

# Department of Mathematics

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The Department of Mathematics offers programs leading to the degrees of Bachelor of Science (BS) and Bachelor of Arts (BA) in Mathematics and in Statistics. It also offers programs leading to the degree of Master of Science (MS) and Master of Arts (MA) in Mathematics and Statistics.

## Undergraduate Program

### BA or BS in Mathematics

In addition to the general requirements of the Faculty of Arts and Sciences, the department requires nine credits in courses numbered 200 or above from the natural sciences for the BS degree, and at least nine credits in courses numbered 200 or above in the arts (humanities or social sciences) for the BA degree. In both cases it is recommended that at least six of these nine credits be in disciplines that use quantitative methods, and be chosen in conjunction with the student's faculty adviser. In addition, the departmental requirements are as follows:

MATH 201, MATH 210, MATH 219, MATH 227, MATH 233, and MATH 241, and 18 more credits chosen from MATH 202 and mathematics courses numbered 213 or above. In addition, students must take CMPS 200, which is a first course in programming.

A transfer student who has done well in MATH 218 can count it toward the mathematics major instead of MATH 219, subject to departmental approval. In such a case, the department will usually require the student to take MATH 220.

Students wishing to pursue graduate study in mathematics are strongly urged to take MATH 214, MATH 220, MATH 223, MATH 242, and MATH 213 or MATH 216. They may also want to consider taking one or more graduate course in their senior year. Students with an interest in applied mathematics are urged to take MATH 202, MATH 220, MATH 224, MATH 251, and MATH 234, and to choose their additional courses to include a significant use of mathematical techniques. Students interested in high school teaching are encouraged to include MATH 202, MATH 213, MATH 251, and MATH 261 among their courses.

A minor in mathematics requires 18 credits: MATH 201, MATH 210, either MATH 218 or MATH 219, and nine more credits in mathematics courses numbered MATH 202, MATH 211 or above, and statistics courses numbered 230 or above.

## BA or BS in Statistics

In addition to the general requirements of the Faculty of Arts and Sciences, the department requires nine credits in courses numbered 200 or above from the natural sciences for the BS degree, and at least nine credits in courses numbered 200 or above in the arts (humanities or social sciences) for the BA degree. In both cases it is recommended that at least six of these nine credits be in disciplines that use quantitative methods, and be chosen in conjunction with the student's faculty adviser. In addition, the departmental requirements are as follows:

In statistics: STAT 233, STAT 234, STAT 235, STAT 236, STAT 237 and STAT 238, and nine more credits chosen from MATH 202 and from mathematics, statistics, and computer science courses numbered 212 or above, excluding STAT 230

In mathematics: MATH 201, MATH 210, and MATH 218 or MATH 219

In computer science: CMPS 200

Students planning to go for higher education in statistics are advised to take their electives in advanced mathematics courses such as MATH 223 and MATH 227. Other students are encouraged to choose among their electives MATH 251 and other computing-oriented courses.

It is to be noted that STAT 201, 210, and 230 are mainly service courses. STAT 201 is essentially equivalent to EDUC 227, and STAT 210 is essentially equivalent to ECON 213. Students can get credit for only one of the following: STAT 201, STAT 210, STAT 230, EDUC 227, ECON 213.

A minor in statistics requires 18 credits: MATH 201, MATH 210, and STAT 233, and nine more credits in statistics courses numbered 211 or above excluding STAT 230.

## Undergraduate Courses

### Mathematics

**MATH 101**                      **Calculus and Analytic Geometry I**                      **3.1; 3 cr.**  
Limits, continuity, differentiation with application to curve plotting; Rolle's theorem; integration with application to area, distance, volume, arc-length; fundamental theorem of calculus, transcendental functions. *Annually.*

**MATH 102**                      **Calculus and Analytic Geometry II**                      **3.1; 3 cr.**  
Methods of integration, improper integrals, polar coordinates, conic sections, analytic geometry in space, parametric equations, and vector functions and their derivatives. *Prerequisite: MATH 101. Annually.*

**MATH 201**                      **Calculus and Analytic Geometry III**                      **3.1; 3 cr.**  
Multivariable functions, partial derivatives, cylindrical and spherical coordinates, multiple integrals, sequences and series, and integration in vector fields. *Prerequisite: MATH 102. Annually.*

