# MATHEMATICS

# **Undergraduate Study**

For the undergraduate curriculum in liberal arts and sciences, major in mathematics, leading to the degree bachelor of science, see Liberal Arts and Sciences, Curriculum.

The program in mathematics offers training suitable for students planning to enter secondary school teaching, to work in mathematics and computation for industry or government, or to continue their studies in graduate school. Students may satisfy the major requirements in several ways, suitable for various career objectives. Graduates can construct rigorous arguments to demonstrate mathematical facts. They can communicate their mathematical methods to others and can justify their assumptions.

# **Traditional Program**

The traditional program of study for mathematics majors gives students a thorough grounding in mathematics. Graduates understand a broad range of mathematical topics and are familiar with a broad range of mathematical models. They have skills for solving problems in diverse situations. The program allows flexibility for specialization, and students are encouraged to steer their education according to career objectives.

This traditional program of study:

MATH 101	Orientation in Mathematics	1
MATH 165	Calculus I	4
MATH 166	Calculus II	4
MATH 201	Introduction to Proofs	3
MATH 265	Calculus III	4
MATH 317	Theory of Linear Algebra	3-4
or MATH 407	Applied Linear Algebra	
MATH 301	Abstract Algebra I	3
MATH 414	Analysis I	3
MATH 266	Elementary Differential Equations	3-4
or MATH 267	Elementary Differential Equations and Laplace Transforms	
One of the followi	ng:	2
MATH 492	Undergraduate Seminar	
C I 480C	Pre-Student Teaching Experience III: Mathematics	
Additional Mather	matics courses at the 300 level or above	15
Total Credits		45-4
<sup>1</sup> C I 480C is available only for students seeking secondary school certification.		
The courses liste	d above must include one of the sequences:	
MATH 301 Abstract Algebra I		6

I	MATH 301	Abstract Algebra I	6
8	& MATH 302	and Abstract Algebra II	
۱ ۶	MATH 373 & MATH 481	Introduction to Scientific Computing and Numerical Methods for Differential Equations	6
8	MATH 304 & MATH 314	Combinatorics and Graph Theory	6

MATH 414	Analysis I	6
& MATH 415	and Analysis II	
MATH 435	Geometry I	6
& MATH 436	and Geometry II	

# **Communication Proficiency requirement:**

Eľ	NGL 150	Critical Thinking and Communication <sup>2</sup>	3
0	ne of the followi	ng:	3
	ENGL 250	Written, Oral, Visual, and Electronic Composition <sup>2</sup>	
	ENGL 250H	Written, Oral, Visual, and Electronic Composition: Honors <sup>2</sup>	
0	ne of the followi	ng:	3
	MATH 491	Undergraduate Thesis <sup>3</sup>	
	ENGL 302	Business Communication	
	ENGL 305	Creative Writing: Nonfiction	
	ENGL 309	Proposal and Report Writing	
	ENGL 314	Technical Communication	
	JL MC 201	Reporting and Writing for the Mass Media	
2			

<sup>2</sup> The department requires a grade of C- or better.

<sup>3</sup> With departmental approval.

# **Mathematics Plus**

The Mathematics Plus option is for students who wish to establish a clear strength in a field of application of mathematics. They obtain the mathematics major by pursuing study of mathematics, through the upper division level, complementary to their application area. This program makes double majors more feasible and is appropriate for students who plan on employment or graduate study in the application field. It is not intended for students who plan on graduate study in mathematics. For more information, see the mathematics department web site or consult an adviser in mathematics.

# **Secondary Education**

For certification requirements for teaching of mathematics in grades 5-12, see the Mathematics Department and School of Education web sites or consult an adviser.

# Recommendations

The department strongly recommends that each student majoring in mathematics include in the program substantial supporting work beyond the minimum general education requirement of the college in one or more areas of application of mathematics, such as other mathematical sciences, engineering, natural science, or social science. Particularly 7 useful are:

COM S 207	Fundamentals of Computer Programming	3
COM S 208	Intermediate Computer Programming	3
PHYS 221	Introduction to Classical Physics I	5
PHYS 222	Introduction to Classical Physics II	5
STAT 341	Introduction to the Theory of Probability and Statistics I	3
STAT 342	Introduction to the Theory of Probability and Statistics II	3

It also recommends that students contemplating graduate study in mathematics acquire a reading knowledge of French, German, or Russian.

# **Credits Not Counted**

Credits earned in the following cannot be counted toward graduation by mathematics majors:

MATH 104	Introduction to Probability	3
MATH 105	Introduction to Mathematical Ideas	3
MATH 140	College Algebra	3
MATH 143	Preparation for Calculus	4
MATH 145	Applied Trigonometry	3
MATH 150	Discrete Mathematics for Business and Social Sciences	3
MATH 151	Calculus for Business and Social Sciences	3
MATH 160	Survey of Calculus	4
MATH 181	Calculus and Mathematical Modeling for the Life Sciences I	4
MATH 182	Calculus and Mathematical Modeling for the Life Sciences II	4
MATH 195	Mathematics for Elementary Education I	3
MATH 196	Mathematics for Elementary Education II	3

# **Minor in Mathematics**

The department offers a minor in mathematics, which may be earned by credit in the following:

MATH 201	Introduction to Proofs	3
MATH 265	Calculus III	4
MATH 301	Abstract Algebra I	3
One of the following		
MATH 266	Elementary Differential Equations	3
MATH 267	Elementary Differential Equations and Laplace Transforms	4
One of the following		
MATH 317	Theory of Linear Algebra	4
MATH 407	Applied Linear Algebra	3

