Rose-Hulman Institute of Technology Course Catalog

Mathematics

Why study mathematics? Many of the new wonders that we take for granted in our modern technological society have mathematical ideas and applications as their basis, though this role is often hidden from view. Complex economic and planning decisions, scientific discoveries that improve our lives, and new technologies and products are often possible only after mathematical or statistical analysis, or a computer visualization, simulation, design and implementation based on mathematics. Therefore, mathematicians, as well as mathematically educated scientists, engineers and economists, make important daily contributions in the understanding and advancement of science, the improvement and discovery of new technology, and decision-making and planning in business, industry and government. Students interested in using their mathematical skills in solving real world problems are well prepared, by majoring or minoring in mathematics, for careers such as in the insurance industry, software design, data and systems analysis, scientific computing, combustion research, the animated movie industry, and cryptanalysis to name a few, or a graduate degree in a related technical field. Those students with a very strong interest in mathematics itself can pursue graduate study in mathematics in preparation for careers as university or college mathematics teachers and in the development of new mathematical and statistical concepts and methods as researchers in academia, government and industry.

The curriculum of the program in the Department of Mathematics is designed to provide a broad education in both theoretical and applied mathematics. It also develops the scientific knowledge and the problem solving, computing, and communications skills that are critical to a successful mathematically based career. This preparation is greatly enhanced by taking advantage of the wide variety of science and engineering courses available to students and developing good communications skills, both through technical courses and the strong humanities program. The program offers a solid grounding in the foundational areas of calculus, differential equations, linear algebra, discrete and combinatorial algebra, and probability and statistics. These basic courses are complemented by a varied selection of upper division courses for further elective study in areas such as numerical analysis, operations research, advanced statistics, mathematical modeling, optimization, and other advanced topics in mathematics. Students are encouraged to develop a strong background in an area of science or engineering through election of courses leading to a minor or double major. By appropriate course selection students may complete a double major in mathematics and another field such as computer science, physics, chemistry, applied biology, or economics.

PROGRAM GOALS AND OBJECTIVES

To provide a foundation for further learning as well as contributing to the general education of students, the programs at Rose-Hulman all have a heavy investment in mathematics and science in the first two years. The freshman and sophomore mathematics curriculum is designed to contribute to this foundation by ensuring that students are familiar with basic mathematical and statistical concepts, and mathematical and statistical reasoning and modeling. Students will also understand the use of mathematics in other disciplines as well as developing an appreciation of mathematics as a discipline in its own right. In addition, students will learn to be competent users of mathematics, especially in problem solving, and be able to effectively communicate

mathematically. The curriculum makes strong use of computer methods to develop students' mathematical understanding and to enhance their ability to use the computer in modeling, computation and problem solving.

For students seeking a major in mathematics, the curriculum prepares them for a mathematically based career after graduation or further graduate study. The major builds upon the goals and objectives of the freshman and sophomore curriculum. In addition to a deeper and broader study of mathematics, majors will further develop their ability to formulate and solve problems from a mathematical perspective, become familiar with the use of mathematics in other fields, and develop competence at the application of mathematics to at least one other field. Graduates will also be able to use technology effectively in mathematics and the application of mathematics. To complement these technical skills graduates will learn the professional skills of effective communication with both technical and non-technical audiences and the ability to work cooperatively with others.

Mathematics Program Goals and Student Learning Outcomes

Mathematics majors should be able to meet the following Student Learning Outcomes

Goal 1: Students will learn the fundamental principles underlying the major areas of mathematics

- SLO 1.1. Perform calculations and prove statements about objects, morphisms, and structure theorems in vector spaces and abstract algebra.
- SLO 1.2. Write rigorous proofs and state key counterexamples in the areas of sequences, continuity, differentiability, and integrability.
- SLO 1.3. Select, and produce appropriate characterizations for, a model for a random process through functions of random variables (e.g., expectation or probability statements).

Goal 2: Students will have a well-rounded scientific and mathematical background

- SLO 2.1. Develop focused further knowledge of at least one of the fields of mathematical sciences.
- SLO 2.2. Synthesize new and previous knowledge in cooperation with a faculty member.
- SLO 2.3. Demonstrate basic literacy in a number of scientific areas

Goal 3: Students will be able to use technology in a mathematical setting.

- SLO 3.1. Describe and implement computational approaches to solving a mathematical model.
- SLO 3.2. Use mathematical technology to analyze mathematical problems in at least one area.

Goal 4: Students will develop and utilize effective written and oral communication skills in a mathematical setting

- SLO 4.1. Rigorously write and critique mathematical proofs.
- SLO 4.2. Speak about mathematics in an articulate, sound, and well-organized fashion.

SLO 4.3. Write a formal mathematical thesis or report.

Goal 5: Students will develop a broad appreciation for mathematics both as a discipline and as a tool for solving real world problems.

- SLO 5.1. Construct, analyze, and interpret a mathematical model to explain and predict relationships for given deterministic systems and random systems from science or industry.
- SLO 5.2. Create, manipulate, and interpret discrete models and continuous models to illustrate dynamics of a system over time.
- SLO 5.3. Generalize properties of numbers and functions to other algebraic, analytic, topological, or geometric structures.

DEGREE REQUIREMENTS

Major Concentrations: Mathematics majors choose to complete their program in one of four concentrations: Mathematics, Continuous Applied Mathematics, Discrete Applied Mathematics, or Statistics and Operations Research. The Mathematics concentration provides the foundational mathematical depth of a traditional mathematics major and is intended for students planning on graduate study in an area of mathematics. In applied mathematics there are two areas: the Continuous Applied Mathematics concentration and the Discrete Applied Mathematics concentration. Students selecting these concentrations may tailor their programs to interface with another major or to enhance industrial employment or graduate school opportunities. The Statistics and Operations Research concentration is recommended for students pursuing careers in actuarial science, graduate study in statistics, or employment in government or industry in a statistical capacity. It is strongly recommended that students considering graduate education in mathematics include MA 376 Abstract Algebra among their elective mathematics courses. Upon graduation a student may request the Head of the Mathematics Department to issue a letter attesting to the fact that the requirements in the chosen concentration have been completed.

Mathematics Coursework Requirements: All mathematics majors must complete a common core consisting of 39 credit hours of mathematics coursework, which provides breadth across the main areas of mathematics. A mathematics major must also complete an additional 12 credit hours of mathematics coursework specified for the selected major concentration plus an additional 12 credit hours earned in free elective mathematics or biomathematics courses. A mathematics major must additionally complete an 8-credit hour capstone experience. A total of 71 credit hours of mathematics courses is required for the major. None of the credits in the 71 hours above may be taken from the courses MA190, MA351-MA356, MA450 or MA223 (unless approved by the department head). These courses (except MA190) may be taken as free electives. Finally, a student taking a degree program in which mathematics is the primary major must also take MA190. A student whose second major is mathematics is not required to take MA 190, but is strongly encouraged to do so.

Common Required Core		**39 hrs.**
MA 111, 112, 113 Calculus I, II, III	15 hrs.	
MA 221 Matrix Algebra and Differential Equations I	4 hrs.	

MA 222 Matrix Algebra and Differential Equations II	4 hrs.
MA 276 Introduction to Proofs	4 hrs.
MA 366 Introduction to Real Analysis	4 hrs.
MA 371 Linear Algebra I	4 hrs.
MA 381 Introduction to Probability with Applications to Statistics	4 hrs.

Mathematics Concentration Core		**12 hrs.**
Three courses selected as follows:		
MA 367	Functions of a Complex Variable	4 hrs.
MA 376	Abstract Algebra	4 hrs.
One of the following		4 hrs.
MA 433	Numerical Analysis	
MA 436	Introduction to Partial Differential Equations	
MA 446	Combinatorial Optimization	
MA 481	Introduction to Mathematical Statistics	

Continuous Applied Mathematics Concentration Core		**12 hrs.**
Three courses selected per the list below. Students completing the Continuous Applied Mathematics Concentration are strongly urged to complete mathematics coursework in statistics as elective coursework.		
MA 330	Vector Calculus	4 hrs.
MA 336	Boundary Value Problems	4 hrs.
MA 433	Numerical Analysis	4 hrs.