- MATH 202                      Differential Equations                      3.0; 3 cr.**  
 First-order differential equations, linear differential equations, series solutions, Bessel's and Legendre's functions, Laplace transform, and systems. *Prerequisite: MATH 102 or 204. Annually.*
- MATH 203                      Mathematics for Social Sciences I                      3.0; 3 cr.**  
 Polynomials, factoring, first- and second-degree equations, inequalities, absolute value, straight lines, Gaussian elimination, functions, graphs, exponential and logarithmic functions, and differentiation. *Not open to students with prior credit in MATH 101 or its equivalent. Annually.*
- MATH 204                      Mathematics for Social Sciences II                      3.0; 3 cr.**  
 Matrix operations, inverses, determinants, set operations, permutations, combinations, probability, rate of change, techniques of integration, differential equations, graphs of multivariate functions, partial derivatives, and optimization. *Prerequisite: MATH 101 or MATH 203. Annually.*
- MATH 210                      Introduction to Analysis                      3.0; 3 cr.**  
 The real numbers, completeness, sequences, some basic topology of the real line, compact sets, Heine-Borel theorem, continuous functions, intermediate value theorem, uniform continuity, extreme values, differentiation, mean-value theorem, Taylor's theorem, and integration, sequences and series of functions. *Prerequisite: MATH 201. Annually.*
- MATH 211                      Discrete Structures                      3.0; 3 cr.**  
 Logical reasoning, sets, relations and functions; mathematical induction, counting, and simple finite probability theory; modular arithmetic and arithmetic in different bases; recurrence relations and difference equations; truth tables and switching circuits; graphs and trees; strings and languages. *Annually.*
- MATH 212                      Introductory Partial Differential Equations                      3.0, 3 cr.**  
 Partial differential equations as mathematical models in science, Fourier series, Fourier inversion, Gibbs phenomenon, applications of Fourier series to partial differential equations (heat equation, Laplace equation, wave equation), Sturm-Liouville Systems, Fourier and Laplace transforms and applications to partial differential equations, pointwise and uniform convergence of sequences and series of functions. *Prerequisites: MATH 201, MATH 202. No credit given for MATH 212 and MATH 224.*
- MATH 213                      Higher Geometry                      3.0; 3 cr.**  
 Topics chosen from isometries of Euclidean space, inversion, elements of differential geometry, the Frenet frame, curvature, torsion, the pseudo-sphere, hyperbolic geometry, and affine and projective geometry. *Biennially.*
- MATH 214                      Topology I                      3.0; 3 cr.**  
 Topological spaces, continuous functions, separation axioms, compactness, connectedness, metrizable spaces, and finite product spaces. *Prerequisite: MATH 210. Annually.*
- MATH 216                      Topology II                      3.0; 3 cr.**  
 A senior level course covering more advanced topics in topology. *Prerequisite: Consent of instructor. Biennially.*
- MATH 218                      Elementary Linear Algebra with Applications                      3.0; 3 cr.**  
 An introduction to linear algebra at a less theoretical level than MATH 219. Systems of linear equations and Gaussian elimination, vectors in  $\mathbb{R}^n$ , matrices, determinants, vector spaces, subspaces and dimension, orthogonal projection and least-squares approximation, eigenvalues, eigenvectors, and selected applications. *Students cannot receive credit for both MATH 219 and MATH 218. Annually.*

**MATH 219                      Linear Algebra I    3.0; 3 cr.**

A rigorous introduction to linear algebra, with emphasis on proof and conceptual reasoning. Vector spaces, linear transformations and their matrix representation, linear independence, bases and dimension, rank-nullity, systems of linear equations, brief discussion of inner products, projections, orthonormal bases, change of basis, determinants, eigenvalues, eigenvectors, and spectral theorem. *Students can not receive credit for both MATH 219 and MATH 218. Annually.*

**MATH 220                      Linear Algebra II    3.0; 3 cr.**

A deeper study of determinants, inner product spaces, and eigenvalue theory. Adjoint and the spectral theorem, primary decomposition, quotient spaces, diagonalization, triangularization, rational and Jordan forms, connection with modules over a PID, dual spaces, bilinear forms, and tensors. *Prerequisite: MATH 241 or consent of instructor. Biennially.*

**MATH 223                      Advanced Calculus    3.0; 3 cr.**

Metric spaces, normed vector spaces, the derivative as a linear transformation, chain rule, vector versions of mean-value theorem, Taylor's formula, inverse and implicit function theorems, divergence, curl, differential forms, Stokes's theorem, and notions of differential geometry. *Prerequisite: MATH 210 or MATH 224, and MATH 218 or MATH 219. Biennially.*