# With 5-12 Teacher Certification

Freshman		
Fall	Credits Spring	Credits
ENGL 150	3 MATH 166	4
LIB 160	1 STAT 201	4
MATH 101	1 C I 204	3
MATH 165	4 C I 219	1
PSYCH 230	3 C I 280L	0.5
General Education	6 General Education	6
	18	18.5
Sophomore		
Fall	Credits Spring	Credits
MATH 201	3 MATH 266 or 267 - Differential Equations	3-4
MATH 265	4 MATH 317	4
ENGL 250	3 C I 333	3
C I 202	3 COM S 107 or 207 - Programming	3
General Education	4 General Education	3

Take Praxis-I by October 1	2.5 GPA for Admission to	
	Teacher Ed	
	17	16-17
Junior		
Fall	Credits Spring	Credits
MATH 301	3 MATH 342 <sup>2</sup>	3
MATH 341	3 MATH 397	3
MATH 435	3 MATH 436	3
C I 406	3 C I 280A	2
Communication Choice <sup>1</sup>	3 C I 426	3
General Education	3 C I 395	3
	18	17
Senior		
Fall	Credits Spring	Credits
MATH 414	3 C I 417C	14
MATH 497	3	
C I 480C	2	
SP ED 401	3	
General Education	4	
	15	14

# Total Credits: 133.5-134.5

Students in all ISU majors must complete a three-credit course in U.S. diversity and a three-credit course in international perspectives. Check (http://www.registrar.iastate.edu/courses/div-ip-guide.html) for a list of approved courses. Discuss with your adviser how the two courses that you select can be applied to your graduation plan.

LAS majors require a minimum of 120 credits, including a minimum of 45 credits at the 300/400 level. Three of the required 45 300+ level credits must be earned in a general education group outside the group of your major. You must also complete the LAS foreign language requirement and any high school unmet admissions requirements.

Students pursuing licensure to teach grades 5 - 12 must meet the general education and professional teacher education requirements established by the University Teacher Education Program. (Check http://www.education.iastate.edu/te/) for the requirements.

- <sup>1</sup> ENGL 302, 305, 309, or 314, or JL MC 201.
- <sup>2</sup> Recommended

Without Teacher Certification

Freshman		
Fall	Credits Spring	Credits
MATH 101	1 MATH 166	4
MATH 165	4 General Education/ Electives/Foreign Language	11
ENGL 150	3	
LIB 160	1	
General Education/ Electives/Foreign Languag	6 Je	
	15	15
Sophomore		
Fall	Credits Spring	Credits
MATH 201	3 MATH 267	4

MATH 265	4 MATH 317	4
ENGL 250	3 General Education/Electives	7
General Education/Electives	5	
	15	15
Junior		
Fall	Credits Spring	Credits
MATH 301	3 MATH 302 <sup>2,3</sup>	3
MATH 414	3 MATH 415 <sup>2,3</sup>	3
Communication Choice <sup>1</sup>	3 General Education/Electives	9
General Education/Electives	6	
	15	15
Senior		
Fall	Credits Spring	Credits
Mathematics Choice, Level 300+	3 Mathematics Choice, Level 300+	3
Mathematics Choice, Level 300+	3 MATH 492	2
General Education/Electives	9 General Education/Electives	10
	15	15
T . Lo. 1. 100		

Total Credits: 120

Students in all ISU majors must meet the U.S. Diversity and the International Perspectives requirements. Check (http:// www.registrar.iastate.edu/courses/div-ip-guide.html) for a list of approved courses. These courses may be courses that apply to other requirements.

The LAS General Education requirements for Mathmatics majors are 12 credits Arts and Humanities, 8 credits Natural Science, and 9 credits Social Science from the approved lists available on the Liberal Arts and Sciences web site.

LAS majors require a minimum of 120 credits, including a minimum of 45 credits at the 300/400 level. Three of the required 45 300+ level credits must be earned in a general educational group outside the group of the major. Students must also meet the LAS foreign-language requirement and complete any unmet admission requirements.

- <sup>1</sup> ENGL 302, 305, 309, or 314, or JL MC 201.
- Or other mathematics choice at the 300+ level.But the program must include MATH 301, MATH 414, and one of the two-course sequences 301, 302; 304, 314; 373, 481; 414, 415; or 435, 436.
- <sup>3</sup> Available Spring semester only.

# **Graduate Study**

The department offers programs leading to a Master of Science or Doctor of Philosophy degree in mathematics or applied mathematics, as well as minor work for students whose major is in another department. The department also offers a program leading to the degree of Master of School Mathematics (M.S.M.).

Students desiring to undertake graduate work leading to the M.S. or Ph.D. degree should prepare themselves by taking several upper division mathematics courses. It is desirable that these credits include introduction to analysis and abstract algebra.

The M.S. degree requires a student to take at least 30 credit hours and to write a creative component or thesis.Additionally, students must pass a comprehensive oral examination over their coursework and their creative

component or thesis. See the online Mathematics Graduate Handbook for specific requirements.

The Ph.D. degree requires a student to take 48 credit hours of coursework in addition to research hours, pass written qualifying examinations, pass an oral preliminary exam, and perform an original research project culminating in a dissertation which is defended by an oral exam. Ph.D. candidates must have at least one year of supervised teaching experience. See the on-line Mathematics Graduate Handbook for specific requirements.

The M.S.M. degree is primarily for in-service secondary mathematics teachers. Students desiring to pursue the M.S.M degree should present some undergraduate work in mathematics beyond calculus. Candidates for the M.S.M. degree must write an approved creative component and pass a comprehensive oral examination over their course work and their creative component.

# Courses primarily for undergraduates:

#### MATH 010: High School Algebra

(4-0) Cr. 0. F.S.

