Mathematics and Computer Science

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The undergraduate major in mathematics and computer science leads to a bachelor of arts or bachelor of science degree. The major combines elements of the mathematics and computer and information science curricula into a four-year program that offers an alternative to the undergraduate degree programs in either field. It serves students who want knowledge in both fields but are not ready to specialize in either. The courses selected for the program provide a solid foundation for professional work or for advanced study.

The program is designed to develop team players for information-based occupations. Its graduates have the tools to analyze complex problems and compute the answers to them. Consistent with its emphasis on teamwork and communication, the program requires college-level exposure to an additional scientific field and an upper-division writing course.

Students with strong mathematics backgrounds in high school are frequently advised to major in computer science at the university, often without a clear idea of what the field of study is actually like. The joint major program offers such students the chance to experiment with computer science while retaining the anchor to mathematics. It also allows students the possibility of changing easily to the single-major program in either mathematics or CISwith no loss of credit and, at least through the junior year, without jeopardizing degree completion in four years.

Careers

Graduates with this major can enter industrial positions that require computer science skills and mathematical problem-solving ability. They are particularly well suited for positions in the high-performance computing industry, developing the software tools for large-scale scientific computation. The combination of mathematics and computer science forms an excellent professional background for secondary-school mathematics teachers, and the major program also provides a solid foundation for actuarial, financial, and related professions. Graduates are also prepared to enter advanced programs of study in either mathematics or computer science, or in applied areas such as biological computational science.

Preparation

A high school student planning to major in mathematics and computer science should pursue a strong academic program with four years of mathematics. Courses in algebra, geometry, trigonometry, and more advanced topics should be included. Experience preparing substantial written reports is highly desirable.

Transfer Students

College transfer students who have completed a year of calculus should be able to fit the remaining mathematics courses for the degree into just two years, provided that they have already completed the bulk of their general-education requirements before they transfer.

Transfer students should call or write to the Department of Computer and Information Science to determine whether computer courses they have taken can be counted toward the joint major requirements. Sequential subjects such as mathematics and computer science typically require several years to progress from introductory to senior-level courses. The joint program lets students move forward in both fields at once with limited prerequisites, making it relatively accessible to transfer students and to students who change from other major programs. Students who want to pursue the material in greater depth need to consider prerequisite paths carefully.

Students attending community college in Oregon are encouraged to obtain the Associate of Arts Oregon Transfer degree before entering the University of Oregon. While earning this degree, community college transfer students should take as much discrete mathematics, calculus, and computer science as possible, and also try to complete the science requirement for the major. The associate degree does not automatically satisfy the science requirement for this major.

Faculties and Facilities

The faculties and facilities in both the mathematics and the computer and information science departments are available to students in the combined major program. For detailed descriptions, see those sections of this catalog. Information is also available online.

Honors Program

Both of the cooperating departments offer departmental honors programs to their undergraduate majors. After obtaining advance approval from both of their advisors, students in the joint degree program are eligible to attain honors in mathematics and computer science by meeting the honors requirements of either department, including writing a thesis.

Preparation for Kindergarten through Secondary School Teaching Careers

The College of Education offers a fifth-year program for middle-secondary licensure in mathematics and for elementary teaching. More information is available from the mathematics department's education advisor, Shlomo Libeskind; see also the **College of Education** section of this catalog.

Minor

Minors are offered by the Department of Mathematics and the Department of Computer and Information Science. There is no joint minor in mathematics and computer science.

- **Bachelor of Arts**
- **Bachelor of Science**

Undergraduate Studies

Bachelor of Arts Degree Requirements

Core Courses		
CIS210–212	Computer Science I-III	12
MATH231–232	Elements of Discrete Mathematics I-II	8
MATH251–253	Calculus I-III	12
orMATH261–263	Calculus with Theory I-III	
Mathematics Requirements		
MATH315	Elementary Analysis	4
MATH341–342	Elementary Linear Algebra	8
MATH351–352	Elementary Numerical Analysis I-II	8

orMATH461–462	Introduction to Mathematical Methods of Statistics I-II	
Upper-level mathematics course [1]		4
Computer and Information Science		
CIS313	Intermediate Data Structures	4
CIS314	Computer Organization	4
CIS315	Intermediate Algorithms	4
CIS425	Principles of Programming Languages	4
Select one of the following:		4
CIS330	C/C++ and Unix	
CIS420	Automata Theory	
CIS422	Software Methodology I	
Two other upper-division CIS courses [2]		8
Writing Requirements		
WR320	Scientific and Technical Writing	4
orWR321	Business Communications	
Science Requirements		
Select 12 credits from the following:		12
Biology [3]		
BI211,213	General Biology I,III	
orBI211–212	General Biology I-II	
Chemistry [3]		
CH111	Introduction to Chemical Principles	
orCH113	The Chemistry of Sustainability	
orCH221	General Chemistry	
orCH224H	Honors General Chemistry	
CH221–223	General Chemistry	
orCH224H–226H	Honors General Chemistry	
Geography		
GEOG141	The Natural Environment	
Select two of the following:		
GEOG321	Climatology	
GEOG322	Geomorphology	
GEOG323	Biogeography	
Geological Sciences		
GEOL201	Earth's Interior Heat and Dynamics	
GEOL202	Earth Surface and Environmental Geology	
GEOL203	Evolution of the Earth	
Physics [3]		
PHYS201–203	General Physics	
orPHYS251–253	Foundations of Physics I	
Psychology		
PSY201	Mind and Brain	
PSY202	Mind and Society	
Select one of the following:		
PSY304	Biopsychology	
PSY330	Thinking	
PSY348	Music and the Brain	
Total Credits		**100**

1 Excludes Statistical Methods I-II (MATH425–426)

2 Special Studies: [Topic] (CIS399) and Experimental Course: [Topic] (CIS410)courses used as electives must have a prerequisite of Intermediate Data Structures (CIS313) and have regular class meetings and homework assignments. At least one course must be numbered 410 or above.