**MATH 224                      Fourier Series and Applications    3.0; 3 cr.**

Uniform and absolute convergence of infinite series and integrals, Laplace's method and Stirling's formula, Sturm-Liouville systems, Gram-Schmidt orthogonalization, orthogonal polynomials, Fourier series, Fourier integrals, Parseval and Plancherel theorems, and some partial differential equations. *Prerequisite: MATH 201. Annually.*

**MATH 227                      Introduction to Complex Analysis    3.0; 3 cr.**

Complex numbers, analytic functions, integration in the complex plane, Cauchy's integral theorem, Taylor series, Laurent series, singularities, residues, and contour integration. *Prerequisites: MATH 201 and consent of instructor. Annually.*

**MATH 233                      Advanced Probability and Random Variables    3.0; 3 cr.**

Same description as STAT 233. *Annually.*

**MATH 234                      Introduction to Statistical Inference    3.0; 3 cr.**

Same description as STAT 234. *Annually.*

**MATH 238                      Applied Probability Models    3.0; 3 cr.**

Same description as STAT 238. *Annually.*

**MATH 241                      Introduction to Abstract Algebra    3.0; 3 cr.**

Groups, subgroups, homomorphisms, normal subgroups and quotient groups, permutation groups, orbits and stabilizers, statement of Sylow theorems, rings, ideals, homomorphisms and quotient fields, and Euclidean and principal ideal domains. *Prerequisite: MATH 219 or MATH 218 with a good understanding of proof, or consent of instructor. Annually.*

**MATH 242                      Topics in Algebra    3.0; 3 cr.**

Topics chosen among: fields and Galois theory, group theory, ring theory, modules over a PID, and other topics as determined by the instructor. *Prerequisite: MATH 241. Biennially.*

**MATH 251 Numerical Computing 3.0; 3 cr.**

Techniques of numerical analysis: number representations and round-off errors, root finding, approximation of functions, integration, solving initial value problems, Monte-Carlo methods. Implementations and analysis of the algorithms are stressed. Projects using MATLAB or a similar tool are assigned. *Prerequisites: CMPS 200 and MATH 201. Annually.*

**MATH 261 Number Theory 3.0; 3 cr.**

Prime factorization, the Euclidean algorithm, congruences, quadratic reciprocity, some Diophantine equations, binary quadratic forms, and continued fractions. *Prerequisite: MATH 219 or consent of instructor. Annually.*

**MATH 271 Set Theory 3.0; 3 cr.**

Operations on sets and families of sets, ordered sets, transfinite induction, axiom of choice and equivalent forms, and ordinal and cardinal numbers. *Biennially.*

**MATH 281 Numerical Linear Algebra 3.0; 3 cr.**

*Equivalent to CMPS 281. Biennially.*

**MATH 293/294 Senior Tutorial Courses 3.0; 3 cr.**

*Prerequisite: Senior standing.*

## BA in Mathematics

### 36 Credits in Mathematics

Modes of Analysis	English and Arabic (9)	Humanities (12)	Economics and Social Sciences (9)	Sciences, Math, and Technology (18+18+4)
Lecture Courses (9+12+9+39)	<ol style="list-style-type: none"> <li>Required Arabic courses (3): ARAB 201A or B or any upper level course (3), as determined by placement</li> <li>Required English courses (usually 6): ENGL 203(3), and/or 204(3), as determined by placement</li> </ol>	Required credits in the humanities: 12 credits including 6 credits from CVSP (see pp. 163–65)	<ol style="list-style-type: none"> <li>Required courses (3)</li> <li>Required electives (6)<sup>1</sup></li> </ol>	<ol style="list-style-type: none"> <li>Required mathematics courses (18): MATH 201(3), 210(3), 219(3), 227(3), 233(3), 241(3)</li> <li>Required mathematics electives (18): MATH 202(3), and/or mathematics courses numbered 213 and above</li> <li>Required programming course (4): CMPS 200<sup>(4)</sup></li> </ol>
Seminar (0)				
Laboratory (1)				CMPS 200(4 hrs/week)
Research Project (0)				

<sup>1</sup> May be from the humanities.

<sup>2</sup> CMPS 200 is a 4-credit course with 3 lecture hours (3 credits) and 3–4 lab hours (1 credit) per week.