Discrete Applied Mathematics Concentration Core		**12 hrs.**
Three courses selected per the list below. Students completing the Discrete Applied Mathematics Concentration are strongly urged to complete mathematics coursework in statistics as elective coursework.		
MA 374	Combinatorics	4 hrs.
MA 444	Deterministic Models in Operations Research	4 hrs.
One of the following		4 hrs.

MA 376	Abstract Algebra
MA 475	Topics in Discrete Mathematics
MA 476	Algebraic Codes
MA 477	Graph Theory

Statistics and Operations Research Concentration Core		**12 hrs.**
Three courses selected per the list below. Students completing the Statistics and Operations Research Concentration are strongly urged to complete mathematics coursework in applied mathematics as elective coursework.		
MA 382	Introduction to Statistics with Probability	4 hrs.
MA 444	Deterministic Models in Operations Research	4 hrs.
One of the Following		4 hrs.
MA 445	Stochastic Models in Operations Research	
MA 446	Combinatorial Optimization	
MA 481	Introduction to Mathematical Statistics	
MA 485	Applied Regression Analysis and Introduction to Time Series	
MA 487	Design of Experiments	
It is strongly suggested that the student take as many of the above courses as possible.		

Free Mathematics Electives—12 hrs.

Additional mathematics and biomathematics coursework in courses numbered 300 or above (MA 351- MA 356, MA 450, BMTH496-498 not allowed).

MA 190 – Contemporary Mathematical Problems (2 hrs.) A student taking a degree program in which mathematics is the primary major must also take MA 190. A student whose second major is mathematics is not required to take MA190, but is strongly encouraged to do so.

- **Senior Capstone (8 hrs.)** A student must complete an 8-credit hour Senior Capstone by completing MA496 (4 hrs.), MA497 (2 hrs.), and MA498 (2 hrs.). Note that MA491 may replace 2 hours of MA496 and that MA497 and MA498 must be taken in separate terms. The capstone is an important experience for the mathematics major, representing a sustained effort to solve a complex problem in

the mathematical sciences. The Senior Capstone must involve significant individual work, and it must culminate with both a written report and an oral presentation. Both the report and the presentation must be submitted to the department.

Students double majoring in mathematics and another program who complete the senior project courses for that program must also complete MA491 for the senior project to satisfy the Senior Capstone requirement within the mathematics major. Students double majoring in mathematics and another program who complete the senior thesis courses for that program can directly use those courses to satisfy the Senior Capstone requirement within the mathematics major. The Mathematics Capstone does not constitute a culminating major engineering design experience for students also majoring in an ABET accredited program.

Summary of Requirements		
Mathematics Coursework - core, concentration and electives (MA351-MA356, MA450, BMTH496-498 not allowed)		63 hrs.
Mathematics Senior Capstone		8 hrs.
MA 190 - Contemporary Mathematical Problems (primary major only)		2 hrs.
Physical and Life Sciences*		24 hrs.
Computer Science**		8 hrs.
Humanities, Social Sciences, and the Arts (standard requirement, one course must be ENGL H290)		36 hrs.
Technical Electives***		24 hrs.
Free Electives		28 hrs.
Miscellaneous****		2 hr.
Total hours required for graduation		**195 hrs.**
*	PH 111, 112, and 113 — Physics I, II, and III	12 hrs.
	BIO 101 — Essential Biology (or higher-level BIO course)	4 hrs.
	CHEM 111 — General Chemistry I	4 hrs.
	4 additional credit hours in Physical or Life Sciences	4 hrs.
**	CSSE 120 — Introduction to Software Development	4 hrs.

	CSSE 220 — Object-Oriented Software Development	4 hrs.
	MA 332 - Introduction to Computational Science - may be taken instead of CSSE 220 but then MA 332 cannot be counted towards the 63 hours of mathematics coursework	
***	200 level or above coursework, approved by the major advisor, in areas of science, engineering, or economics in which 12 credit hours constitute a coherent set of three courses representing a specific area of technical depth and 12 credit hours represent technical breadth. Coursework in mathematics and biomathematics is not allowed.	24 hrs.
****	RHIT 100 — Foundations of Rose-Hulman Success MA 200 - Career Preparation (primary major only)	1 hr. 1 hr.

SUGGESTED SCHEDULE

The schedule (Course Sequence) on the right is a suggested schedule only. Scheduling of courses may be altered, subject to the approval of the advisor, in order to take advantage of advanced placement or to accommodate a second major, area minor or other special program. However, note that some courses are offered only at certain times during the year, and all prerequisites must be met. In the schedule an MA elective is either a concentration elective or free math elective, as described above, and a science elective is a physical or life science elective as defined on this page.

Alternate Science Schedule: The recommended science schedule of six science courses starts with PH 111. If CHEM 111 is required in the fall quarter because of a double major or minor, then the alternate science sequence may be completed by taking the second science course in each place where a choice is given. Two science courses are to be taken in the winter quarter of freshman year.

COMPUTATIONAL SCIENCE MAJOR (CPLS) (Second Major Only)

Computational methods are widely employed in science and engineering for simulation, experimentation, analysis, and design. In many areas the use of high-performance computing is essential. The Computational Science major provides Rose-Hulman students with the opportunity to add to their primary major a second major that increases their knowledge and skill in applied scientific and engineering computation.

Computational Science Program Student Learning Objectives:

Graduates with a second major in CPLS will have an ability to:

1.) Develop goals for a computational model such that the results will inform a scientific/ engineering decision or provide a desired level of understanding

2.) Choose a computational modelling approach that meets the goals and implement it

3.) Validate a computational model of a complex phenomenon or system and demonstrate that the goals have been met

Requirements for a second major in Computational Science (72 credit hours)
The second major in Computational Science is open to all students. It requires 72 credit hours, including a 52 credit hour core and a 20 credit hour specialization. The courses used to satisfy the requirements in the Advanced Core may not be counted toward any other major or minor. All Computational Science programs of study are subject to approval by the Chair of the Computational Science Steering Committee.

Computational Science Core (52 credit hours)

Fundamentals (31 credit hours)

- MA 111, 112, 113 Calculus I, II, III
- MA 221 Matrix Algebra and Differential Equations I
- MA 222 Matrix Algebra and Differential Equations II
- CSSE 120 Introduction to Software Development, or any of BE 100, CE 111*, CHE 110*, ENGD 120, ME 123
- MA 332 Introduction to Computational Science, or any of CHE 310, ME 323*, ME 327

*Courses marked with an asterisk carry only 2 credits and must be augmented by an additional 2 credits of course work, as approved by the Chair of the Computational Science Steering Committee.

Advanced (21 credit hours; these courses may not be counted toward any other major or minor)

- CSSE/MA 335 Introduction to Parallel Computing
- MA 336 Boundary Value Problems
- MA 342 Computational Modeling and MDS 442 Applied Computational Modeling
- MDS 442 Applied Computational Modeling
- MA 435 or ME 422 Finite Difference Methods, Finite Element Methods for Engineering Applications

Any course from the list of Approved Computational Science Electives (or another upper-level course if approved by the Chair of the Computational Science Steering Committee):

- BE 340 Biomedical Signal Processing
- BE 510 Biomedical Signal and Image Processing
- BMTH 312 Bioinformatics
- BMTH 413 Computational Biology
- CHE 310 Numerical Methods for Chemical Engineers
- CE 310 Computer Applications in Civil Engineering
- CSSE 304 Programming Language Concepts
- ECE 480/OE 437 Introduction to Image Processing
- ECE 483 DSP System Design
- MA 323 Geometric Modeling
- MA 384 Data Mining
- MA 433 Numerical Analysis
- MA 434 Topics in Numerical Analysis
- MA 435 Finite Difference Methods
- MA 439 Mathematical Methods of Image Processing
- MA 444 Deterministic Models in Operations Research
- MA 446 Combinatorial Optimization
- ME 422 Finite Element Methods for Engineering Applications
- ME 427 Introduction to Computational Fluid Dynamics
- ME 430 Mechatronic Systems
- ME 522 Advanced Finite Elements Analysis
- ME 536 Computational Intelligence in Control Engineering
- PH 540 Computer Physics

Area of Concentration (20 credit hours): Each student must complete 20 credit hours of advanced work reflecting an Area of Concentration within Computational Science. Courses used to satisfy the core requirements may not be used to satisfy the area of concentration requirements. The 20 credit hours shall consist of at least 16 credit hours within a single Area of Concentration, as specified below, and an additional 4 credit hours from any of the Areas of Concentration, or from the list of Approved Computational Science Electives. Exceptions may be made on occasion (e.g. when an appropriate special topics course has been taken).