3 Students are encouraged to complete the accompanying lab courses.

Bachelor of Science Degree Requirements

Core Courses		
CIS210–212	Computer Science I-III	12
MATH231–232	Elements of Discrete Mathematics I-II	8
MATH251–253	Calculus I-III	12
orMATH261–263	Calculus with Theory I-III	
Mathematics Requirements		
MATH315	Elementary Analysis	4
MATH341–342	Elementary Linear Algebra	8
MATH351–352	Elementary Numerical Analysis I-II	8
orMATH461–462	Introduction to Mathematical Methods of Statistics I-II	
Upper-level mathematics course [1]		4
Computer and Information Science		
CIS313	Intermediate Data Structures	4
CIS314	Computer Organization	4
CIS315	Intermediate Algorithms	4
CIS425	Principles of Programming Languages	4
Select one of the following:		4
CIS330	C/C++ and Unix	
CIS420	Automata Theory	
CIS422	Software Methodology I	
Two other upper-division CIS courses [2]		8
Writing Requirements		
WR320	Scientific and Technical Writing	4
orWR321	Business Communications	
Science Requirements		
Select 12 credits from the following:		12
Biology [3]		
BI211,213	General Biology I,III	
orBI211–212	General Biology I-II	
Chemistry [3]		
CH111	Introduction to Chemical Principles	
orCH113	The Chemistry of Sustainability	
orCH221	General Chemistry	
orCH224H	Honors General Chemistry	
CH221–223	General Chemistry	
orCH224H–226H	Honors General Chemistry	
Geography		
GEOG141	The Natural Environment	
Select two of the following:		
GEOG321	Climatology	
GEOG322	Geomorphology	
GEOG323	Biogeography	

Geological Sciences	
GEOL201	Earth's Interior Heat and Dynamics
GEOL202	Earth Surface and Environmental Geology
GEOL203	Evolution of the Earth
Physics [3]	
PHYS201–203	General Physics
orPHYS251–253	Foundations of Physics I
Psychology	
PSY201	Mind and Brain
PSY202	Mind and Society
Select one of the following:	
PSY304	Biopsychology
PSY330	Thinking
PSY348	Music and the Brain
Total Credits	**100**

1 Excludes Statistical Methods I-II (MATH425–426)

2 Special Studies: [Topic] (CIS399) and Experimental Course: [Topic] (CIS410)courses used as electives must have a prerequisite of Intermediate Data Structures (CIS313) and have regular class meetings and homework assignments. At least one course must be numbered 410 or above.

3 Students are encouraged to complete the accompanying lab courses.

Additional Bachelor Requirements

Students must earn no grade below a mid-C in required lower division math and computer science courses for automatic advancement to upper division courses. At least 12 of the mathematics upper-division credits applied to the degree must be taken in residence at the university. The science courses may be taken pass/no pass (P/N) or for letter grades.

Advising and Program Planning

Each major is assigned two advisors, one in the Department of Mathematics and one in the Department of Computer and Information Science. One of the two is designated as the advisor of record for the student, but both cooperate in planning the student's program. Because of the interrelationship between mathematics and computer science courses, it is especially important that a student planning for the combined major consult closely with both advisors. Since both mathematics and computer science are sequential subjects, prerequisite planning should be discussed with the student's advisors.

Programming Experience

Students who take Computer Science I-III (CIS210–212) are expected to have programming experience, which may have been acquired in a high school course, through employment, or in a course such as Introduction to Programming and Problem Solving (CIS122). Students who are unsure about their level of preparation should meet with a CISadvisor.

Sequence of Courses

Elements of Discrete Mathematics I-II (MATH231–232) and Computer Science I-III (CIS210–212) go well together, as do calculus and physics. Students with advanced placement credit in calculus and programming experience may want to take Elements of Discrete Mathematics I-II (MATH231–232) and Computer Science I-III (CIS210–212)in the freshman year. Students with little or no programming experience should plan to take Introduction to Programming and Problem Solving (CIS122), Calculus I-III (MATH251–253), and the major science requirement in the freshman year. In the sophomore year, students should take whichever of calculus or computer science was not taken freshman year, and continue into the 300 level of the branch that was taken.

Major Progress Review and Major in Good Standing

Each major must meet with a CIS advisor to file a Major Progress Review form after completing 12 credits of the upper-division core, including at least one course from each department. Mathematics and computer science courses used to satisfy upper-division major requirements must be taken for letter grades and passed with grades of C– or better. At least 12 of the upper-division mathematics credits and 12 of the upper-division computer and information science credits applied to the degree must be taken in residence at the university. A student who receives two grades below C– in the upper-division core is removed from the major.

MATH315	Elementary Analysis	4
MATH341–342	Elementary Linear Algebra	8
CIS313	Intermediate Data Structures	4
CIS314	Computer Organization	4
CIS315	Intermediate Algorithms	4
CIS425	Principles of Programming Languages	4
One of the following:		4
CIS330	C/C++ and Unix	
CIS420	Automata Theory	
CIS422	Software Methodology I	

Courses

CIS105. Explorations in Computing. 4 Credits.
Overview of basic ideas and areas of computer science: includes algorithms, hardware, machine organization, programming languages, networks, artificial intelligence, and associated ethical issues.

CIS110. Fluency with Information Technology. 4 Credits.
Introduction to information technology (IT), the study of computer-based information systems. Basics of the Internet and World Wide Web. Students create websites using XHTML and CSS.

CIS111. Introduction to Web Programming. 4 Credits.
Project-based approach to learning computer programming by building interactive web pages using JavaScript and XHTML. Programming concepts including structured and object-oriented program design. CIS 110 recommended preparation.

CIS115. Multimedia Web Programming. 4 Credits.
Intermediate web programming with an emphasis on HTML5 multimedia: two-dimensional graphics, image processing, animation, video, user interaction, geolocation. Continuing JavaScript, DOM, Ajax, and JSON use, programming fundamentals, and debugging techniques.
Prereq: CIS 111.

CIS122. Introduction to Programming and Problem Solving. 4 Credits.
Computational problem solving, algorithm design, data structures, and programming using a multi-paradigm programming language. Introduces techniques for program design, testing, and debugging.

CIS196. Field Studies: [Topic]. 1-2 Credits.
Repeatable.

CIS198. Workshop: [Topic]. 1-2 Credits.
Repeatable.

CIS199. Special Studies in Computer Science: [Topic]. 1-5 Credits.
Repeatable.

CIS210. Computer Science I. 4 Credits.
Basic concepts and practices of computer science. Topics include algorithmic problem solving, levels of abstraction, object-oriented design and programming, software organization, analysis of algorithm and data structures. Sequence.
Prereq: programming experience and MATH 112.

CIS211. Computer Science II. 4 Credits.
Basic concepts and practices of computer science. Topics include algorithmic problem solving, levels of abstraction, object-oriented design and programming, software organization, analysis of algorithm and data structures. Sequence.
Prereq: CIS 210.

CIS212. Computer Science III. 4 Credits.
Basic concepts and practices of computer science. Topics include algorithmic problem solving, levels of abstraction, object-oriented design and programming, software organization, analysis of algorithm and data structures. Sequence.
Prereq: CIS 211.

CIS313. Intermediate Data Structures. 4 Credits.
Design and analysis of data structures as means of engineering efficient software; attention to data abstraction and encapsulation. Lists, trees, heaps, stacks, queues, dictionaries, priority queues.
Prereq: CIS 212, MATH 232 with grades of B- or better.

CIS314. Computer Organization. 4 Credits.
Introduction to computer organization and instruction-set architecture--digital logic design, binary arithmetic, design of central processing unit and memory, machine-level programming.
Prereq: CIS 212, MATH 231 with grades of B- or better.