For students who do not have adequate facility with topics from high school algebra or do not meet the algebra admission requirement. The course is divided into tracks of one- and two-semester lengths. For most students a diagnostic exam will determine which track must be taken. Students will receive a grade in MATH 25 or MATH 30 respectively depending on the level of material covered. Satisfactory completion of MATH 30 is recommended for students planning to take MATH 140, MATH 143, MATH 145, MATH 150, or MATH 151, while MATH 25 is sufficient for MATH 104, MATH 105, MATH 195, STAT 101 or STAT 105. Students must complete MATH 30 to remove a deficiency in the algebra admission requirement. Topics include signed numbers, polynomials, rational and radical expressions, exponential and logarithmic expressions, and equations. Offered on a satisfactory-fail basis only.

### MATH 025: High School Algebra

(4-0) Cr. 0. F.S.

Students should initially enroll in MATH 10. See description of MATH 10. Offered on a satisfactory-fail basis only.

### MATH 030: High School Algebra

(4-0) Cr. 0. F.S.

Students should initially enroll in MATH 10. See description of MATH 10. Offered on a satisfactory-fail basis only.

#### MATH 101: Orientation in Mathematics

#### (1-0) Cr. 1. F.S.

For new majors. Academic policies and procedures. Campus resources and opportunities available to students. Careers and programs of study in mathematics. Mathematical reasoning, culture and resources. Description of main branches of mathematics. Offered on a satisfactoryfail basis only.

# MATH 104: Introduction to Probability

(3-0) Cr. 3. F.S.SS.

Prereq: Satisfactory performance on placement assessment, 2 years of high school algebra, 1 year of high school geometry

Permutations, combinations, probability, expected value, and applications. Either MATH 104 or MATH 150 may be counted toward graduation, but not both.

#### MATH 105: Introduction to Mathematical Ideas

(3-0) Cr. 3. F.S.SS.

Prereq: Satisfactory performance on placement assessment, 2 years of high school algebra, 1 year of high school geometry.

Introduction to contemporary mathematics with an emphasis on use of mathematics to solve real world problems. Typical topics are the mathematics of voting, methods of fair division and apportionment, and elementary game theory.

#### MATH 140: College Algebra

#### (3-1) Cr. 3. F.S.SS.

Prereq: Satisfactory performance on placement assessment, 2 years of high school algebra, 1 year of high school geometry; or MATH 30.

Coordinate geometry, quadratic and polynomial equations, functions, graphing, rational functions, exponential and logarithmic functions, inverse functions, quadratic inequalities. Students in the College of Liberal Arts and Sciences may not count MATH 140 toward the General Education Requirements.

#### MATH 143: Preparation for Calculus

#### (4-0) Cr. 4. F.S.

Prereq: Satisfactory performance on placement assessment, 2 years of high school algebra, 1 year of high school geometry; or MATH 140.

Preparation for MATH 160, 165, and 181. Functions, graphing, basic trigonometry, logarithms, exponentials. Emphasis on co-variational reasoning. Students in the College of Liberal Arts and Sciences may not count MATH 143 toward General Education Requirements. Only one of MATH 143 and 145 may count toward graduation.

#### MATH 145: Applied Trigonometry

#### (3-0) Cr. 3. F.S.

Prereq: Satisfactory performance on placement assessment, 2 years of high school algebra, 1 year of high school geometry; or minimum of C- in MATH 140.

Mathematical ideas regarding the conception of space. General trigonometry, with an emphasis on the calculation of lengths, areas, and angles. The Law of Sines and the Law of Cosines. Polar, cylindrical, and spherical coordinate systems. Conic sections and quadric surfaces. Students in the College of Liberal Arts and Sciences may not count Math 145 toward the General Education Requirements. Only one of Math 143 and 145 may count toward graduation.

# MATH 150: Discrete Mathematics for Business and Social Sciences (2-1) Cr. 3. F.S.SS.

Prereq: Satisfactory performance on placement assessment, 2 years of high school algebra, 1 year of high school geometry

Linear equations and inequalities, matrix algebra, linear programming, discrete probability. Either MATH 104 or MATH 150 may be counted toward graduation, but not both.

#### MATH 151: Calculus for Business and Social Sciences

#### (2-1) Cr. 3. F.S.SS.

Prereq: Satisfactory performance on placement assessment, 2 years of high school algebra, 1 year of high school geometry

Differential calculus, applications to max-min problems, integral calculus and applications. Will not serve as prerequisite for MATH 265 or MATH 266. Only one of MATH 151, MATH 160, the sequence MATH 165-MATH 166, or the sequence MATH 181-MATH 182 may be counted towards graduation.

#### MATH 160: Survey of Calculus

#### (4-0) Cr. 4. F.S.

Prereq: Satisfactory performance on placement assessment, 2 years of high school algebra, 1 year of geometry; or MATH 143

Analytic geometry, derivatives and integrals of elementary functions, simple differential equations, and applications. Will not serve as a prerequisite for MATH 265 or MATH 266. Only one of MATH 151, MATH 160, the sequence MATH 165-MATH 166, or the sequence MATH 181-MATH 182 may be counted towards graduation.

# MATH 165: Calculus I

#### (4-0) Cr. 4. F.S.SS.

Prereq: Satisfactory performance on placement assessment, 2 years of high school algebra, 1 year of geometry, 1 semester of trigonometry; or MATH 143 Differential calculus, applications of the derivative, introduction to integral calculus. Only one of Math 151 or 160 or the sequence MATH 165-MATH 166, or the sequence MATH 181-MATH 182 may be counted towards graduation.

### MATH 166: Calculus II

#### (4-0) Cr. 4. F.S.SS.

Prereq: Minimum of C- in MATH 165 or high math placement scores Integral calculus, applications of the integral, infinite series, parametric curves and polar coordinates. Only one of MATH 151, MATH 160, the sequence MATH 165-MATH 166, or the sequence MATH 181-MATH 182 may be counted towards graduation.