Computational Methods

- MA 371 or MA 373 Linear Algebra I, Applied Linear Algebra for Engineers
- MA 433 Numerical Analysis
- Eight credit hours chosen from BMTH 413, CSSE 304, CSSE/MA 473, MA 384, MA 386, MA 434, MA 435, MA439, MA 444, MA 446, MA 485, ME 422

Computational Mechanics

- MA 435 or ME 422 Finite Difference Methods, Finite Element Methods for Engineering Applications
- ME 401 Foundations of Fluid Mechanics
- ME 427 Introduction to Computational Fluid Dynamics
- ME 522 Advanced Finite Element Analysis

Computational Signals and Image Processing

- ECE 380 Discrete-Time Signals and Systems
- ECE 480/OE 437 Introduction to Image Processing
- ECE 483 DSP System Design
- MA 439 Mathematical Methods of Image Processing

Computational Physics and Chemistry

- CHEM 361 Physical Chemistry I*
- CHEM 362 Physical Chemistry II*
- CHEM 363 Quantum Chemistry & Molecular Spectroscopy
- OE 450 Nanomedicine
- PH 540 Computer Physics

*For CHE students, CHEM 361 and CHEM 362 may be substituted by CHE 303, CHE 304 and CHEM 360

Computational Biomedics

- BE 482/MA 482 Bioengineering Statistics
- BE 535/OE 535 Biomedical Optics
- BE 541/ECE 584 Medical Imaging Systems
- BMTH 310 Mathematical Biology
- BMTH 413 Computational Biology

DATA SCIENCE MAJOR (SECOND MAJOR ONLY)

Data Science is open to all students as a second major; this means that the student will have some other discipline as their primary major. Students whose primary major is in Computer Science, Software Engineering or Mathematics will find the Data Science program the easiest since there is considerable overlap between those programs and the Data Science requirements Students from other disciplines are also encouraged to participate, but will have to take more courses. All students are encouraged to take the individual courses in the program, regardless of whether they wish to fulfill the second major requirements. Learn more about Data Science requirements.

MINOR IN MATHEMATICS

Any student not pursuing a major or second major in either mathematics or in biomathematics may obtain a minor in mathematics by taking 10 or more mathematics courses as follows:

- **Six courses in foundational mathematics**
  - Calculus, Matrix Algebra and Differential Equations, Introduction to Proofs : MA 111, MA 112, MA 113, MA 221, and either MA 222 or MA276.
  - Introductory Statistics or Probability: either MA 223 or MA 381
- **Sixteen additional credit hours of “upper division” courses:**
  - Courses selected from MA 222, MA 223, MA 276, all MA courses numbered 300 or higher (except MA351-356 and MA450, MA492-494, and MA496-498), all BMTH courses numbered 300 or higher (except BMTH 496-498), or other MA courses approved by the minor advisor for mathematics. Computer Science majors cannot use either MA 473 or MA 474 to satisfy both

their computer science major requirements and the requirements of the mathematics minor.

Approval and Math Minor Form

All minors must be approved by the minor advisor and the student's advisor. The department has a form for the planning and approval of a mathematics minor.

Notes and Limitations on Requirements:

- Almost all students are required to take six foundational courses as a requirement for their major; therefore only four "extra courses" are required for most students.
- Only MA111, MA112, MA113, MA221, MA222 and one of MA223, MA381, or MA382 can be counted towards any combination of the multiple minors offered by the mathematics department.
- No student can take both MA 371 and MA 373 for credit.
- No student can take both MA223 and MA382 for credit
- Except as noted above, if MA 381 is being counted towards the four additional courses then, MA 223 may be taken and counted towards the Introductory Statistics and Probability.
- Science and engineering, especially the most recent "high tech" developments, have sophisticated mathematical and statistical concepts and methodologies as their foundation. Thus a well-chosen set of courses for a mathematics minor (or a second major in mathematics) will greatly enhance a student's analytical and computational skills. Students thinking of going on to graduate school should especially give consideration to this option.

MINOR IN COMPUTATIONAL SCIENCE

Any student may obtain a minor in Computational Science by taking the following courses:

- Five courses in foundational mathematics: MA111, MA112, MA113, MA221, MA222
- Basic computing course: CSSE 120 or departmental equivalent of at least 4 credit hours
- Introductory Computational Science courses:
  - MA332 Introduction to Computational Science
  - MA342 Computational Modeling
- Four credit hours of applied Computational Science course from list A
- Four credit hours of additional Computational Science course from list B

List A: Applied Computational Science courses

- MA323 – Geometric Modeling
- MA439 – Mathematical Methods of Image Processing
- MA444 – Deterministic Models in Operations Research
- CSSE351 – Computer Graphics
- CSSE451 - Advanced Computer Graphics
- CSSE413 – Artificial Intelligence
- CSSE453 – Topics in Artificial Intelligence
- CSSE461 – Computer Vision
- CSSE463 - Image Recognition

- CE522 - Advanced Finite Element Analysis
- ME422 – Finite Elements for Engineering Applications
- ME427 - Introduction to Computational Fluid Dynamics
- ME511 - Numerical Methods for Dynamic Systems Analysis
- ME522 - Advanced Finite Elements Analysis
- 4XX – Introduction to MEMS:Fabrication and Applications
- 5XX – Advanced Topics in MEMS
- CHE521 – Advanced Chemical Engineering Computation
- BE510 – Biomedical Signal and Image Processing
- ECE420 - Nonlinear Control Systems
- ECE480//PH437 – Introduction to Image Processing
- ECE582/PH537 – Advanced Image Processing
- ECE483 - DSP System Design

List B: Additional Computational Science courses

- MA/CSSE335 - Introduction to Parallel Computing
- MA433 - Numerical Analysis
- MA434 – Topics in Numerical Analysis
- MA446 - Combinatorial Optimization
- CSSE304 - Programming Language Concepts
- CSSE371 - Software Requirements and Specification

Electives not on list A or B may be substituted with other courses with the approval of the area minor advisor.

The minor must be approved by the minor advisor for Computational Science and the student's advisor. The department has a form for the planning and approval of a minor.

Notes and limitations on requirements

- Almost all students are required to take the five foundational courses as a requirement for their major
- Most majors should be able to apply the basic computing requirement and/or one of the elective courses towards their major.
- Math majors or double majors are not allowed to count MA332 and MA342 for both the minor and the major.
- A student may not apply the four upper-division courses toward both this minor and a math or statistics minor.

MINOR IN STATISTICS

Any student may obtain a minor in statistics by taking ten or more mathematics courses (24 credit hours) including the following:

4 credit hours – Foundational Statistics Course:

One of the following:

- MA 223 Engineering Statistics I
- MA 382 Introduction to Statistics with Probability

If MA 381 is taken before MA223/MA382, it will be strongly recommended the student take MA382 instead of MA223.

20 credit hours – Additional Coursework:

Five courses selected from the following list, at least two of which must be starred (*). Courses not on this list may count towards the minor if approved by the statistics minor advisor.

- MA 381 Introduction to Probability with Applications to Statistics
- MA 383 Engineering Statistics II
- MA 386 Statistical Programming
- MA 481 Mathematical Statistics
- MA 482* Biostatistics
- MA 483* Bayesian Data Analysis
- MA 485* Applied Linear Regression
- MA 487* Design of Experiments
- MA 480 Topics in Probability and Statistics
- EMGT 572 Reliability Engineering

All minors must be approved by the minor advisor and the student's advisor. The department has a form for the planning and approval of a minor.