**THE REQUIREMENTS LISTED ABOVE APPLY TO STUDENTS WHO JOINED THEIR MAJOR AS OF OCTOBER 1, 2001–02. STUDENTS WHO JOINED A MAJOR PRIOR TO THAT DATE SHOULD CONSULT THE 2000–01 CATALOGUE.**

## BS in Mathematics

### 36 Credits in Mathematics

Modes of Analysis	English and Arabic (9)	Humanities (12)	Economics and Social Sciences (3)	Sciences, Math, and Technology (18+18+3)
Lecture Courses (9+12+3+48)	<ol style="list-style-type: none"> <li>Required Arabic courses (3): ARAB 201A or B, or any upper level course (3), as determined by placement</li> <li>Required English courses (usually 6): ENGL 203(3), 204(3), as determined by placement</li> </ol>	Required credits in the humanities: 12 credits including 6 credits from CVSP (see pp. 163–65)	Required Courses (3)	<ol style="list-style-type: none"> <li>Required mathematics courses (18): MATH 201(3), 210(3), 219(3), 227(3), 233(3), 241(3)</li> <li>Elective mathematics courses (18): MATH 202(3), and/or courses numbered 213 and above</li> <li>Required programming course (4): CMPS 200<sup>1</sup>(4)</li> <li>Required science electives (9)</li> </ol>
Seminar (0)				
Laboratory (1)				CMPS 200(4 hrs/week)
Research Project (0)				

<sup>1</sup> CMPS 200 is a 4-credit course with 3 lecture hours (3 credits) and 3–4 lab hours (1 credit) per week.

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## Statistics

- STAT 201 Elementary Statistics for the Social Sciences 3.0; 3 cr.**  
 (Formerly MATH 207) Data organization and frequency distributions; measures of central tendency and dispersion; probability and random variables; binomial and normal distributions; correlation, regression, estimation, and hypothesis testing. *Open only to arts students whose mathematical preparation does not allow them to take STAT 210. Students can get credit for only one of STAT 201, STAT 210, STAT 230, EDUC 227, or ECON 213. Annually.*
- STAT 210 Elementary Statistics for the Sciences 3.0; 3 cr.**  
 (Formerly MATH 208) Populations, samples, and sampling error; types of data, frequency distributions, and graphical displays of data; empirical definition of probability and probability distributions; conditional probability, independence, Bayes' rule, and counting rules; discrete and continuous distributions, random variables, binomial, normal, and t distributions; point and interval estimation and hypothesis testing; linear regression and correlation. Computer packages may be used to illustrate methods. *Students can get credit for only one of STAT 201, STAT 210, STAT 230, EDUC 227, or ECON 213. Annually.*
- STAT 230 Introduction to Probability and Random Variables 3.0; 3 cr.**  
 Display of data, properties of probability, methods of enumeration, conditional probability, and independent events; discrete and continuous univariate distributions, generating functions, independent random variables, and the central limit theorem. *Prerequisite: MATH 201. Students can get credit for only one of STAT 201, STAT 210, STAT 230, STAT 233, EDUC 227, or ECON 213. Annually.*
- STAT 233 Advanced Probability and Random Variables 3.0; 3 cr.**  
 Axiomatic definition of probability, random variables, univariate and multivariate p.d.f. and c.d.f.; expectation; moment generating function; conditional distribution; families of discrete and continuous random variables; distribution of functions of random variables; stochastic convergence and convergence of distribution functions; the law of large numbers and the central limit theorem. *Prerequisites: MATH 201. Annually.*
- STAT 234 Introduction to Statistical Inference 3.0; 3 cr.**  
 Sampling distribution; point and interval estimation; Neuman-Pearson theory of hypothesis testing; likelihood ratio test; sequential analysis; elementary decision theory. *Prerequisite: STAT 233 or consent of instructor. Annually.*
- STAT 235 Applied Regression Analysis 3.0; 3 cr.**  
 Straight line regression, multiple regression, analysis of variance and analysis of covariance, multiple and partial correlation; hypothesis testing; confounding, interaction and regression diagnostics; discriminant and factor analysis. *Prerequisite: STAT 234. Annually.*
- STAT 236 Sampling Techniques 3.0; 3 cr.**  
 Simple random, systematic, stratified, cluster, and two-stage sampling; estimation of parameters and properties of estimates; ratio and regression estimates; problem of non-response. *Prerequisite: STAT 234. Annually.*
- STAT 237 Applied Nonparametric Methods 3.0; 3 cr.**  
 Order statistics; sign test, Wilcoxon signed-rank test, and Mann-Whitney test; run test and test for randomness; goodness of fit tests; efficiency. *Prerequisite: STAT 234 or consent of instructor. Annually.*