# MATH 166H: Calculus II, Honors

#### (4-0) Cr. 4. F.

Prereq: Permission of instructor and MATH 165 or high math placement scores

Integral calculus, applications of the integral, infinite series, parametric curves, and polar coordinates. Additional material of a theoretical, conceptual, computational, or modeling nature. Some of the work may require more ingenuity than is required for MATH 166. Preference will be given to students in the University Honors Program. Only one of MATH 151 or MATH 160, the sequence MATH 165-MATH 166, or the sequence MATH 181-MATH 182 may be counted towards graduation.

# MATH 181: Calculus and Mathematical Modeling for the Life Sciences I (4-0) Cr. 4. F.S.

Prereq: Satisfactory performance on placement assessment, 2 years of high school algebra, 1 year of high school geometry, 1 semester of trigonometry; or MATH 143

Exponential and logarithm functions, difference equations, derivatives, and applications of the derivative. Examples taken from biology. Only one of MATH 151, MATH 160, the sequence MATH 165- MATH 166, or the sequence MATH 181-MATH 182 may be counted towards graduation.

# MATH 182: Calculus and Mathematical Modeling for the Life Sciences II (4-0) Cr. 4. S.

#### Prereq: MATH 181

Integration, first and second order differential equations, applications of the definite integral, introduction to multivariable calculus. Examples taken from biology. Only one of MATH 151, MATH 160, the sequence MATH 165-MATH 166, or the sequence MATH 181-MATH 182 may be counted towards graduation.

#### MATH 195: Mathematics for Elementary Education I

(2-2) Cr. 3. F.S.

Prereq: Satisfactory performance on placement assessment, 2 years high school algebra, 1 year of high school geometry, enrollment in elementary education or early childhood education

Whole number operations through analysis of properties, theoretical and hands-on models, mathematical analysis of elementary students' thinking, standard and non-standard algorithms; structure of the decimal system; linear measurement, and two- and three-dimensional geometric shapes and spatial sense, number theory, algebra as it relates to elementary curricula/teaching profession. Students in the College of Liberal Arts and Sciences may not count MATH 195 toward General Education Requirements.

#### MATH 196: Mathematics for Elementary Education II

(2-2) Cr. 3. F.S.

# Prereq: Minimum of C- in MATH 195 and enrollment in elementary education or early childhood education.

Integer, fraction and decimal operations through analysis of properties, theoretical and hands-on models, mathematical analysis of elementary students' thinking, standard and non-standard algorithms: two- and threedimensional measurement; probability, statistics, proportional reasoning, algebra as it relates to elementary curricula and teaching profession.

#### MATH 201: Introduction to Proofs

(3-0) Cr. 3. F.S.

# Prereq: MATH 166 or MATH 166H

Logic and techniques of proof including induction. Communicating mathematics. Writing proofs about sets, functions, real numbers, limits, sequences, infinite series and continuous functions.

#### MATH 207: Matrices and Linear Algebra

(3-0) Cr. 3. F.S.SS.

#### Prereq: 2 semesters of calculus

Systems of linear equations, determinants, vector spaces, linear transformations, orthogonality, least-squares methods, eigenvalues and eigenvectors. Emphasis on applications and techniques. Only one of MATH 207 and MATH 317 may be counted toward graduation.

#### MATH 265: Calculus III

(4-0) Cr. 4. F.S.SS.

*Prereq: Minimum of C- in MATH 166 or MATH 166H* Analytic geometry and vectors, differential calculus of functions of several variables, multiple integrals, vector calculus.

#### MATH 265H: Calculus III, Honors

#### (4-0) Cr. 4. F.S.

Prereq: Permission of the instructor; and MATH 166 or MATH 166H Analytic geometry and vectors, differential calculus of functions of several variables, multiple integrals, vector calculus. Additional material of a theoretical, conceptual, computational, or modeling nature. Some of the work may require more ingenuity than is required in MATH 265. Preference will be given to students in the University Honors Program.

#### MATH 266: Elementary Differential Equations

(3-0) Cr. 3. F.S.SS.

Prereq: Minimum of C- in MATH 166 or MATH 166H

Solution methods for ordinary differential equations. First order equations, linear equations, constant coefficient equations. Eigenvalue methods for systems of first order linear equations. Introduction to stability and phase plane analysis.

# MATH 267: Elementary Differential Equations and Laplace Transforms (4-0) Cr. 4. F.S.SS.

*Prereq: Minimum of C- in MATH 166 or MATH 166H* Same as MATH 266 but also including Laplace transforms and series solutions to ordinary differential equations.

#### MATH 268: Laplace Transforms

(1-0) Cr. 1. F.S.SS. Prereg: MATH 266

Laplace transforms and series solutions to ordinary differential equations. Together, MATH 266 and MATH 268 are the same as MATH 267.

# MATH 269: Systems of Differential Equations

(1-0) Cr. 1. F.S.SS.

Prereq: Familiarity with ordinary differential equations of first and second order, permission of department.

Systems portion of MATH 266 and MATH 267: Eigenvalue methods for systems of first order linear equations. Introduction to stability and phase plane analysis. For students supplementing transfer courses in differential equations in order to earn credit in MATH 266 or 267. Students with credit in 266 or 267 may not earn credit in 269.

#### MATH 290: Independent Study

Cr. 1-3. Repeatable. *Prereq: Permission of the instructor.* Independent study.

#### MATH 290H: Independent Study, Honors

Cr. 1-3. Repeatable. *Prereq: Permission of the instructor.* Independent study.

#### MATH 297: Intermediate Topics for School Mathematics

(2-2) Cr. 3. F.

Prereq: Enrollment in elementary education and minimum of C- in MATH 196 Mathematical reasoning and topics in Euclidean and non-Euclidean geometry including transformations, congruence, and similarity. Exploration of probability with simulations. Use of technology to learn and teach mathematics.