CIS315. Intermediate Algorithms. 4 Credits.
Algorithm design, worst-case and average-behavior analysis, correctness, computational complexity.
Prereq: CIS 313.

CIS330. C/C++ and Unix. 4 Credits.
Practical software design and programming activities in a C/C++ and Unix environment, with emphasis on the details of C/C++ and good programming style and practices.
Prereq: CIS 314.

CIS399. Special Studies: [Topic]. 1-5 Credits.
Repeatable.
Prereq: CIS 313.

CIS401. Research: [Topic]. 1-21 Credits.
Repeatable.

CIS403. Thesis. 1-12 Credits.
Repeatable.

CIS404. Internship; [Topic]. 1-4 Credits.
Repeatable.
Prereq: CIS 313.

CIS405. Reading and Conference: [Topic]. 1-12 Credits.
Repeatable.

CIS406. Field Studies: [Topic]. 1-21 Credits.
Repeatable.

CIS407. Seminar: [Topic]. 1-5 Credits.
Repeatable. Opportunity to study in greater depth specific topics arising out of other courses.

CIS408. Workshop: [Topic]. 1-21 Credits.
Repeatable.

CIS409. Practicum: [Topic]. 1-2 Credits.
The student assists other students who are enrolled in introductory programming classes. For each four hours of scheduled weekly consulting, the student is awarded 1 credit. Repeatable for maximum of 4 credits.

CIS410. Experimental Course: [Topic]. 1-5 Credits.
Repeatable.

CIS413. Advanced Data Structures. 4 Credits.
Complex structures, storage management, sorting and searching, hashing, storage of texts, and information compression.
Prereq: CIS 315.

CIS415. Operating Systems. 4 Credits.
Principles of operating system design. Process and memory management, concurrency, scheduling, input-output and file systems, security.
Prereq: CIS 330.

CIS420. Automata Theory. 4 Credits.
Provides a mathematical basis for computability and complexity. Models of computation, formal languages, Turing machines, solvability. Nondeterminism and complexity classes.
Prereq: CIS 315.

CIS422. Software Methodology I. 4 Credits.
Technical and nontechnical aspects of software development, including specification, planning, design, development, management and maintenance of software projects. Student teams complete projects.
Prereq: CIS 313.

CIS423. Software Methodology II. 4 Credits.
Application of concepts and methodologies covered in CIS 422/522. Student teams complete a large system design and programming project. Final system specification, test plan, user documentation, and system walk throughs.
Prereq: CIS 422.

CIS425. Principles of Programming Languages. 4 Credits.
Syntax and semantics. Scope rules, environments, stores, denoted and expressed values, procedures, and parameters. Definitional interpreters. Types, overloading, parametric polymorphism, and inheritance. Varieties of abstraction.
Prereq: CIS 315.

CIS427. Introduction to Logic. 4 Credits.
Basic notions of logic: propositional logic, first-order logic, Hilbert systems, sequent calculus, natural deduction. Soundness, completeness, undecidability. Current research in logic frameworks, automated deduction, Curry-Howard isomorphism.
Pre- or coreq: CIS 425.

CIS429. Computer Architecture. 4 Credits.
RISC (reduced instruction-set computer) and CISC (complex instruction-set computer) design, storage hierarchies, high-performance processor design, pipelining, vector processing, networks, performance analysis.
Prereq: CIS 330.

CIS431. Introduction to Parallel Computing. 4 Credits.
Parallel architecture, theory, algorithms, and programming with emphasis on parallel programming, focusing on models, languages, libraries, and runtime systems.
Prereq: CIS 330.

CIS432. Introduction to Networks. 4 Credits.
Principles of computer network design. Link technologies, packet switching, routing, inter-networking, reliability. Internet protocols. Programming assignments focus on protocol design.
Prereq: CIS 330. CIS 415 recommended.

CIS433. Computer and Network Security. 4 Credits.
Security for various aspects of computers and networks. Elementary cryptography, program security, trusted operating systems, network security, privacy, and legal and ethical issues.
Prereq: CIS 415.

CIS441. Introduction to Computer Graphics. 4 Credits.
Introduction to the hardware, geometrical transforms, interaction techniques, and shape representation schemes that are important in interactive computer graphics. Programming assignments using contemporary graphics hardware and software systems.
Prereq: CIS 330.

CIS443. User Interfaces. 4 Credits.
Introduction to user interface software engineering. Emphasis on theory of interface design, understanding the behavior of the user, and implementing programs on advanced systems.
Prereq: CIS 313.

CIS445. Modeling and Simulation. 4 Credits.
Theoretical foundations and practical problems for the modeling and computer simulation of discrete and continuous systems. Simulation languages, empirical validation, applications in computer science.
Prereq: CIS 315, 330.

CIS451. Database Processing. 4 Credits.
Fundamental concepts of DBMS. Data modeling, relational models and normal forms. File organization and index structures. SQL, embedded SQL, and concurrency control.
Prereq: CIS 313, 314.

CIS452. Database Issues. 4 Credits.
Covers central database issues such as access methods, security, tuning, and concurrency control. Examines alternative database models.
Prereq: CIS 451.

CIS453. Data Mining. 4 Credits.
Databases, machine learning, artificial intelligence, statistics, and data visualization. Examines data warehouses, data preprocessing, association and classification rule mining, and cluster analysis.
Prereq: CIS 451/551.

CIS454. Bioinformatics. 4 Credits.
Introduction to bioinformatics from a computer science perspective covering algorithms for basic operations such as sequence comparison and phylogenetic inference on existing databases.

CIS461. Introduction to Compilers. 4 Credits.
Lexical analysis, parsing, attribution, code generation.
Prereq: CIS 314, 425. CIS 420 strongly recommended.

CIS471. Introduction to Artificial Intelligence. 4 Credits.
Basic themes, issues, and techniques of artificial intelligence, including agent architecture, knowledge representation and reasoning, problem solving and planning, game playing, and learning.
Prereq: CIS 315.

CIS472. Machine Learning. 4 Credits.
A broad introduction to machine learning and its established algorithms. Topics include concept learning, decision trees, neural network.
Prereq: CIS 315.

CIS490. Computer Ethics. 4 Credits.
Addresses ethical issues and social impacts of computing. Topics include crime, hacking, intellectual property, privacy, software reliability, employment, and worldwide networks.

CIS503. Thesis. 1-16 Credits.
Repeatable.

CIS507. Seminar: [Topic]. 1-5 Credits.
Repeatable. Opportunity to study in greater depth specific topics arising out of other courses.

CIS508. Workshop: [Topic]. 1-21 Credits.
Repeatable.

CIS510. Experimental Course: [Topic]. 1-5 Credits.
Repeatable.

