational solutions to these models will be developed and implemented to validate the model and to further explore the biological phenomena.