#### MATH 301: Abstract Algebra I

(3-0) Cr. 3. F.S. Prereq: MATH 166 or MATH 166H, MATH 317 or MATH 407, and grade of C- or better in MATH 201

Theory of groups. Homomorphisms. Quotient groups. Introduction to rings. Emphasis on writing proofs.

#### MATH 302: Abstract Algebra II

(3-0) Cr. 3. S. *Prereq: MATH 301* Theory of rings and fields. Introduction to Galois theory. Emphasis on writing proofs.

#### MATH 304: Combinatorics

(3-0) Cr. 3. F.

Prereq: MATH 166 or MATH 166H; MATH 201 or experience with proofs Enumeration strategies involving permutations, combinations, partitions, binomial coefficients, inclusion-exclusion principle, recurrence relations, generating functions. Additional topics selected from probability, algebraic combinatorics, and applications.

# MATH 314: Graph Theory

#### (3-0) Cr. 3. S.

Prereq: MATH 166 or MATH 166H; MATH 201 or experience with proofs Structure and extremal properties of graphs. Topics are selected from: trees, networks, colorings, paths and cycles, connectivity, planarity, directed graphs, matchings, Ramsey theory, forbidden structures, enumeration, applications.

### MATH 317: Theory of Linear Algebra

#### (4-0) Cr. 4. F.S.

#### Prereq: Credit or enrollment in MATH 201

Systems of linear equations, determinants, vector spaces, inner product spaces, linear transformations, eigenvalues and eigenvectors. Emphasis on writing proofs and results. Only one of MATH 207 and MATH 317 may be counted toward graduation.

#### MATH 331: Topology

(3-0) Cr. 3. Alt. F., offered even-numbered years. *Prereq: MATH 301* 

Set theory, metric spaces, topological spaces, continuity, connectedness, functions, homeomorphisms, compactness, and topological invariants. Examples from surfaces, knots, and various abstract objects. Emphasis on writing proofs.

# MATH 341: Introduction to the Theory of Probability and Statistics I

(Cross-listed with STAT). (3-0) Cr. 3. F.S.

Prereq: MATH 265 (or MATH 265H)

Probability; distribution functions and their properties; classical discrete and continuous distribution functions; multivariate probability distributions and their properties; moment generating functions; simulation of random variables and use of the R statistical package. Credit for both STAT 341 and STAT 447 may not be applied toward graduation.

# MATH 342: Introduction to the Theory of Probability and Statistics II

(Cross-listed with STAT). (3-0) Cr. 3. F.S.

Prereq: STAT 341; MATH 207 or MATH 317

Transformations of random variables; sampling distributions; confidence intervals and hypothesis testing; theory of estimation and hypothesis tests; linear model theory; use of the R statistical package for simulation and data analysis.

# MATH 350: Number Theory

(Cross-listed with COM S). (3-0) Cr. 3. S. Prereq: MATH 201 or COM S 230

Divisibility, integer representations, primes and divisors, linear diophantine equations, congruences, and multiplicative functions. Applications to cryptography.

# MATH 365: Complex Variables with Applications

(3-0) Cr. 3. S.

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Prereq: MATH 265
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Functions of a complex variable, including differentiation, integration and series expansions, residues, evaluation of integrals, conformal mapping.

# MATH 373: Introduction to Scientific Computing

# (3-0) Cr. 3. F.

Prereq: MATH 265

Vector and matrix programming and graphing in MATLAB for scientific applications. Polynomial interpolation and approximation. Systems of linear equations and numerical linear algebra. Numerical differentiation and integration. Newton methods for solving nonlinear equations and optimization in one and several variables. Fast Fourier transform. Emphasis on effective use of mathematical software and understanding of its strengths and limitations.

# MATH 385: Introduction to Partial Differential Equations

#### (3-0) Cr. 3. F.S.

Prereq: MATH 265 and one of MATH 266, MATH 267

Separation of variables methods for elliptic, parabolic, and hyperbolic partial differential equations. Topics from Fourier series, Sturm-Liouville theory, Bessel functions, spherical harmonics, and method of characteristics.

# MATH 397: Teaching Secondary Mathematics Using University Mathematics

(2-2) Cr. 3. S. Prereq: MATH 201, MATH 301

Coursework in university mathematics including calculus, abstract algebra, discrete mathematics, geometry, and other topics as it relates to teaching mathematics in grades 5-12.

### MATH 398: Cooperative Education

Cr. R. Repeatable, maximum of 2 times. F.S.SS.

Prereq: Permission of the department cooperative education coordinator; junior classification

Required of all cooperative education students. Students must register for this course prior to commencing each work period.

# MATH 407: Applied Linear Algebra

(Dual-listed with MATH 507). (3-0) Cr. 3. F.

Prereq: MATH 207 or MATH 317

Advanced topics in applied linear algebra including eigenvalues, eigenvalue localization, singular value decomposition, symmetric and Hermitian matrices, nonnegative and stochastic matrices, matrix norms, canonical forms, matrix functions. Applications to mathematical and physical sciences, engineering, and other fields.

# MATH 414: Analysis I

(3-0) Cr. 3. F.S.SS. *Prereq: Minimum of C- in MATH 201* A careful development of calculus of functions of one real variable: real number properties, sequences and series, limits, continuity, differentiation, and integration.

#### MATH 415: Analysis II

#### (3-0) Cr. 3. S.

Prereq: MATH 414; MATH 265; and MATH 317 or MATH 407 Sequences and series of functions of a real variable, uniform convergence, power series and Taylor series, Fourier series, topology of n-dimensional space, implicit function theorem, calculus of the plane and 3-dimensional space. Additional topics may include metric spaces or Stieltjes or Lebesgue integration.