Notes and Limitations on Requirements

1. Almost all students are required to take either MA223 or MA381 as a requirement for their major; therefore, only five “extra courses” are required for most students.
2. Only one of MA223, MA381, or MA382 can be counted towards any combination of the multiple minors offered by the mathematics department.
3. Mathematics majors or biomathematics majors must have at least 16 credit hours of separation between their major and this minor.
4. No student can take both MA223 and MA382 for credit.
5. Note that MA481, MA483, and EMGT572 have MA381 as a pre-requisite.

Plan of Study

Freshman

Fall

Course	Credit
MA 111 Calculus I	5
PH 111 Physics I or CHEM 111 General Chemistry I	4
HUM H190 First-Year Writing Seminar or HSSA Elective	4
RHIT 100 Foundations for Rose-Hulman Success	1
CSSE 120 Introduction to Software Development	4
	Total Credits: 18

Winter

Course	Credit
MA 112 Calculus II	5
PH 112 Physics II or PH 111 Physics I	4
CHEM 111 General Chemistry I or BIO 101 Essential Biology (or higher level BIO course)	4
HSSA Elective or HUM H190 First-Year Writing Seminar	4
	Total Credits: 17

Spring

Course	Credit
MA 113 Calculus III	5
PH 113 Physics III or PH 112 Physics II	4
MA 190 Contemporary Mathematics Problems	2
HSSA Elective	4
	Total Credits: 15

Sophomore

Fall

Course	Credit
MA 221 Matrix Algebra & Differential Equations I	4
MA 276 Introduction to Proofs	4
BIO 101 Essential Biology (or higher level BIO course) or PH 113 Physics III	4
*CSSE 220 Object-Oriented Software Development	4
	Total Credits: 16

Winter

Course	Credit
MA 222 Matrix Algebra & Differential Equations II	4
Science Elective	4
Technical Elective	4
HSSA Elective	4
**MA 200 Career Preparation	1
	Total Credits: 17

Spring

Course	Credit
MA 381 Introduction to Probability	4
MA 371 Linear Algebra I	4
Technical Elective	4
HSSA Elective	4
	Total Credits: 16

Junior

Fall

Course	Credit
MA Elective	4
Technical Elective	4
Technical Elective	4
HSSA Elective or ENGL H290 Technical & Professional Communication	4
	Total Credits: 16

Winter

Course	Credit
MA 366 Introduction to Real Analysis	4
MA Elective	4
Technical Elective	4
HSSA Elective or ENGL H290 Technical & Professional Communication	4
	Total Credits: 16

Spring

Course	Credit
MA Elective	4
MA Elective	4
Technical Elective	4
HSSA Elective or ENGL H290 Technical & Professional Communication	4
	Total Credits: 16

Senior

Fall

Course	Credit
MA496 Senior Capstone I (4hrs) or MA 491 Intro to Math Modeling (2 hrs.) and MA 496 (2 hrs.)	4
Free Elective	4
Free Elective	4
HSSA Elective	4
	Total Credits: 16

Winter

Course	Credit
MA 497 Senior Capstone II (2 hrs.)	2
MA Elective	4
Free Elective	4
Free Elective	4
Free Elective	4
	Total Credits: 18

Spring

Course	Credit
MA 498 Senior Capstone III (2 hrs.)	2
MA Elective	4
Free Elective	4
Free Elective	4
	Total Credits: 14

Notes:

*MA 332 - Introduction to Computational Science - may be taken instead of CSSE 220 but then MA 332 cannot be counted towards the 63 hours of mathematics coursework
**MA 200 - Career Preparation - may be taken in the winter quarter of the sophomore year

Notes and Definitions

- The suggested four year plan is a guideline.
- Close consultation with the advisor on electives is required, especially for electives after the freshman year, or if a double major or minor is planned.

The following definitions of electives are specific to the Mathematics Department.

- **Math Elective:** A course either required by the concentration or a true math elective.
- **Science Elective:** Any Physical or Life Sciences elective (not Computer Science) at any level.

- **Technical Elective:** Non-mathematics courses numbered 200 or above in Engineering, Science or Economics; coursework in mathematics and biomathematics is not allowed.
- **Free Elective:** Any course.

Mathematics - Course Descriptions

MA 105 Calculus A 5R-0L-5C F

Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Calculus and analytic geometry in the plane. Algebraic and trigonometric functions. Limits and continuity. Differentiation, geometric and physical interpretations of the derivative. Introduction to integration and the Fundamental Theorem of Calculus. A student cannot earn credit for both MA 105 and MA 111.

MA 106 Calculus B 4R-0L-4C W

Prerequisites: MA 105 F
Corequisites: There are no corequisites for this course.
Definitions, properties, and derivatives of exponentials and logarithms. Antiderivatives, integral properties, integration by substitution, integration by parts, integrals of transcendental functions, numerical integration, applications of integration, and improper integrals. Applications of integration, e.g. area, displacement, volumes of revolution, arc length, surface area of revolution, and work. Newton's method. Computer algebra systems.

MA 107 Calculus C 4R-0L-4C S

Prerequisites: MA 106 W
Corequisites: There are no corequisites for this course.
Partial fractions and Integration. Hyperbolic functions. Separable first order differential equations, applications of separable first order differential equations. Series of constants, power series, Taylor polynomials, Taylor and McLaurin series. Computer algebra systems.

MA 111 Calculus I 5R-0L-5C F,W

Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Calculus and analytic geometry in the plane. Algebraic and transcendental functions. Limits and continuity. Differentiation, geometric and physical interpretations of the derivative, Newton's method. Introduction to integration and the Fundamental Theorem of Calculus. A student cannot earn credit for both MA 105 and MA 111.

MA 112 Calculus II 5R-0L-5C F,W,S

Prerequisites: MA 111 F,W
Corequisites: There are no corequisites for this course.
Techniques of integration, numerical integration, applications of integration. L'Hopital's rule and improper integrals. Separable first order differential equations, applications of separable first order differential equations. Series of constants, power series, Taylor polynomials, Taylor and McLaurin series.

MA 113 Calculus III 5R-0L-5C F,W,S

Prerequisites: MA 112 F,W,S or MA 107 S

Corequisites: There are no corequisites for this course.
Vectors and parametric equations in three dimensions. Functions of several variables, partial derivatives, maxima and minima of functions of several variables, multiple integrals, and other coordinate systems. Applications of partial derivatives and multiple integrals.

MA 190 Contemporary Mathematical Problems 2R-0L-2C S

Prerequisites: There are no prerequisites for this course.
Corequisites: MA 113 5R-0L-5C F,W,S
A seminar-style course consisting of an overview of selected contemporary problems and areas in the mathematical sciences. Problems to be discussed will be selected from recent publications in research and applications, famous problems, and outstanding problems of great significance.

MA 195 Topics in Mathematics 1-4C See Dept

Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
This course will cover introductory-level topics in mathematics not offered in listed courses. A student may take the course for credit more than once provided the topics are different.

MA 199 Professional Experience 1R-0L-1C

Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
The professional experiences course captures the practical work experiences related to the student's academic discipline. Students are required to submit a formal document of their reflections, which communicates how their employment opportunity reinforced and enhanced their academic studies. The course will be graded as "S" satisfactory, or "U" unsatisfactory based on the written report of the professional experience.

MA 200 Career Preparation 1R-0L-1C W

Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
This course is for mathematics majors to be taken in the second year. The course addresses career choices, summer opportunities, employment and graduate school preparation, and curriculum vitae and resumes preparation. Cross-listed with CHEM 200 and PH200.

MA 221 Matrix Algebra & Differential Equations I 4R-0L-4C F,W,S

Prerequisites: MA 113 F,W,S
Corequisites: There are no corequisites for this course.
First order scalar differential equations including basic solution techniques and numerical methods. Second order linear, constant coefficient differential equations, including both the homogeneous and non-homogeneous cases. Basic matrix algebra with emphasis on understanding systems of linear equations from algebraic and geometric viewpoints, and eigenvalues and eigenvectors. Introduction to complex arithmetic. Applications to problems in science and engineering.