**STAT 238 Applied Probability Models****3.0; 3 cr.**

Conditional probability and expectation; discrete and continuous time Markov chains; Chapman-Kolmogorov difference and differential equations; limiting probabilities; branching, Poisson, and birth and death processes; distribution of arrival times; queuing theory. *Prerequisite: STAT 233 or consent of instructor. Annually.*

**BA in Statistics****36 Credits in Statistics/Mathematics**

<b>Modes of Analysis</b>	<b>English and Arabic (9)</b>	<b>Humanities (12)</b>	<b>Economics and Social Sciences (9)</b>	<b>Sciences, Math, and Technology (9+18+9+3)</b>
Lecture Courses (9+12+9+39)	<ol style="list-style-type: none"> <li>Required Arabic courses (3): ARAB 201A or B, or any upper level course (3) as determined by placement</li> <li>Required English courses (usually 6): ENGL 203(3), 204(3) as determined by placement</li> </ol>	Required credits in the humanities: 12 credits including 6 credits from CVSP (see pp. 163–65)	<ol style="list-style-type: none"> <li>Required courses (3):</li> <li>Required Electives (6)<sup>1</sup></li> </ol>	<ol style="list-style-type: none"> <li>Required mathematics courses (9): MATH 201(3), 210(3), 219(3)</li> <li>Required statistics courses (18): STAT 233(3), 234(3), 235(3), 236(3), 237(3), 238(3)</li> <li>Elective MATH/STAT/CMPS (9): Courses numbered 210 and above, excluding STAT 230</li> <li>Required programming course (4): CMPS 200<sup>2</sup>(4)</li> </ol>
Seminar (0)				
Laboratory (1)				CMPS 200 <sup>2</sup> (4 hrs/week)
Research Project (0)				

<sup>1</sup> May be from the humanities.

<sup>2</sup> CMPS 200 is a 4-credit course with 3 lecture hours (3 credits) and 3–4 lab hours (1 credit) per week.

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## BS in Statistics

### 36 Credits in Statistics/Mathematics

Modes of Analysis	English and Arabic (9)	Humanities (12)	Economics and Social Sciences (3)	Sciences, Math, and Technology (9+18+9+3+9)
Lecture Courses (9+12+3+48)	<ol style="list-style-type: none"> <li>Required Arabic course (3): ARAB 201A or B, or any upper level course (3) as determined by placement</li> <li>Required English courses (6): ENGL 203(3), 204(3), as determined by placement</li> </ol>	Required credits in the humanities: 12 credits including 6 credits from CVSP (see pp. 163–65)	Required Courses (3)	<ol style="list-style-type: none"> <li>Required mathematics courses (9): MATH 201(3), 210(3), 219(3)</li> <li>Required statistics courses (18): STAT 233(3), 234(3), 235(3), 236(3), 237(3), 238(3)</li> <li>Elective MATH/STAT/CMPS (9): Courses numbered 210 and above, excluding STAT 230</li> <li>Required programming course (4): CMPS 200(4)</li> <li>Required science electives (9)</li> </ol>
Seminar (0)				
Laboratory (1)				CMPS 200(4 hrs/week)
Research Project (0)				

1 CMPS 200 is a 4-credit course with 3 lecture hours (3 credits) and 3–4 lab hours (1 credit) per week.

**THE REQUIREMENTS LISTED ABOVE APPLY TO STUDENTS WHO JOINED THEIR MAJOR AS OF OCTOBER 1, 2001–02. STUDENTS WHO JOINED A MAJOR PRIOR TO THAT DATE SHOULD CONSULT THE 2000–01 CATALOGUE.**

# Graduate Program

## MA or MS in Mathematics

In addition to the university requirements for graduate study in the Faculty of Arts and Sciences, students must complete at least 24 credits and a thesis. A minimum of 21 credits of the 24 must be at the graduate level, i.e., courses numbered 300 or above. These must include MATH 303, MATH 314, and MATH 341.

## MA or MS in Statistics

In addition to the university requirements for graduate study in the Faculty of Arts and Sciences, students must complete at least 24 credits and a thesis. A minimum of 21 credits must be at the graduate level, i.e., courses numbered 300 or above. At least 18 of the 24 credits must be taken in the department, and must include MATH 303, STAT 331, STAT 332, STAT 333, and STAT 334. Students interested in taking courses outside the department may do so after obtaining approval from the department.