#### MATH 421: Logic for Mathematics and Computer Science

(Cross-listed with COM S). (3-0) Cr. 3. S. *Prereq: MATH 301 or MATH 207 or MATH 317 or COM S 230* Propositional and predicate logic. Topics selected from Horn logic, equational logic, resolution and unification, foundations of logic programming, reasoning about programs, program specification and verification, model checking and binary decision diagrams, temporal logic and modal logic.

### MATH 424: Introduction to High Performance Computing

(Cross-listed with COM S, CPR E). (2-2) Cr. 3. F. *Prereq: MATH 265; MATH 207 or MATH 317* Numerical serial and parallel computing using the Message Passing Interface. Oral and written semester project.

#### MATH 435: Geometry I

(3-0) Cr. 3. F. *Prereq: MATH 207 or MATH 317* Euclidean geometry. Points, lines, circles, triangles, congruence, similarity, properties invariant under rigid motions. Synthetic, analytic, and axiomatic methods.

#### MATH 436: Geometry II

(3-0) Cr. 3. S. *Prereq: MATH 435* Continuation of Euclidean geometry with topics from elliptic, projective, or hyperbolic geometry. Emphasis on analytic methods.

# MATH 439: Mathematics of Fractals and Chaos

(3-0) Cr. 3. Alt. F., offered odd-numbered years. *Prereq: MATH 265 and either MATH 266 or MATH 267* Iteration of maps; classification of periodic points; Julia sets and the Mandelbrot set; fractals and fractal dimension; chaos.

#### MATH 474: Mathematics of Finance

(3-0) Cr. 3. S.

Prereq: MATH 265; STAT 101 or 104 or 105 or 201 or 226.

Applications of mathematical methods to problems in finance. Lagrange Multiplier Method, applications to mean-variance portfolio selection and utility maximization, binomial asset pricing model. Binary Martingales, Optional Stopping Theorem, Central Limit Theorem, applications to financial derivative pricing.

#### MATH 481: Numerical Methods for Differential Equations

(Cross-listed with COM S). (3-0) Cr. 3. S.

Prereq: MATH 265 and either MATH 266 or MATH 267; knowledge of a programming language

First order Euler method, high order Runge-Kutta method, and multistep method for solving ordinary differential equations. Finite difference and finite element methods for solving partial differential equations. Local truncation error, stability, and convergence for finite difference method. Numerical solution space, polynomial approximation, and error estimate for finite element method.

#### MATH 490: Independent Study

Cr. 1-3. Repeatable, maximum of 9 credits.

Prereq: Permission of instructor.

No more than 9 credits of Math 490 or Math 490H may be counted toward graduation.

#### MATH 490H: Independent Study: Honors

Cr. 1-3. Repeatable, maximum of 9 credits. *Prereq: Permission of the instructor.* 

No more than 9 credits of Math 490 or 490H may be counted toward graduation.

#### MATH 491: Undergraduate Thesis

Cr. 2-3.

Writing and presenting a formal mathematics paper. Upon approval by the department, the paper will satisfy the departmental advanced English requirement.

#### MATH 492: Undergraduate Seminar

(2-0) Cr. 2. F.S.

Prereq: MATH 317 or MATH 407

Introduction to independent mathematical thought, with emphasis on oral communication of an advanced topic. Seminar content varies.

#### MATH 497: Teaching Secondary School Mathematics

(Cross-listed with C I). (3-0) Cr. 3. F.

Prereq: 15 credits in college mathematics and admission to a teacher licensure program, concurrent enrollment in C I 426 or C I 526; C I 480C Theory and methods for teaching mathematics in grades 5-12. Includes critical examination of instructional strategies, curriculum materials, learning tools, assessment methods, Common Core State Standards-Mathematics, and equity issues.

# MATH 498: Cooperative Education

Cr. R. Repeatable, maximum of 2 credits. F.S.SS.

Prereq: Permission of the department cooperative education coordinator; senior classification

Required of all cooperative education students. Students must register for this course prior to commencing each work period.

# Courses primarily for graduate students, open to qualified undergraduates:

#### MATH 501: Introduction to Real Analysis

(3-0) Cr. 3. F.

Prereq: MATH 265 and (MATH 207 or MATH 317) A development of the real numbers. Study of metric spaces, completeness, compactness, sequences, and continuity of functions. Differentiation and integration of real-valued functions, sequences of functions, limits and convergence, equicontinuity.

### MATH 502: Topology

(3-0) Cr. 3. S.

Prereq: MATH 414 or MATH 501 Introduction to general topology. Topological spaces, continuous functions, connectedness, compactness. Topics selected from countability and separation axioms, metrization, and complete metric spaces. Topics in algebraic topology.

# MATH 504: Abstract Algebra I

(3-0) Cr. 3. F. *Prereq: MATH 302* Algebraic systems and their morphisms, with emphasis on groups and rings.

# MATH 505: Abstract Algebra II

(3-0) Cr. 3. S.

Prereq: MATH 504

Continuation of Math 504. Algebraic systems and their morphisms, with emphasis on modules and fields.

#### MATH 507: Applied Linear Algebra

(Dual-listed with MATH 407). (3-0) Cr. 3. F. *Prereq: MATH 207 or MATH 317* 

Advanced topics in applied linear algebra including eigenvalues, eigenvalue localization, singular value decomposition, symmetric and Hermitian matrices, nonnegative and stochastic matrices, matrix norms, canonical forms, matrix functions. Applications to mathematical and physical sciences, engineering, and other fields.

# MATH 510: Linear Algebra

(3-0) Cr. 3. F.

Prereq: MATH 317 or MATH 407 or (MATH 207 and one of MATH 301 or MATH 414)

Advanced topics in linear algebra including canonical forms; unitary, normal, Hermitian and positive-definite matrices; variational characterizations of eigenvalues.