MA 222 Matrix Algebra & Differential Equations II 4R-0L-4C F,W,S

Prerequisites: MA 221 F,W,S
Corequisites: There are no corequisites for this course.

Laplace transforms. Solution of systems of first order linear differential equations by matrix methods and investigation of their solution structure determined by eigensystems. Phase portrait analysis and classification of the nature of the stability of critical points for linear and nonlinear systems. Fourier series and application to solving elementary boundary value problems. Applications to problems in science and engineering.

MA 223 Engineering Statistics I 4R-0L-4C F,W,S

Prerequisites: MA 111 F,W or MA 105 F, and ENGL H100 F or ENGD 100 F or HUM H190 F, W
Corequisites: There are no corequisites for this course.
This is an introductory course in applied statistics emphasizing data analysis. The course is designed to support the research cycle including the formulation of a question of interest, effective data collection techniques, informative data summaries, and appropriate inferences from data. Communication of results and statistical concepts is emphasized. Statistical software will be used for the data analysis throughout, including analysis of variance and simple linear regression. A student cannot take both MA223 and MA382 for credit.

MA 276 Introduction to Proofs 4R-0L-4C F, W

Prerequisites: MA 113 F,W,S
Corequisites: There are no corequisites for this course.
Introduction to writing mathematical proofs. Logic: direct proof, contradiction, contrapositive, counterexamples. Induction. Recursion. Sets: relations (order, equivalence), functions. Properties of infinite sets. Basic number theory. Important preparation for further courses in theoretical mathematics.

MA 290 Topics in Mathematics Variable 1-4 Hours See Dept

Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Variable Topics in Mathematics

MA 323 Geometric Modeling 4R-0L-4C W (Even years)

Prerequisites: MA 113 F,W,S
Corequisites: There are no corequisites for this course.
Covers some of the mathematical methods for describing physical or virtual objects in computer aided geometric design (CAGD) and computer graphics. Emphasizes methods for curve and surface modeling, and discusses both the underlying geometric concepts and the practical aspects of constructing geometric models of objects. Topics covered include Bezier curves, Hermite curves, B-splines, Bezier patches, subdivision surfaces. In discussing these, ideas from analytic geometry, differential geometry, affine geometry, combinatorial geometry, and projective geometry will be introduced.

MA 327 Low Dimensional Topology 4R-0L-4C W (odd years)

Prerequisites: MA 113 F,W,S or consent of instructor
Corequisites: There are no corequisites for this course.
An introduction to the topology of one-, two-, and three-dimensional manifolds and its application to other areas of mathematics and science. Topics may include, but are not restricted to, classification of curves and surfaces, Euler characteristic, tiling and coloring theorems, graph embeddings, vector fields, knots and links, and

elementary algebraic topology. Intended for science and engineering majors as well as mathematics majors.

MA 330 Vector Calculus 4R-0L-4C F,S

Prerequisites: MA 222 F,W,S
Corequisites: There are no corequisites for this course.
Calculus of vector- valued functions of one and several variables. Topics include differentiation (divergence, gradient and curl of a vector field) and integration (line integrals and surface integrals). Applications of Green's theorem, Stokes' theorem and the divergence theorem to potential theory and/or fluid mechanics will be provided.

MA 332 Introduction to Computational Science 4R-0L-4C F,W

Prerequisites: MA 221 F,W,S
Corequisites: There are no corequisites for this course.
An introduction to Computational Science using Matlab. Floating point arithmetic, Matlab programming, solution of nonlinear equations, interpolation, least squares problems, numerical differentiation and integration, solution of linear systems.

MA 335 Introduction to Parallel Computing 4R-0L-4C S

Prerequisites: MA 221 F,W,S and programming experience
Corequisites: There are no corequisites for this course.
Principles of scientific computation on parallel computers. Algorithms for the solution of linear systems and other scientific computing problems on parallel machines. Course includes a major project on RHIT's parallel cluster. Same as CSSE 335.

MA 336 Boundary Value Problems 4R-0L-4C F,S

Prerequisites: MA 222 F,W,S
Corequisites: There are no corequisites for this course.
Introduction to boundary value problems and partial differential equations. Emphasis on boundary values problems that arise from the wave equation, diffusion equation, and Laplace's equation in one, two and three dimensions. Solutions to such boundary value problems will be discussed using Fourier series, numerical techniques, and integral transforms.

MA 341 Topics in Mathematical Modeling 4R-0L-4C W

Prerequisites: MA 222 F,W,S
Corequisites: There are no corequisites for this course.
An introduction to techniques of mathematical modeling involved in the analysis of meaningful and practical problems arising in many disciplines including mathematical sciences, operations research, engineering, and the management and life sciences. Topics may include creative and empirical model construction, model fitting, models requiring optimization, and modeling dynamic behavior. Student participation in significant individual and group projects will be emphasized.

MA 342 Computational Modeling 4R-0L-4C S

Prerequisites: MA 222 F,W,S, and either CE 310 S or CHE 310 See Department or MA 332 F,W or ME 327 W,S
Corequisites: There are no corequisites for this course.
Computational modeling and simulation of scientific problems using Matlab. Students will create and utilize computer-based models to solve practical problems. Monte Carlo methods, linear systems, solution of ODEs.

MA 351 Problem Solving Seminar 1R-0L-1C F,W,S
Prerequisites: consent of instructor
Corequisites: There are no corequisites for this course.
An exposure to mathematical problems varying widely in both difficulty and content. Students will be expected to participate actively, not only in the solution process itself but also in the presentation of finished work, both orally and in writing. A student may earn a maximum of six credits in MA 351-6. Cannot count toward mathematics major core hours or the math minor.

MA 366 Introduction to Real Analysis 4R-0L-4C F, W
Prerequisites: MA 371 F,S, and MA 276 F, W
Corequisites: There are no corequisites for this course.
Calculus of functions of a single variable. A more careful development of the basic concepts of analysis, including sequences, limits, continuity, differentiability, integration, infinite series, power series, Taylor's Theorem, and uniform convergence, with an emphasis on proof.

MA 367 Functions of a Complex Variable 4R-0L-4C S
Prerequisites: MA 221 F,W,S
Corequisites: There are no corequisites for this course.
Elementary properties of analytic functions including Cauchy's theorem and its consequences, Laurent series, the Residue Theorem, and mapping properties of analytic functions.

MA 371 Linear Algebra I 4R-0L-4C F,S
Prerequisites: MA 221 F,W,S or consent of instructor
Corequisites: There are no corequisites for this course.
Similar to MA373, but with an emphasis on the theory behind matrices and vector spaces. Systems of linear equations, Gaussian elimination, and the LU decomposition of a matrix. Projections, least squares approximations, and the Gram-Schmidt process. Eigenvalues and eigenvectors of a matrix. The diagonalization theorem. The singular value decomposition of a matrix. Introduction to vector spaces. Some proof writing will be required. Those interested in applications of matrices and vector spaces should take MA373. A student cannot take both MA 371 and MA 373 for credit.

MA 373 Applied Linear Algebra for Engineers 4R-0L-4C W
Prerequisites: MA 221 F,W,S or consent of instructor
Corequisites: There are no corequisites for this course.
Similar to MA 371, but with emphasis on applications of matrices and vector spaces. Systems of linear equations, Gaussian elimination, and the LU decomposition of a matrix. Projections, least squares approximations, and the Gram-Schmidt process. Eigenvalues and eigenvectors of a matrix. The diagonalization theorem. The singular value decomposition of a matrix. Those interested in the theory behind matrices and vector spaces should take MA 371. A student cannot take both MA 371 and MA 373 for credit.

MA 374 Combinatorics 4R-0L-4C F, W, S
Prerequisites: MA 221 F,W,S
Corequisites: There are no corequisites for this course.
A first course in combinatorics. Basic counting principles, permutations, combinations. Combinatorial proof. The pigeonhole principle. The principle of inclusion/exclusion.