## Graduate Courses

### Mathematics

**MATH 301/302 Graduate Tutorial Courses 1–3 cr.**

*Prerequisite: graduate standing or consent of instructor.*

**MATH 303 Measure and Integration 3.0; 3 cr.**

A first course in measure theory, including general properties of measures, construction of Lebesgue measure in  $\mathbb{R}^n$ , Lebesgue integration and convergence theorems,  $L_p$ -spaces, Hardy-Littlewood maximal function, Fubini's theorem, and convolutions. *Prerequisite: MATH 223.*

**MATH 304 Complex Analysis 3.0; 3 cr.**

A second course in complex analysis, covering the homotopy version of Cauchy's theorem, the open mapping theorem, maximum principle, Schwarz's lemma, harmonic functions, normal families, Riemann mapping theorem, Riemannian metrics, method of negative curvature, Picard's theorem, analytic continuation, monodromy, and modular function. *Prerequisite: MATH 227.*

**MATH 305 Functional Analysis 3.0; 3 cr.**

Vector spaces, Hamel basis, Hahn-Banach theorem, Banach spaces, continuous linear operators and functionals, Hilbert spaces, and weak topologies. *Prerequisite: MATH 223. Annually.*

**MATH 306 Calculus on Manifolds 3.0; 3 cr.**

*Prerequisite: MATH 223.*

**MATH 307 Topics in Analysis 3.0; 3 cr.**

**MATH 314 Algebraic Topology I 3.0; 3 cr.**

Closed surfaces, categories and functors, monodromy, the fundamental group functor, and covering spaces. *Prerequisites: MATH 214 and MATH 241. Annually.*

**MATH 315 Algebraic Topology II 3.0; 3 cr.**  
Singular homology with applications to Euclidean spaces and an introduction to cohomology theory. *Prerequisite: MATH 314. Annually.*

**MATH 316 Topics in Topology 3.0; 3 cr.**

**MATH 341 Modules and Rings 3.0; 3 cr.**  
Fundamental concepts of modules and rings, projective and injective modules, modules over a PID, Artinian and Noetherian modules and rings, modules with composition series, semi-simplicity, and tensor products. *Prerequisite: MATH 241. Annually.*

**MATH 342 Modules and Rings II 3.0; 3 cr.**  
A course covering more advanced topics in modules and rings. *Prerequisite: MATH 341. Annually.*

**MATH 343 Field Theory 3.0; 3 cr.**  
*Prerequisite: MATH 242.*

**MATH 344 Commutative Algebra 3.0; 3 cr.**  
*Prerequisites: MATH 242 and MATH 341.*

**MATH 345 Topics in Algebra 3.0; 3 cr.**

**MATH 350 Discrete Models for Differential Equations 3.1; 3 cr.**  
A detailed study of methods and tools used in deriving discrete algebraic systems of equations for ordinary and partial differential equations: finite difference and finite element discretization procedures; generation and decomposition of sparse matrices, finite-precision arithmetic, ill-conditioning and pre-conditioning, scalar, vector, and parallelized versions of the algorithms.

The course includes tutorial "immersion" sessions in which students become acquainted with state-of-the-art scientific software tools on standard computational platforms. *Prerequisite: Linear algebra and the equivalent of MATH/CMPS 251 (which can be taken concurrently) or consent of instructor. Same as CMPS 350. Annually.*

**MATH 351 Optimization and Non-Linear Problems 3.1; 3 cr.**  
A study of practical methods for formulating and solving numerical optimization problems that arise in science, engineering, and business applications. Newton's method for nonlinear equations and unconstrained optimization. Simplex and interior-point methods for linear programming. Equality and inequality-constrained optimization. Sequential Quadratic Programming. Emphasis is on algorithmic description and analysis. The course includes an implementation component where students develop software and use state-of-the-art numerical libraries. *Prerequisite: MATH/CMPS 350 or consent of instructor. Same as CMPS 351. Annually.*

**MATH 358 Introduction to Symbolic Computing 3.0; 3 cr.**  
Introductory topics in computer algebra and algorithmic number theory that includes fast multiplication of polynomials and integers, fast Fourier transforms, primality testing and integers factorization. Applications to cryptography and pseudo-random number generation. Linear algebra and polynomial factorization over finite fields. Applications to error-correcting codes. Introduction to Grobner bases. *Prerequisite: Good background in programming, linear algebra, discrete mathematics or consent of instructor. Same as CMPS 358. Annually.*