#### MATH 511: Functions of a Single Complex Variable

(3-0) Cr. 3. S.

#### Prereq: MATH 414 or MATH 501

Theory of analytic functions, integration, topology of the extended complex plane, singularities and residue theory, maximum principle, conformal mapping, meromorphic functions, argument principle.

#### MATH 515: Real Analysis I

(3-0) Cr. 3. F.

Prereq: MATH 414 or MATH 501

Lebesgue measure and Lebesgue integral, one variable differentiation theory, Fubini and Tonelli theorems in R<sup>A</sup>n, Lp spaces.

#### MATH 516: Real Analysis II

(3-0) Cr. 3. S. *Prereq: MATH 515* Metric spaces, topological spaces, compactness, abstract theory of measure and integral, differentiation of measures, Banach spaces.

#### MATH 517: Finite Difference Methods

(3-0) Cr. 3. S.

#### Prereq: MATH 481 or MATH 561

Finite difference methods for partial differential equations. Methods for elliptic equations; explicit and implicit methods for parabolic and hyperbolic equations; stability, accuracy, and convergence theory, including von Neumann analysis, modified equations, and the Courant-Friedrichs-Lewy condition.

#### MATH 519: Methods of Applied Mathematics I

(3-0) Cr. 3. F.

# Prereq: MATH 414 or MATH 501

Techniques of classical and functional analysis with applications to differential equations and integral equations. Vector spaces, metric spaces, Hilbert and Banach spaces, Sobolev spaces and other function spaces, contraction mapping theorem, distributions, Fourier series and Fourier transform, linear operators, spectral theory of differential and integral operators, Green's functions and boundary value problems, weak solutions of partial differential equations and variational methods, calculus in Banach spaces and applications.

#### MATH 520: Methods of Applied Mathematics II

(3-0) Cr. 3. S. *Prereq: MATH 519* Continuation of Math 519.

# MATH 525: Numerical Analysis of High Performance Computing

(Cross-listed with COM S, CPR E). (3-0) Cr. 3. S. Prereq: CPR E 308 or MATH 481; experience in scientific programming; knowledge of FORTRAN or C

Introduction to parallelization techniques and numerical methods for distributed memory high performance computers. A semester project in an area related to each student's research interests is required.

# MATH 533: Cryptography

(Cross-listed with CPR E, INFAS). (3-0) Cr. 3. S. *Prereq: MATH 301 or CPR E 310 or COM S 330* Basic concepts of secure communication, DES and AES, public-key cryptosystems, elliptic curves, hash algorithms, digital signatures, applications. Relevant material on number theory and finite fields.

#### MATH 535: Steganography and Digital Image Forensics

(Cross-listed with CPR E, INFAS). (3-0) Cr. 3. Alt. S., offered evennumbered years.

Prereq: E E 524 or MATH 317 or MATH 407 or COM S 330

Basic principles of covert communication, steganalysis, and forensic analysis for digital images. Steganographic security and capacity, matrix embedding, blind attacks, image forensic detection and device identification techniques. Related material on coding theory, statistics, image processing, pattern recognition.

# MATH 540: Seminar in Mathematics Education

(1-0) Cr. 1. SS.

# Prereq: Enrollment in the Master of School Mathematics program or professional studies in education

Research studies in mathematics learning and teaching, exemplary practices in mathematics education, and current state and national trends in the mathematics curriculum in grades K-12. Students in MSM take each of 540A, 540B, and 540C. Topics are offered on a 3-year cycle. A. Assessment, equity, and teaching of statistics. Offered SS 2017. B. Geometry and discrete mathematics, and problem solving. Offered SS 2018. C. Teaching of analysis, algebra, and the use of technology. Offered SS 2016.

# MATH 540A: Seminar in Mathematics Education: Assessment, equity, and teaching of statistics.

(1-0) Cr. 1.

Prereq: Enrollment in the Master of School Mathematics program or professional studies in education

Research studies in mathematics learning and teaching, exemplary practices in mathematics education, and current state and national trends in the mathematics curriculum in grades K-12. Topics are offered on a 3-year cycle. Offered SS 2017.

# MATH 540B: Seminar in Mathematics Education: Geometry and discrete mathematics, and problem solving.

(1-0) Cr. 1.

Prereq: Enrollment in the Master of School Mathematics program or professional studies in education

Research studies in mathematics learning and teaching, exemplary practices in mathematics education, and current state and national trends in the mathematics curriculum in grades K-12. Offered on a 3-year cycle. Offered SS 2018.

# MATH 540C: Seminar in Mathematics Education: Teaching of analysis, algebra, and the use of technology.

(1-0) Cr. 1.

Prereq: Enrollment in the Master of School Mathematics program or professional studies in education

Research studies in mathematics learning and teaching, exemplary practices in mathematics education, and current state and national trends in the mathematics curriculum in grades K-12. Topics are offered on a 3-year cycle. Offered SS 2016.

# MATH 545: Intermediate Calculus

#### (4-0) Cr. 4.

Prereq: 3 semesters of calculus and enrollment in the master of school mathematics program

Offered on a 3-year cycle, offered SS. 2016. The fundamental concepts of calculus which are critical to the effective understanding of the material in first year calculus. Emphasis is on a constructivist approach to learning, cooperative groups, problem solving, and use of technology.

# MATH 546: Algorithms in Analysis and Their Computer Implementation (2-2) Cr. 3.

*Prereq: 3 semesters in calculus or concurrent enrollment in 545 and enrollment in the master of school mathematics program* 

Offered on a 3- year cycle, offered SS. 2016. The use of technology in secondary mathematics with an emphasis on the exploration, creation, and implementation of algorithms.