CIS513. Advanced Data Structures. 4 Credits.
Complex structures, storage management, sorting and searching, hashing, storage of texts, and information compression.

CIS520. Automata Theory. 4 Credits.
Provides a mathematical basis for computability and complexity. Models of computation, formal languages, Turing machines, solvability. Nondeterminism and complexity classes.

CIS522. Software Methodology I. 4 Credits.
Technical and nontechnical aspects of software development, including specification, planning, design, development, management and maintenance of software projects. Student teams complete projects.

CIS523. Software Methodology II. 4 Credits.
Student teams complete a large system design and programming project. Final system specifications, test plan, user documentation, and system walk-through.
Prereq: CIS 522

CIS527. Introduction to Logic. 4 Credits.
Basic notions of logic: propositional logic, first-order logic, Hilbert systems, sequent calculus, natural deduction. Soundness, completeness, undecidability. Current research in logic frameworks, automated deduction, Curry-Howard isomorphism.

CIS529. Computer Architecture. 4 Credits.
RISC (reduced instruction-set computer) and CISC (complex instruction-set computer) design, storage hierarchies, high-performance processor design, pipelining, vector processing, networks, performance analysis.

CIS531. Introduction to Parallel Computing. 4 Credits.
Parallel architecture, theory, algorithms, and programming with emphasis on parallel programming, focusing on models, languages, libraries, and runtime systems.

CIS532. Introduction to Networks. 4 Credits.
Principles of computer network design. Link technologies, packet switching, routing, inter-networking, reliability. Internet protocols. Programming assignments focus on protocol design.

CIS533. Computer and Network Security. 4 Credits.
Security for various aspects of computers and networks. Elementary cryptography,program security, trusted operating systems, network security, privacy, and legal and ethical issues.

CIS541. Introduction to Computer Graphics. 4 Credits.
Introduction to the hardware, geometrical transforms, interaction techniques, and shape representation schemes that are important in interactive computer graphics. Programming assignments using contemporary graphics hardware and software systems.

CIS543. User Interfaces. 4 Credits.
Introduction to user interface software engineering. Emphasis on theory of interface design, understanding the behavior of the user, and implementing programs on advanced systems.

CIS545. Modeling and Simulation. 4 Credits.
Theoretical foundations and practical problems for the modeling and computer simulation of discrete and continuous systems. Simulation languages, empirical validation, applications in computer science.

CIS551. Database Processing. 4 Credits.
Fundamental concepts of DBMS. Data modeling, relational models and normal forms. File organization and index structures. SQL, embedded SQL, and concurrency control.

CIS552. Database Issues. 4 Credits.
Covers central database issues such as access methods, security, tuning, and concurrency control. Examines alternative database models.
Prereq: CIS 4/551.

CIS553. Data Mining. 4 Credits.
Databases, machine learning, artificial intelligence, statistics, and data visualization. Examines data warehouses, data preprocessing, association and classification rule mining, and cluster analysis.
Prereq: CIS 451/551.

CIS554. Bioinformatics. 4 Credits.
Introduction to bioinformatics from a computer science perspective covering algorithms for basic operations such as sequence comparison and phylogenetic inference on existing databases.

CIS561. Introduction to Compilers. 4 Credits.
Lexical analysis, parsing, attribution, code generation.
Prereq: CIS 314 or equivalent, 624. CIS 420/520 strongly recommended.

CIS571. Introduction to Artificial Intelligence. 4 Credits.
Basic themes, issues, and techniques of artificial intelligence, including agent architecture, knowledge representation and reasoning, problem solving and planning, game playing, and learning.

CIS572. Machine Learning. 4 Credits.
A broad introduction to machine learning and its established algorithms. Topics include concept learning, decision trees, neural network.

CIS590. Computer Ethics. 4 Credits.
Addresses ethical issues and social impacts of computing. Topics include crime, hacking, intellectual property, privacy, software reliability, employment, and worldwide networks.

CIS601. Research: [Topic]. 1-16 Credits.
Repeatable.

CIS602. Supervised College Teaching. 1-5 Credits.
Repeatable.

CIS603. Dissertation. 1-16 Credits.
Repeatable.

CIS604. Internship: [Topic]. 1-4 Credits.
Repeatable.

CIS605. Reading and Conference: [Topic]. 1-16 Credits.
Repeatable.

CIS606. Field Studies: [Topic]. 1-16 Credits.
Repeatable.

CIS607. Seminar: [Topic]. 1-5 Credits.
Repeatable. Research topics are presented.

CIS608. Colloquium: [Topic]. 1 Credit.
Repeatable.

CIS609. Final Project. 1-16 Credits.
Repeatable. Final project for master's degree without thesis.

CIS610. Experimental Course: [Topic]. 1-5 Credits.
Repeatable.

CIS621. Algorithms and Complexity. 4 Credits.
Design and analysis of algorithms, strategies for efficient algorithms, introduction to complexity theory including NP-completeness.
Prereq: CIS 420/520 strongly recommended.

CIS622. Theoretical Foundations: [Topic]. 4 Credits.
Selected topics from computability and complexity theory. Repeatable twice when topic changes for maximum of 12 credits.
Prereq: CIS 621.

CIS624. Structure of Programming Languages. 4 Credits.
Introduction to axiomatic, operational, and denotational semantics. Environments, stores, and continuations. Type theory, subtypes, polymorphism, and inheritance. Functional and logic programming.

CIS630. Distributed Systems. 4 Credits.
Principles of distributed computer systems: interprocess communication, distributed file systems, distributed timing and synchronization, distributed programming, transactions, process scheduling, distributed shared memory.
Prereq: CIS 415 or equivalent, CIS 429/529.

CIS631. Parallel Processing. 4 Credits.
Advanced topics in parallel processing including massively parallel computer architecture, supercomputers, parallelizing compiler technology, performance evaluation, parallel programming languages, parallel applications.
Prereq: CIS 429/529.

CIS632. Computer Networks. 4 Credits.
Advanced issues in computer networks, focusing on research to extend the services offered by the Internet.
Prereq: CIS 432/532.

CIS633. Advanced Network Security. 4 Credits.
Classic and state-of-the-art research topics in network security; threats and attacks, defense algorithms and mechanisms, measurement and evaluation of both security problems and solutions. Offered alternate years.
Prereq: CIS 533.

CIS640. Writing in Computer Research. 2 Credits.
Students learn to provide and accept constructive criticism of writing samples in a workshop format.

CIS650. Software Engineering. 4 Credits.
Examines recent models and tools in software engineering including modifications to the traditional software life-cycle model, development environments, and speculative view of the future role of artificial intelligence.

CIS677. Knowledge-Based Interfaces. 4 Credits.
Examination of research knowledge-based user interfaces with particular attention to cognitive modeling. Topics include intelligent tutoring systems, natural language interfaces, and expert systems explanation.
Prereq: CIS 471/571.