Generating functions. Recurrence relations. Additional topics in combinatorics, which may include permutation groups and Burnside's Lemma, Polya enumeration, multivariate generating functions, combinatorial designs, Ramsey theory, order relations, or other topics at the discretion of the instructor.

MA 376 Abstract Algebra 4R-0L-4C S

Prerequisites: MA 276 F, W
Corequisites: There are no corequisites for this course.
An introduction to Group Theory. Topics include: matrix groups, groups of integers modulo a natural number, symmetric and dihedral groups, homomorphisms, subgroups, cosets, quotient groups and group actions. Applications, possibly including games and puzzles, cryptography, and coding theory. Other topics may also be introduced according to time and student interest.

MA 378 Number Theory 4R-0L-4C S

Prerequisites: consent of instructor
Corequisites: There are no corequisites for this course.
Divisibility, congruences, prime numbers, factorization algorithms, RSA encryption, solutions of equations in integers, quadratic residues, reciprocity, generating functions, multiplicative and other important functions of elementary number theory. Mathematical conjecture and proof, mathematical induction.

MA 381 Introduction to Probability with Applications to Statistics 4R-0L-4C F,W,S

Prerequisites: MA 113 F,W,S
Corequisites: There are no corequisites for this course.
Introduction to probability theory; axioms of probability, sample spaces, and probability laws (including conditional probabilities). Univariate random variables (discrete and continuous) and their expectations including these distributions: binomial, Poisson, geometric, uniform, exponential, and normal. Introduction to moment generating functions. Introduction to jointly distributed random variables. Univariate and joint transformations of random variables. The distribution of linear combinations of random variables and an introduction to the Central Limit Theorem. Applications of probability to statistics.

MA 382 Introduction to Statistics with Probability 4R-0L-4C F

Prerequisites: MA 381 F,W,S
Corequisites: There are no corequisites for this course.
This is an introductory course in statistics. Dual emphasis is placed on deriving statistical techniques and using the methods within data analyses. Study design and informative data summaries motivate the statistical inference techniques for linear models. Statistical thinking and communication skills are developed through analysis of data from a variety of fields. A statistical programming language is used for data visualization, analysis, and simulations. A student cannot take both MA 223 and MA 382 for credit.

MA 383 Engineering Statistics II 4R-0L-4C F

Prerequisites: MA 223 F,W,S or MA 382 F
Corequisites: There are no corequisites for this course.
Hypothesis testing, confidence intervals, sample size determination, and power calculations for means and proportions; two factor analysis of variance (with and without interactions); analysis of several proportions; confidence and prediction intervals

for estimated values using simple linear regression; Pearson (linear) correlation coefficient; introduction to multiple regression to include polynomial regression; review of fundamental prerequisite statistics will be included as necessary.

MA 384 Data Mining 4R–0L–4C

Prerequisites: CSSE 120 F,W,S, and MA 221 F,W,S, and either MA 223 F,W,S or MA 381 F,W,S
Corequisites: There are no corequisites for this course.
An introduction to data mining for large data sets, include data preparation, exploration, aggregation/reduction, and visualization. Elementary methods for classification, association, and cluster analysis are covered. Significant attention will be given to presenting and reporting data mining results.

MA 386 Statistical Programming 4R-0L-4C

Prerequisites: MA 223 F,W,S or MA 382 F and previous programming course
Corequisites: There are no corequisites for this course.
Computational data analysis is an essential part of modern statistics. This course provides a practical foundation for students to compute with data. This course will introduce students to tools for data management, manipulation and analysis that are common in statistics and data science. The R computing language will be introduced. Topics will include data structures in R, writing functions, webscraping, data cleaning (both quantitative and textual data), processing unstructured data, static and interactive graphical presentations of data, and coding of modern algorithms for data analysis (bootstrapping and Monte Carlo methods).

MA 390 Topics in the Mathematics of Engineering 1-4C Arranged

Prerequisites: Consent of instructor
Corequisites: There are no corequisites for this course.
A succinct mathematical study that is supportive of the engineering curricula. Topics could be chosen from signal processing, fluid dynamics, thermodynamics, as well as others. A student may take the course for credit more than once provided the topics are different.

MA 415 Machine Learning 4R-0L-4C S

Prerequisites: MA 221 F,W,S*, and either MA 223 F,W,S or MA 381 F,W,S, and either CHE 310 See Department or CSSE 220 F,W,S or ECE 230 W,S or MA 332 F,W or MA 386 F,W or ME 327 W,S Prerequisite Clarification for MA415: Junior standing and MA221, and either MA223 or MA381, and one of CHE310, CSSE220, ECE230, MA332, MA386 or (ME323 or ME327).
Corequisites: There are no corequisites for this course.
An introduction to machine learning. Topics include: error metrics, accuracy vs interpretability trade-off, feature selection, feature engineering, bias-variance trade-off, under-fitting vs. overfitting, regularization, cross-validation, the bootstrap method, the curse of dimensionality and dimensionality reduction using the singular value decomposition. Both parametric and nonparametric methods are covered including: k-nearest neighbors, linear and logistic regression, decision trees and random forests, and support vector machines. Same as CSSE415.

MA 416 Deep Learning 4R-0L-4C Arranged

Prerequisites: MA 221 F,W,S, and either MA 223 F,W,S or MA 381 F,W,S, and either CHE 310 See Department or CSSE 220 F,W,S or ECE 230 W,S or MA 332 F,W or MA 386 F,W or ME 327 W,S
Corequisites: There are no corequisites for this course.
An introduction to deep learning using both fully-connected and convolutional neural networks. Topics include: least squares estimation and mean square error, maximum likelihood estimation and cross-entropy, convexity, gradient descent and stochastic gradient descent algorithms, multivariate chain rule and gradient computation using back propagation, linear vs nonlinear operations, convolution, over-fitting vs under-fitting and hyper-parameter optimization, L2, early stopping and dropout regularization, data augmentation and transfer learning.

MA 421 Tensor Calculus & Riemannian Geometry 4R-0L-4C Fall (Odd years)
Prerequisites: MA 330 F,S
Corequisites: There are no corequisites for this course.
An introduction to the calculus of tensor fields and the local geometry of manifolds.Topics covered include: manifolds, tangent space, cotangent spaces, vector fields, differential forms, tensor fields, Riemannian metrics, covariant derivative and connections, parallel transport and geodesics, Ricci tensor, Riemannian curvature tensor. Applications will be given in physics (general relativity, mechanics, string theory) and engineering (continuum mechanics).

MA 423 Topics in Geometry 4R-0L-4C Arranged
Prerequisites: MA 371 F,S or MA 373 W or consent of instructor
Corequisites: There are no corequisites for this course.
An advanced geometry course with topics possibly chosen from the areas of projective geometry, computational geometry, differential geometry algebraic geometry, Euclidean geometry or non-Euclidean geometry. A student may take the course for credit more than once provided the topics are different.

MA 430 Topics in Applied Mathematics 4R-0L-4C Arranged
Prerequisites: Instructor permission
Corequisites: There are no corequisites for this course.
A topics course in the general area of continuous applied mathematics. Topics may include mathematical physics, mathematical biology, mathematical finance, mathematics of vision, PDEs, image processing methods, continuum mechanics, dynamical systems, and mathematical modeling. A student may take the course for credit more than once provided the topics are different.

MA 431 Calculus of Variations 4R-0L-4C Arranged
Prerequisites: MA 330 F,S
Corequisites: There are no corequisites for this course.
Euler-Lagrange and Hamiltonian equations, with possible applications in mechanics, electrostatics, optics, quantum mechanics and elasticity theory. An introduction to “direct methods.” Applications will be chosen in accordance with the interest of the students. Both classical and numerical methods have their place in this course.

MA 433 Numerical Analysis 4R-0L-4C W
Prerequisites: MA 332 F,W or MA 366 F, W or MA 371 F,S or MA 435 W
Corequisites: There are no corequisites for this course.