Courses

MATH070. Elementary Algebra. 4 Credits.
Basics of algebra, including arithmetic of signed numbers, order of operations, arithmetic of polynomials, linear equations, word problems, factoring, graphing lines, exponents, radicals. Credit for enrollment (eligibility) but not for graduation; satisfies no university or college requirement. Additional fee.

MATH095. Intermediate Algebra. 4 Credits.
Topics include problem solving, linear equations, systems of equations, polynomials and factoring techniques, rational expressions, radicals and exponents, quadratic equations. Credit for enrollment (eligibility) but not for graduation; satisfies no university or college requirement. Additional fee.
Prereq: MATH 70 or satisfactory placement test score.

MATH105. University Mathematics I. 4 Credits.
Topics include logic, sets and counting, probability, and statistics. Instructors may include historical context of selected topics and applications to finance and biology.
Prereq: MATH 95 or satisfactory placement test score.

MATH106. University Mathematics II. 4 Credits.
Topics include mathematics of finance, applied geometry, exponential growth and decay, and a nontechnical introduction to the concepts of calculus.
Prereq: MATH 95 or satisfactory placement test score.

MATH107. University Mathematics III. 4 Credits.
Topics chosen from modular arithmetic and coding, tilings and symmetry, voting methods, apportionment, fair division, introductory graph theory, or scheduling.
Prereq: MATH 95 or satisfactory placement test score.

MATH111. College Algebra. 4 Credits.
Algebra needed for calculus including graph sketching, algebra of functions, polynomial functions, rational functions, exponential and logarithmic functions, linear and nonlinear functions.
Prereq: MATH 95 or satisfactory placement test score.

MATH112. Elementary Functions. 4 Credits.
Exponential, logarithmic, and trigonometric functions. Intended as preparation for MATH 251.
Prereq: Satisfactory placement test score.

MATH199. Special Studies: [Topic]. 1-5 Credits.
Repeatable.

MATH211. Fundamentals of Elementary Mathematics I. 4 Credits.
Structure of the number system, logical thinking, topics in geometry, simple functions, and basic statistics and probability. Calculators, concrete materials, and problem solving are used when appropriate. Covers the mathematics needed to teach grades K–8. Sequence.
Prereq: MATH 111 or satisfactory placement test score.

MATH212. Fundamentals of Elementary Mathematics II. 4 Credits.
Structure of the number system, logical thinking, topics in geometry, simple functions, and basic statistics and probability. Calculators, concrete materials, and problem solving are used when appropriate. Covers the mathematics needed to teach grades K–8. Sequence.
Prereq: MATH 211, C- or better.

MATH213. Fundamentals of Elementary Mathematics III. 4 Credits.
Structure of the number system, logical thinking, topics in geometry, simple functions, and basic statistics and probability. Calculators, concrete materials, and problem solving are used when appropriate. Covers the mathematics needed to teach grades K–8. Sequence.
Prereq: MATH 212, C- or better.

MATH231. Elements of Discrete Mathematics I. 4 Credits.
Sets, mathematical logic, induction, sequences, and functions. Sequence.
Prereq: MATH 112 or satisfactory placement test score.

MATH232. Elements of Discrete Mathematics II. 4 Credits.
Relations, theory of graphs and trees with applications, permutations and combinations.
Prereq: MATH 231.

MATH233. Elements of Discrete Mathematics III. 4 Credits.
Discrete probability, Boolean algebra, elementary theory of groups and rings with applications.
Prereq: MATH 232.

MATH241. Calculus for Business and Social Science I. 4 Credits.
Introduction to topics in differential and integral calculus including some aspects of the calculus of several variables. Sequence. Students cannot receive credit for both MATH 241 and 251.
Prereq: MATH 111 or satisfactory placement test score; a programmable calculator capable of displaying function graphs.

MATH242. Calculus for Business and Social Science II. 4 Credits.
Introduction to topics in differential and integral calculus including some aspects of the calculus of several variables. Students cannot receive credit for both MATH 242 and 252.
Prereq: MATH 241.

MATH243. Introduction to Methods of Probability and Statistics. 4 Credits.
Discrete and continuous probability, data description and analysis, sampling distributions, emphasizes confidence intervals and hypothesis testing. Students cannot receive credit for both MATH 243 and 425.
Prereq: MATH 95 or satisfactory placement test score; MATH 111 recommended; a programmable calculator capable of displaying function graphs.

MATH246. Calculus for the Biological Sciences I. 4 Credits.
For students in biological science and related fields. Emphasizes modeling and applications to biology. Differential calculus and applications. Sequence. Students cannot receive credit for more than one of MATH 241, 246, 251.
Prereq: MATH 112 or satisfactory placement test score.

MATH247. Calculus for the Biological Sciences II. 4 Credits.
For students in biological science and related fields. Emphasizes modeling and applications to biology. Integral calculus and applications. Students cannot receive credit for more than one of MATH 242, 247, 252.
Prereq: MATH 246.

MATH251. Calculus I. 4 Credits.
Standard sequence for students of physical and social sciences and of mathematics. Differential calculus and applications. Sequence. Students cannot receive credit for more than one of MATH 241, 246, 251.
Prereq: MATH 112 or satisfactory placement test score.

MATH252. Calculus II. 4 Credits.
Standard sequence for students of physical and social sciences and of mathematics. Integral calculus. Sequence. Students cannot receive credit for more than one of MATH 242, 247, 252.
Prereq: MATH 251.

MATH253. Calculus III. 4 Credits.
Standard sequence for students of physical and social sciences and of mathematics. Introduction to improper integrals, infinite sequences and series, Taylor series, and differential equations. Sequence. Students cannot receive credit for more than one of MATH 253, 263.
Prereq: MATH 252.

MATH256. Introduction to Differential Equations. 4 Credits.
Introduction to differential equations and applications. Linear algebra is introduced as needed.
Prereq: MATH 253.

MATH261. Calculus with Theory I. 4 Credits.
Covers both applications of calculus and its theoretical background. Axiomatic treatment of the real numbers, limits, and the least upper bound property.

MATH262. Calculus with Theory II. 4 Credits.
Covers both applications of calculus and its theoretical background. Differential and integral calculus.
Prereq: MATH 261.

MATH263. Calculus with Theory III. 4 Credits.
Covers both applications of calculus and its theoretical background. Sequences and series, Taylor's theorem.
Prereq: MATH 262.

MATH281. Several-Variable Calculus I. 4 Credits.
Introduction to calculus of functions of several variables including partial differentiation; gradient, divergence, and curl; line and surface integrals; Green's and Stokes's theorems. Linear algebra introduced as needed. Sequence.
Prereq: MATH 253.

MATH282. Several-Variable Calculus II. 4 Credits.
Introduction to calculus of functions of several variables including partial differentiation; gradient, divergence, and curl; line and surface integrals; Green's and Stokes's theorems. Linear algebra introduced as needed.
Prereq: MATH 281.

MATH307. Introduction to Proof. 4 Credits.
Proof is how mathematics establishes truth and communicates ideas. Introduces students to proof in the context of interesting mathematical problems.
Prereq: MATH 247 or 252 or 262.

MATH315. Elementary Analysis. 4 Credits.
Rigorous treatment of certain topics introduced in calculus including continuity, differentiation and integration, power series, sequences and series, uniform convergence and continuity.
Prereq: MATH 253 or equivalent; one from MATH 232, 262, 307.

MATH341. Elementary Linear Algebra. 4 Credits.
Vector and matrix algebra; n-dimensional vector spaces; systems of linear equations; linear independence and dimension; linear transformations; rank and nullity; determinants; eigenvalues; inner product spaces; theory of a single linear transformation. Sequence.
Prereq: MATH 252. MATH 253 is recommended.

MATH342. Elementary Linear Algebra. 4 Credits.
Vector and matrix algebra; n-dimensional vector spaces; systems of linear equations; linear independence and dimension; linear transformations; rank and nullity; determinants; eigenvalues; inner product spaces; theory of a single linear transformation.
Prereq: MATH 341.

MATH343. Statistical Models and Methods. 4 Credits.
Review of theory and applications of mathematical statistics including estimation and hypothesis testing.
Prereq: MATH 252.

MATH346. Number Theory. 4 Credits.
Topics include congruences, Chinese remainder theorem, Gaussian reciprocity, basic properties of prime numbers.
Prereq: MATH 253 or equivalent; one from MATH 232, 262, 307.

MATH351. Elementary Numerical Analysis I. 4 Credits.
Basic techniques of numerical analysis and their use on computers. Topics include root approximation, linear systems, interpolation, integration, and differential equations. Sequence.
Prereq: MATH 253 or equivalent; one from MATH 232, 262, 307.

MATH352. Elementary Numerical Analysis II. 4 Credits.
Basic techniques of numerical analysis and their use on computers. Topics include root approximation, linear systems, interpolation, integration, and differential equations.
Prereq: MATH 351.

MATH391. Fundamentals of Abstract Algebra I. 4 Credits.
Introduction to algebraic structures including groups, rings, fields, and polynomial rings. Sequence.
Prereq: MATH 341; one from MATH 232, 262, 307.

MATH392. Fundamentals of Abstract Algebra II. 4 Credits.
Introduction to algebraic structures including groups, rings, fields, and polynomial rings.
Prereq: MATH 391.

MATH393. Fundamentals of Abstract Algebra III. 4 Credits.
Introduction to algebraic structures including groups, rings, fields, and polynomial rings.
Prereq: MATH 392.

MATH394. Geometries from an Advanced Viewpoint I. 4 Credits.
Topics in Euclidean geometry in two and three dimensions including constructions. Emphasizes investigations, proofs, and challenging problems. For prospective secondary and middle school teachers.
Prereq: MATH 253 or equivalent; one from MATH 232, 262, 307.

MATH395. Geometries from an Advanced Viewpoint II. 4 Credits.
Analysis of problems in Euclidean geometry using coordinates, vectors, and the synthetic approach. Transformations in the plane and space and their groups. Introduction to non-Euclidean geometries. For prospective secondary teachers.
Prereq: grade of C- or better in MATH 394.

MATH399. Special Studies: [Topic]. 1-5 Credits.
Repeatable.

MATH401. Research: [Topic]. 1-21 Credits.
Repeatable.

MATH403. Thesis. 1-4 Credits.
Repeatable.

MATH405. Reading and Conference: [Topic]. 1-4 Credits.
Repeatable.

MATH407. Seminar: [Topic]. 1-4 Credits.
Repeatable.

MATH410. Experimental Course: [Topic]. 1-4 Credits.
Repeatable.

MATH411. Functions of a Complex Variable I. 4 Credits.
Complex numbers, linear fractional transformations, Cauchy-Riemann equations, Cauchy's theorem and applications, power series, residue theorem, harmonic functions, contour integration, conformal mapping, infinite products. Sequence.
Prereq: MATH 281; one from MATH 232, 262, 307.

MATH412. Functions of a Complex Variable II. 4 Credits.
Complex numbers, linear fractional transformations, Cauchy-Riemann equations, Cauchy's theorem and applications, power series, residue theorem, harmonic functions, contour integration, conformal mapping, infinite products.
Prereq: MATH 411.

MATH413. Introduction to Analysis I. 4 Credits.
Differentiation and integration on the real line and in a dimensional Euclidean space; normed linear spaces and metric spaces; vector field theory and differential forms. Sequence.
Prereq: MATH 282, 315.

MATH414. Introduction to Analysis II. 4 Credits.
Differentiation and integration on the real line and in a dimensional Euclidean space; normed linear spaces and metric spaces; vector field theory and differential forms.
Prereq: MATH 413.

MATH415. Introduction to Analysis III. 4 Credits.
Differentiation and integration on the real line and in a dimensional Euclidean space; normed linear spaces and metric spaces; vector field theory and differential forms. Sequence.
Prereq: MATH 414.

MATH420. Ordinary Differential Equations. 4 Credits.
Ordinary differential equations. General and initial value problems. Explicit, numerical, graphical solutions; phase portraits. Existence, uniqueness, stability. Power series methods. Gradient flow; periodic solutions.
Prereq: MATH 263 or 315.

MATH421. Partial Differential Equations: Fourier Analysis I. 4 Credits.
Introduction to PDEs; wave and heat equations. Classical Fourier series on the circle; applications of Fourier series. Generalized Fourier series, Bessel and Legendre series.
Prereq: MATH 281 and either MATH 256 or 420.

MATH422. Partial Differential Equations: Fourier Analysis II. 4 Credits.
General theory of PDEs; the Fourier transform. Laplace and Poisson equations; Green's functions and application. Mean value theorem and max-min principle.
Prereq: MATH 421.

MATH425. Statistical Methods I. 4 Credits.
Statistical methods for upper-division and graduate students anticipating research in nonmathematical disciplines. Presentation of data, sampling distributions, tests of significance, confidence intervals, linear regression, analysis of variance, correlation, statistical software. Sequence. Only nonmajors may receive upper-division credit. Students cannot receive credit for both MATH 243 and 425.
Prereq: MATH 111 or satisfactory placement test score.

MATH431. Introduction to Topology. 4 Credits.
Elementary point-set topology with an introduction to combinatorial topology and homotopy. Sequence.
Prereq: MATH 315.

MATH432. Introduction to Topology. 4 Credits.
Elementary point-set topology with an introduction to combinatorial topology and homotopy. Sequence.
Prereq: MATH 431.