Root-finding, computational matrix algebra, nonlinear optimization, polynomial interpolation, splines, numerical integration, numerical solution of ordinary differential equations. Principles of error analysis and scientific computation. Selection of appropriate algorithms based on the numerical problem and on the software and hardware (such as parallel machines) available.

MA 434 Topics in Numerical Analysis 4R-0L-4C Arranged
Prerequisites: MA 433 W
Corequisites: There are no corequisites for this course.
An extension of the material presented in MA433. Topics may include numerical problems, numerical solution of partial differential equations (finite differences, finite elements, spectral methods), sparse matrices, global optimization, approximation theory. A student may take the course for credit more than once provided the topics are different.

MA 435 Finite Difference Methods 4R-0L-4C W
Prerequisites: MA 332 F,W or MA 371 F,S or MA 373 W or MA 433 W
Corequisites: There are no corequisites for this course.
An introduction to finite difference methods for linear parabolic, hyperbolic, and elliptic partial differential equations. Consistency, stability, convergence, and the Lax Equivalence Theorem. Solution techniques for the resulting linear systems.

MA 436 Introduction to Partial Differential Equations 4R-0L-4C F (even years)
Prerequisites: MA 330 F,S
Corequisites: There are no corequisites for this course.
Partial differential equations, elliptic, hyperbolic, and parabolic equations. Boundary and initial value problems. Separation of variables, special functions. Eigenfunction expansions. Existence and uniqueness of solutions. Sturm-Liouville theory, Green's function.

MA 438 Advanced Engineering Mathematics 4R-0L-4C W
Prerequisites: MA 222 F,W,S senior standing
Corequisites: There are no corequisites for this course.
A fast-paced course in advanced applied mathematics for engineering and physics students that combines aspects of MA330, MA336, and MA373. Applied linear algebra, including abstract vector spaces, linear operators, eigentheory, diagonalization, and the matrix exponential; review of partial differentiation and multiple integration, including Lagrange multipliers and other optimization topics; vector analysis, including the Jacobian matrix and the del operator in standard coordinate systems; and Fourier series with application to the solution of partial differential equation boundary value problems. Students who receive credit for MA438 may only receive credit for at most one of MA330, MA336, MA371, and MA373.

MA 439 Mathematical Methods of Image Processing 4R-0L-4C F (Odd years)
Prerequisites: MA 221 F,W,S
Corequisites: There are no corequisites for this course.
Mathematical formulation and development of methods used in image processing, especially compression. Vector space models of signals and images, one- and two-dimensional discrete Fourier transforms, the discrete cosine transform, and block transforms. Frequency domain, basis waveforms, and frequency domain representation of signals and images. Convolution and filtering. Filter banks, wavelets and the discrete

wavelet transform. Application to Fourier based and wavelet based compression such as the JPEG compression standard. Compression concepts such as scalar quantization and measures of performance.

MA 444 Deterministic Models in Operations Research 4R-0L-4C W
Prerequisites: MA 371 F,S or MA 373 W , and programming experience
Corequisites: There are no corequisites for this course.
Formulation of various deterministic problems as mathematical optimization models and the derivation of algorithms to solve them. Optimization models studied include linear programs, integer programs, and various network models. The course will emphasize modeling, algorithm design, and the associated mathematical theory, e.g. polyhedral, duality, convex analysis. Some computer programming is expected.

MA 445 Stochastic Models in Operations Research 4R-0L-4C S (even years)
Prerequisites: MA 381 F,W,S, and MA 221 F,W,S
Corequisites: There are no corequisites for this course.
Introduction to stochastic mathematical models and techniques that aid in the decision-making process. Topics covered include a review of conditional probability, discrete and continuous Markov chains, Poisson processes, queueing theory (waiting line problems), and reliability.

MA 446 Combinatorial Optimization 4R-0L-4C S (odd years)
Prerequisites: MA 276 F, W, and CSSE 220 F,W,S
Corequisites: There are no corequisites for this course.
An introduction to graph- and network-based optimization models, including spanning trees, network flow, and matching problems. Focus is on the development of both models for real-world applications and algorithms for their solution.

MA 450 Mathematics Seminar 1R-0L-1C F,W,S
Prerequisites: Consent of instructor
Corequisites: There are no corequisites for this course.
A student must attend at least 10 mathematics seminars or colloquia and present at one of the seminars, based on material mutually agreed upon by the instructor and the student. A successful presentation is required for a passing grade. As seminars may not be offered every week during the quarter a student may extend the course over more than one quarter, but it must be completed within two consecutive quarters. A student may take this course a maximum of four times.

MA 460 Topics in Analysis 4R-0L-4C Arranged
Prerequisites: Instructor permission
Corequisites: There are no corequisites for this course.
An advanced topics course in analysis. Topic of the course could be advanced topics in real analysis, advanced topics in complex analysis, analysis on manifolds, measure theory or an advanced course in applied analysis (differential equations). May be taken more than once provided topics are different

MA 461 Topics in Topology 4R-0L-4C Arranged
Prerequisites: MA 366 F, W or consent of instructor
Corequisites: There are no corequisites for this course.
Introduction to selected topics from point-set topology or algebraic topology from a rigorous point of view. Possible topics include metric spaces, general topological spaces, compactness, connectedness, separation axioms, compactification and

metrization theorems, homotopy and homology, and covering spaces. Intended for mathematics majors planning to pursue graduate study in mathematics.

MA 466 Introduction to Functional Analysis 4R-0L-4C Arranged

Prerequisites: MA 366 F, W
Corequisites: There are no corequisites for this course.
An introduction to the theory of Banach spaces emphasizing properties of Hilbert spaces and linear operators. Special attention will be given to compact operators and integral equations.

MA 470 Topics in Algebra 4R-0L-4C Arranged

Prerequisites: Instructor permission
Corequisites: There are no corequisites for this course.
An advanced topics course in algebra. Topic of the course could be commutative algebra, Galois theory, algebraic geometry, Lie groups and algebras, or other advanced topics in algebra. May be taken more than once provided topics are different.

MA 471 Linear Algebra II 4R-0L-4C S (even years)

Prerequisites: MA 371 F,S or MA 373 W
Corequisites: There are no corequisites for this course.
Continuation of Linear Algebra I. Properties of Hermitian and positive definite matrices and factorization theorems (LU, QR, spectral theorem, SVD). Linear transformations and vector spaces.

MA 473 Design & Analysis of Algorithms 4R-0L-4C W

Prerequisites: CSSE 230 F,W,S, and MA 276 F, W, and MA 374 F, W, S
Corequisites: There are no corequisites for this course.
Students study techniques for designing algorithms and for analyzing the time and space efficiency of algorithms. The algorithm design techniques include divide-and-conquer, greedy algorithms, dynamic programming, randomized algorithms and parallel algorithms. The algorithm analysis includes computational models, best/average/ worst case analysis, and computational complexity (including lower bounds and NP-completeness). Same as CSSE 473.

MA 474 Theory of Computation 4R-0L-4C S

Prerequisites: CSSE 230 F,W,S, and MA 276 F, W, and MA 374 F, W, S
Corequisites: There are no corequisites for this course.
Students study mathematical models by which to answer three questions: What is a computer? What limits exist on what problems computers can solve? What does it mean for a problem to be hard? Topics include models of computation (including Turing machines), undecidability (including the Halting Problem) and computational complexity (including NP-completeness). Same as CSSE 474.

MA 475 Topics in Discrete Mathematics 4R-0L-4C Arranged

Prerequisites: MA 276 F, W, and MA 374 F, W, S ; additional prerequisites may be required at the discretion of the instructor
Corequisites: There are no corequisites for this course.
An extension of the material presented in MA 276 and 374. Topics may include combinatorial design, Fibonacci numbers, or the Probabilistic Method, among others. A student may take the course for credit more than once provided the topics are different.

MA 476 Algebraic Codes 4R-0L-4C S (odd years)

Prerequisites: MA 276 F, W, and MA 374 F, W, S
Corequisites: There are no corequisites for this course.
Construction and theory of linear and nonlinear error correcting codes. Generator matrices, parity check matrices, and the dual code. Cyclic codes, quadratic residue codes, BCH codes, Reed-Solomon codes, and derived codes. Weight enumeration and information rate of optimum codes.

MA 477 Graph Theory 4R-0L-4C S (even years)
Prerequisites: MA 276 F, W, and MA 374 F, W, S
Corequisites: There are no corequisites for this course.
An introduction to the theory and applications of directed and undirected graphs. Possible topics include the following: Connectivity, subgraphs, graph isomorphism, Euler trails and circuits, planarity and the theorems of Kuratowski and Euler, Hamilton paths and cycles, graph coloring and chromatic polynomials, matchings, trees with applications to searching and coding, and algorithms dealing with minimal spanning trees, articulation points, and transport networks

MA 478 Topics in Number Theory 4R-0L-4C Arranged
Prerequisites: MA 378 S or MA 374 F, W, S or consent of the instructor
Corequisites: There are no corequisites for this course.
Advanced topics in Number Theory. Topics may include elliptic curve cryptography, the Fermat-Wiles Theorem, elliptic curves, modular forms, p-adic numbers, Galois theory, diophantine approximations, analytic number theory, algebraic number theory. A student may take the course for credit more than once provided the topics are different.

MA 479 Cryptography 4R-0L-4C S
Prerequisites: CSSE 220 F,W,S, and MA 276 F, W
Corequisites: There are no corequisites for this course.
Introduction to basic ideas of modern cryptography with emphasis on mathematical background and practical implementation. Topics include: the history of cryptography and cryptanalysis, public and private key cryptography, digital signatures, and limitations of modern cryptography. Touches upon some of the societal issues of cryptography (same as CSSE 479)

MA 480 Topics in Probability or Statistics 4R-0L-4C Arranged
Prerequisites: Instructor permission
Corequisites: There are no corequisites for this course.
An advanced course in probability or statistics. Possible topics include (but are not restricted to) reliability, discrete event simulation, multivariate statistics, Bayesian statistics, actuarial science, nonparametric statistics, categorical data analysis, and time series analysis. May be taken more than once provided topics are different.

MA 481 Mathematical Statistics 4R-0L-4C W (even years)
Prerequisites: MA 382 F, or both MA 381 F,W,S and consent of instructor
Corequisites: There are no corequisites for this course.
An introduction to mathematical statistics. Review of distributions of functions of random variables. Moment generating functions. Limiting distributions. Point estimation and sufficient statistics. Fisher information and Rao-Cramer inequality. Theory of statistical tests.

MA 482 Biostatistics 4R-0L-4C S
Prerequisites: MA 223 F,W,S or MA 382 F

Corequisites: There are no corequisites for this course.
This course introduces statistical techniques for addressing the challenges that arise in the analysis of data from the biological sciences (including biology, biomedical engineering, and the medical community). Topics include linear regression modeling, nonlinear regression, repeated measures analysis (including mixed models), and survival/reliability analysis (analysis of time-to-event data). Flexible modeling strategies including relaxing linearity and distributional assumptions are discussed. Additional topics are introduced when discussing articles found in the literature, including properties of study design, power, meta-analysis, missing data, and causal inference. No prerequisite knowledge of biology is assumed. Review of fundamental prerequisite statistics will be included as necessary.

MA 483 Bayesian Data Analysis 4R-0L-4C W (Odd years)
Prerequisites: MA 381 F,W,S
Corequisites: There are no corequisites for this course.
This course offers an introduction to statistical inference under the Bayesian framework in addition to elements of basic study design. Building from Bayes' Rule for probability computations, we develop a framework of estimation, hypothesis testing and prediction. Topics include the construction of prior distributions to quantify a priori beliefs about unknown parameters, modeling available data, and using data to update beliefs about parameters. Applications include inference for a single response, comparing groups, and regression models; modern applications will be covered, time permitting. The course will make use of heavy use of computational tools for Bayesian inference, including Markov Chain Monte Carlo (MCMC) methods.

MA 485 Applied Linear Regression 4R-0L-4C W (odd years)
Prerequisites: MA 221 F,W,S, and either MA 223 F,W,S or MA 382 F
Corequisites: There are no corequisites for this course.
This is an applied course in multiple linear regression. The techniques presented, all with respect to linear models, develop skills in selecting an appropriate model and performing statistical inference. The use of data from a variety of fields helps demonstrate method implementation and the communication of results in practice. A statistical programming language aids in creating reproducible analysis results.

MA 487 Design of Experiments 4R-0L-4C W (even years)
Prerequisites: MA 223 F,W,S or MA 382 F
Corequisites: There are no corequisites for this course.
This is an applied course in design of experiments. Emphasis is placed on designing statistical studies to solve problems in engineering and science. A variety of designs are presented, including the full factorial, screening, response surface, and split plot. It is demonstrated how constraints on the randomization process due to the design are related to the appropriate analysis method and meaning of the results. Statistical software is used for data analysis throughout.

MA 490 Topics in Mathematics Variable credit
Prerequisites: Consent of instructor
Corequisites: There are no corequisites for this course.
This course will cover advanced topics in mathematics not offered in listed courses.

MA 491 Introduction to Mathematical Modeling 2C F
Prerequisites: Senior Standing or permission of the instructor

Corequisites: There are no corequisites for this course.
An introduction to the process of mathematically modeling a problem, including data collection, defining the appropriate mathematical model and interpreting the results of the proposed model. Emphasis placed on the modeling process, using examples from both continuous and discrete mathematics.

MA 495 Research Project in Mathematics Variable Credit

Prerequisites: Consent of instructor
Corequisites: There are no corequisites for this course.
An undergraduate research project in mathematics or the application of mathematics to other areas. Students may work independently or in teams as determined by the instructor. Though the instructor will offer appropriate guidance in the conduct of the research, students will be expected to perform independent work and collaborative work if on a team. The course may be taken more than once provided that the research or project is different.

MA 496 Senior Capstone I 2C or 4C See Department

Prerequisites: Senior Standing or permission of the instructor
Corequisites: There are no corequisites for this course.
Individual study and research of a topic in mathematics. Topic is expected to be at an advanced level.

MA 497 Senior Capstone II 2C See Department

Prerequisites: MA 496 See Department or permission of instructor
Corequisites: There are no corequisites for this course.
Individual study and research of a topic in mathematics. Topic is expected to be at an advanced level.

MA 498 Senior Capstone III 2C See Department

Prerequisites: MA 497 See Department or permission of instructor
Corequisites: There are no corequisites for this course.
Individual study and research of a topic in mathematics. Topic is expected to be at an advanced level.

MA 538 Advanced Engineering Mathematics 4R-0L-4C W

Prerequisites: Graduate standing
Corequisites: There are no corequisites for this course.
A fast-paced course in advanced applied mathematics for graduate-level engineering students. Applied linear algebra, including abstract vector spaces, linear operators, eigentheory, diagonalization, and the matrix exponential; review of partial differentiation and multiple integration, including Lagrange multipliers and other optimization topics; vector analysis, including the Jacobian matrix, the del operator in standard coordinate systems, and line integrals; and Fourier series with application to the solution of partial differential equation boundary value problems. Students may not receive credit for both MA438 and MA538.

MA 580 Topics in Advanced Probability Theory & Its Applications 4R-0L-4C Arranged

Prerequisites: MA 381 F,W,S
Corequisites: There are no corequisites for this course.
Advanced topics in probability theory as well as applications that are not offered in the listed courses.

MA 581 Topics in Advanced Statistics 4R-0L-4C Arranged

Prerequisites: MA 223 F,W,S or MA 381 F,W,S Consent of instructor
Corequisites: There are no corequisites for this course.
This course will cover advanced topics in mathematical statistics as well as applied statistics that are not offered in the listed courses.

MA 590 Graduate Topics in Mathematics Variable Credit

Prerequisites: Consent of instructor
Corequisites: There are no corequisites for this course.
This course will cover graduate-level topics in mathematics not offered in listed courses.

Last updated: 08/09/2024

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