MATH433. Introduction to Differential Geometry. 4 Credits.
Plane and space curves, Frenet-Serret formula surfaces. Local differential geometry, Gauss-Bonnet formula, introduction to manifolds.
Prereq: MATH 282, 342; one from MATH 232, 262, 307.

MATH441. Linear Algebra. 4 Credits.
Theory of vector spaces over arbitrary fields, theory of a single linear transformation, minimal polynomials, Jordan and rational canonical forms, quadratic forms, quotient spaces.
Prereq: MATH 342; one from MATH 232, 262, 307.

MATH444. Introduction to Abstract Algebra I. 4 Credits.
Theory of groups, rings, and fields. Polynomial rings, unique factorization, and Galois theory. Sequence.
Prereq: MATH 342; one from MATH 232, 262, 307.

MATH445. Introduction to Abstract Algebra II. 4 Credits.
Theory of groups, rings, and fields. Polynomial rings, unique factorization, and Galois theory.
Prereq: MATH 444.

MATH446. Introduction to Abstract Algebra III. 4 Credits.
Theory of groups, rings, and fields. Polynomial rings, unique factorization, and Galois theory.
Prereq: MATH 445.

MATH456. Networks and Combinatorics. 4 Credits.
Fundamentals of modern combinatorics; graph theory; networks; trees; enumeration, generating functions, recursion, inclusion and exclusion; ordered sets, lattices, Boolean algebras.
Prereq: MATH 231 or 346; one from MATH 232, 262, 307.

MATH457. Discrete Dynamical Systems. 4 Credits.
Linear and nonlinear first-order dynamical systems; equilibrium, cobwebs, Newton's method. Bifurcation and chaos. Introduction to higher-order systems. Applications to economics, genetics, ecology.
Prereq: MATH 256; one from MATH 232, 262, 307.

MATH458. Introduction to Mathematical Cryptography. 4 Credits.
Mathematical theory of public key cryptography. Finite field arithmetic, RSA and Diffie-Hellman algorithms, elliptic curves, generation of primes, factorization techniques. Offered alternate years.
Prereq: MATH 341.

MATH461. Introduction to Mathematical Methods of Statistics I. 4 Credits.
Discrete and continuous probability models; useful distributions; applications of moment-generating functions; sample theory with applications to tests of hypotheses, point and confidence interval estimates. Sequence.
Prereq: MATH 253 or 263; one from MATH 232, 262, 307.

MATH462. Introduction to Mathematical Methods of Statistics II. 4 Credits.
Discrete and continuous probability models; useful distributions; applications of moment-generating functions; sample theory with applications to tests of hypotheses, point and confidence interval estimates.
Prereq: MATH 461.

MATH463. Mathematical Methods of Regression Analysis and Analysis of Variance. 4 Credits.
Multinomial distribution and chi-square tests of fit, simple and multiple linear regression, analysis of variance and covariance, methods of model selection and evaluation, use of statistical software.
Prereq: MATH 342, MATH 462.

MATH467. Stochastic Processes. 4 Credits.
Basics of stochastic processes including Markov chains, martingales, Poisson processes, Brownian motion and their applications.
Prereq: MATH 341, MATH 461.

MATH503. Thesis. 1-12 Credits.
Repeatable.

MATH507. Seminar: [Topic]. 1-4 Credits.
Repeatable.

MATH510. Experimental Course: [Topic]. 1-4 Credits.
Repeatable.

MATH511. Functions of a Complex Variable I. 4 Credits.
Complex numbers, linear fractional transformations, Cauchy-Riemann equations, Cauchy's theorem and applications, power series, residue theorem, harmonic functions, contour integration, conformal mapping, infinite products. Sequence.

MATH512. Functions of a Complex Variable II. 4 Credits.
Complex numbers, linear fractional transformations, Cauchy-Riemann equations, Cauchy's theorem and applications, power series, residue theorem, harmonic functions, contour integration, conformal mapping, infinite products.
Prereq: MATH 411/511.

MATH513. Introduction to Analysis I. 4 Credits.
Differentiation and integration on the real line and in a dimensional Euclidean space; normed linear spaces and metric spaces; vector field theory and differential forms. Sequence.

MATH514. Introduction to Analysis II. 4 Credits.
Differentiation and integration on the real line and in a dimensional Euclidean space; normed linear spaces and metric spaces; vector field theory and differential forms. Sequence.
Prereq: MATH 413/513.

MATH515. Introduction to Analysis III. 4 Credits.
Differentiation and integration on the real line and in a dimensional Euclidean space; normed linear spaces and metric spaces; vector field theory and differential forms. Sequence.
Prereq: MATH 414/514.

MATH520. Ordinary Differential Equations. 4 Credits.
Ordinary differential equations. General and initial value problems. Explicit, numerical, graphical solutions; phase portraits. Existence, uniqueness, stability. Power series methods. Gradient flow; periodic solutions.

MATH521. Partial Differential Equations: Fourier Analysis I. 4 Credits.
Introduction to PDEs; wave and heat equations. Classical Fourier series on the circle; applications of Fourier series. Generalized Fourier series, Bessel and Legendre series.
Prereq: MATH 420/520.

MATH522. Partial Differential Equations: Fourier Analysis II. 4 Credits.
General theory of PDEs; the Fourier transform. Laplace and Poisson equations; Green's functions and application. Mean value theorem and max-min principle.
Prereq: MATH 421/521.

MATH525. Statistical Methods I. 4 Credits.
Statistical methods for upper-division and graduate students anticipating research in nonmathematical disciplines. Presentation of data, sampling distributions, tests of significance, confidence intervals, linear regression, analysis of variance, correlation, statistical software. Sequence. Only nonmajors may receive graduate credit.

MATH531. Introduction to Topology. 4 Credits.
Elementary point-set topology with an introduction to combinatorial topology and homotopy. Sequence.

MATH532. Introduction to Topology. 4 Credits.
Elementary point-set topology with an introduction to combinatorial topology and homotopy. Sequence.
Prereq: MATH 431/531.

MATH533. Introduction to Differential Geometry. 4 Credits.
Plane and space curves, Frenet-Serret formula surfaces. Local differential geometry, Gauss-Bonnet formula, introduction to manifolds.

MATH541. Linear Algebra. 4 Credits.
Theory of vector spaces over arbitrary fields, theory of a single linear transformation, minimal polynomials, Jordan and rational canonical forms, quadratic forms, quotient spaces.

MATH544. Introduction to Abstract Algebra I. 4 Credits.
Theory of groups, rings, and fields. Polynomial rings, unique factorization, and Galois theory. Sequence.

MATH545. Introduction to Abstract Algebra II. 4 Credits.
Theory of groups, rings, and fields. Polynomial rings, unique factorization, and Galois theory.
Prereq: MATH 444/544.

MATH546. Introduction to Abstract Algebra III. 4 Credits.
Theory of groups, rings, and fields. Polynomial rings, unique factorization, and Galois theory.
Prereq: MATH 445/545.

MATH556. Networks and Combinatorics. 4 Credits.
Fundamentals of modern combinatorics; graph theory; networks; trees; enumeration, generating functions, recursion, inclusion and exclusion; ordered sets, lattices, Boolean algebras.

MATH557. Discrete Dynamical Systems. 4 Credits.
Linear and nonlinear first-order dynamical systems; equilibrium, cobwebs, Newton's method. Bifurcation and chaos. Introduction to higher-order systems. Applications to economics, genetics, ecology.

MATH561. Introduction to Mathematical Methods of Statistics I. 4 Credits.
Discrete and continuous probability models; useful distributions; applications of moment-generating functions; sample theory with applications to tests of hypotheses, point and confidence interval estimates. Sequence.

MATH562. Introduction to Mathematical Methods of Statistics II. 4 Credits.
Discrete and continuous probability models; useful distributions; applications of moment-generating functions; sample theory with applications to tests of hypotheses, point and confidence interval estimates.
Prereq: MATH 461/561.

MATH563. Mathematical Methods of Regression Analysis and Analysis of Variance. 4 Credits.
Multinomial distribution and chi-square tests of fit, simple and multiple linear regression, analysis of variance and covariance, methods of model selection and evaluation, use of statistical software.
Prereq: MATH 462/562.

MATH567. Stochastic Processes. 4 Credits.
Basics of stochastic processes including Markov chains, martingales, Poisson processes, Brownian motion and their applications.
Prereq: MATH 561.

MATH601. Research: [Topic]. 1-9 Credits.
Repeatable.

MATH602. Supervised College Teaching. 1-16 Credits.
Repeatable.

MATH603. Dissertation. 1-16 Credits.
Repeatable.

MATH605. Reading and Conference: [Topic]. 1-5 Credits.
Repeatable.

MATH607. Seminar: [Topic]. 1-5 Credits.
Repeatable. Topics include Advanced Topics in Geometry, Ring Theory, Teaching Mathematics.

MATH616. Real Analysis. 4-5 Credits.
Measure and integration theory, differentiation, and functional analysis with point-set topology as needed. Sequence.

MATH617. Real Analysis. 4-5 Credits.
Measure and integration theory, differentiation, and functional analysis with point-set topology as needed. Sequence.
Prereq: MATH 616.

MATH618. Real Analysis. 4-5 Credits.
Measure and integration theory, differentiation, and functional analysis with point-set topology as needed. Sequence.
Prereq: MATH 617.

MATH619. Complex Analysis. 4-5 Credits.
The theory of Cauchy, power series, contour integration, entire functions, and related topics.

MATH634. Algebraic Topology. 4-5 Credits.
Development of homotopy, homology, and cohomology with point-set topology as needed. Sequence.

MATH635. Algebraic Topology. 4-5 Credits.
Development of homotopy, homology, and cohomology with point-set topology as needed. Sequence.
Prereq: MATH 634.

MATH636. Algebraic Topology. 4-5 Credits.
Development of homotopy, homology, and cohomology with point-set topology as needed. Sequence.
Prereq: MATH 635.

MATH637. Differential Geometry. 4-5 Credits.
Topics include curvature and torsion, Serret-Frenet formulas, theory of surfaces, differentiable manifolds, tensors, forms and integration. Sequence.

MATH638. Differential Geometry. 4-5 Credits.
Topics include curvature and torsion, Serret-Frenet formulas, theory of surfaces, differentiable manifolds, tensors, forms and integration. Sequence.
Prereq: MATH 637.

MATH639. Differential Geometry. 4-5 Credits.
Topics include curvature and torsion, Serret-Frenet formulas, theory of surfaces, differentiable manifolds, tensors, forms and integration. Sequence.

MATH647. Abstract Algebra. 4-5 Credits.
Group theory, fields, Galois theory, algebraic numbers, matrices, rings, algebras. Sequence.

MATH648. Abstract Algebra. 4-5 Credits.
Group theory, fields, Galois theory, algebraic numbers, matrices, rings, algebras. Sequence.
Prereq: MATH 647.

MATH649. Abstract Algebra. 4-5 Credits.
Group theory, fields, Galois theory, algebraic numbers, matrices, rings, algebras. Sequence.
Prereq: MATH 648.

MATH672. Theory of Probability. 4-5 Credits.
Measure and integration, probability spaces, laws of large numbers, central-limit theory, conditioning, martingales, random walks.
Prereq: MATH 671.

MATH673. Theory of Probability. 4-5 Credits.
Measure and integration, probability spaces, laws of large numbers, central-limit theory, conditioning, martingales, random walks.
Prereq: MATH 672.

MATH681. Advanced Algebra: [Topic]. 4-5 Credits.
Repeatable. Topics selected from theory of finite groups, representations of finite groups, Lie groups, Lie algebras, algebraic groups, ring theory, algebraic number theory.

MATH682. Advanced Algebra: [Topic]. 4-5 Credits.
Repeatable. Topics selected from theory of finite groups, representations of finite groups, Lie groups, Lie algebras, algebraic groups, ring theory, algebraic number theory.

MATH683. Advanced Algebra: [Topic]. 4-5 Credits.
Repeatable. Topics selected from theory of finite groups, representations of finite groups, Lie groups, Lie algebras, algebraic groups, ring theory, algebraic number theory.

MATH684. Advanced Analysis: [Topic]. 4-5 Credits.
Repeatable. Topics selected from Banach algebras, operator theory, functional analysis, harmonic analysis on topological groups, theory of distributions.

MATH685. Advanced Analysis: [Topic]. 4-5 Credits.
Repeatable. Topics selected from Banach algebras, operator theory, functional analysis, harmonic analysis on topological groups, theory of distributions.

MATH686. Advanced Analysis: [Topic]. 4-5 Credits.
Repeatable. Topics selected from Banach algebras, operator theory, functional analysis, harmonic analysis on topological groups, theory of distributions.

MATH690. Advanced Geometry and Topology: [Topic]. 4-5 Credits.
Repeatable. Topics selected from classical and local differential geometry; symmetric spaces; low-dimensional topology; differential topology; global analysis; homology, cohomology, and homotopy; differential analysis and singularity theory; knot theory.

MATH691. Advanced Geometry and Topology: [Topic]. 4-5 Credits.
Repeatable. Topics selected from classical and local differential geometry; symmetric spaces; low-dimensional topology; differential topology; global analysis; homology, cohomology, and homotopy; differential analysis and singularity theory; knot theory.

MATH692. Advanced Geometry and Topology: [Topic]. 4-5 Credits.
Repeatable. Topics selected from classical and local differential geometry; symmetric spaces; low-dimensional topology; differential topology; global analysis; homology, cohomology, and homotopy; differential analysis and singularity theory; knot theory.