#### MATH 547: Discrete Mathematics and Applications

#### (4-0) Cr. 4.

Prereq: Enrollment in the master of school mathematics program Offered on a 3-year cycle, offered SS. 2018. Applications of graph theory, game theory, voting theory, recursion, combinatorics, and algebraic structures. Issues in integrating discrete topics into the secondary curriculum. Use of the computer to explore discrete mathematics.

# MATH 549: Intermediate Geometry

#### (3-0) Cr. 3.

# Prereq: MATH 435 or equivalent and enrollment in the master of school mathematics program

Offered on a 3-year cycle, offered SS. 2018. A study of geometry with emphasis on metrics, the group of isometries, and the group of similarities. Specific spaces studied normally include the Euclidean plane, the 2-sphere, projective 2-space, and hyperbolic geometry. Emphasis on analytical methods. Incorporation of geometry software.

# MATH 554: Introduction to Stochastic Processes

(Cross-listed with STAT). (3-0) Cr. 3. F.

#### Prereq: STAT 542

Markov chains on discrete spaces in discrete and continuous time (random walks, Poisson processes, birth and death processes) and their long-term behavior. Optional topics may include branching processes, renewal theory, introduction to Brownian motion.

# MATH 557: Ordinary Differential Equations and Dynamical Systems

(3-0) Cr. 3. F.

# Prereq: MATH 415 or MATH 501

The initial-value problem, existence and uniqueness theorems, continuous dependence on parameters, linear systems, stability and asymptotic behavior of solutions, linearization, dynamical systems, bifurcations, and chaotic behavior.

### MATH 561: Numerical Analysis I

(3-0) Cr. 3. F.

Prereq: MATH 414 or MATH 501

Approximation theory, including polynomial interpolation, spline interpolation and best approximation; numerical differentiation and integration; numerical methods for ordinary differential equations.

# MATH 562: Numerical Analysis II

(3-0) Cr. 3. S. Prereq: MATH 317

Numerical linear algebra including LU factorization, QR factorization, linear least squares, singular value decompositions, eigenvalue problems, and iterative methods for large linear systems.

# MATH 565: Continuous Optimization

(3-0) Cr. 3. S.

Prereq: MATH 265 and one of MATH 317, 507, 510

Theory and methods for constrained and unconstrained optimization. Steepest-descent, conjugate gradient, Newton and quasi-Newton, line search and trust-region, first and second order necessary and sufficient conditions, linear, quadratic and general nonlinear programming.

# MATH 566: Discrete Optimization

(3-0) Cr. 3. F.

Prereq: MATH 317 or MATH 507 or MATH 510

Algorithms for linear programming, integer and combinatorial optimization. Linear programming, duality theory, simplex algorithm; the solution of the shortest-path, minimum spanning tree, max-flow/mincut, minimum cost flow, maximum matching, and traveling salesman problems; integer linear programming, branch-and-bound, local and global search algorithms; matroids and greedy algorithms.

# MATH 577: Linear Systems

(Cross-listed with AER E, E E, M E). (3-0) Cr. 3. F.

Prereq: E E 324 or AER E 331 or MATH 415; and MATH 207 Linear algebra review. Least square method and singular value decomposition. State space modeling of linear continuous-time systems. Solution of linear systems. Controllability and observability. Canonical description of linear equations. Stability of linear systems. State feedback and pole placements. Observer design for linear systems.

# MATH 578: Nonlinear Systems

(Cross-listed with AER E, E E, M E). (3-0) Cr. 3. S. *Prereq: E E 577* 

Linear vs nonlinear systems. Phase plane analysis. Bifurcation and center manifold theory. Lyapunov stability. Absolute stability of feedback systems. Input-output stability. Passivity theory and feedback linearization. Nonlinear control design techniques.

# MATH 590: Independent Study

Cr. arr. Repeatable.

# MATH 591: Orientation for Mathematics Graduate Students I (0.5-0) Cr. 0.5. F.

Fall semester orientation seminar. Required for graduate students in Mathematics and Applied Mathematics. Topics include teaching at the university level and communication of mathematics. Offered on a satisfactory-fail basis only.

# MATH 592: Orientation for Mathematics Graduate Students II

(0.5-0) Cr. 0.5. S.

Spring semester orientation seminar. Required for graduate students in Mathematics and Applied Mathematics. Topics include teaching at the university level and communication of mathematics. Offered on a satisfactory-fail basis only.

# MATH 595: Special Topics

Cr. arr. Repeatable.

MATH 599: Creative Component Cr. arr.

Courses for graduate students:

# MATH 601: Mathematical Logic

(3-0) Cr. 3. Alt. F., offered odd-numbered years. *Prereq: MATH 504* 

Model theory of propositional and predicate logic, the Soundness Theorem, the Compactness Theorem, the Goedel-Henkin Completeness Theorem, the Incompleteness Theorem, computability theory. As time permits: modal and temporal logic, set theory (the continuum hypothesis). Emphasis on the relationship between `provable' and `true' and the relationship between `computable' and `definable'.

### MATH 605: Design Theory and Association Schemes

(3-0) Cr. 3. Alt. F., offered even-numbered years.

Prereq: MATH 504

Combinatorial designs and Latin squares. Construction methods including finite fields. Error-correcting codes. Adjacency matrices and algebraic combinatorics.

# MATH 606: Enumerative Combinatorics and Ordered Sets

(3-0) Cr. 3. Alt. S., offered odd-numbered years. *Prereq: MATH 504* 

Ordered sets and lattices. Generating functions. Moebius inversion and other enumeration methods.

# MATH 607: Graph Theory

(3-0) Cr. 3. Alt. F., offered odd-numbered years. *Prereq: MATH 314 or MATH 504* 

Structural theory of graphs. Topics include basic structures (trees, paths and cycles), networks, colorings, connectivity, topological graph theory, Ramsey theory, forbidden graphs and minors, applications.

# MATH 608: Extremal Graph Theory

(3-0) Cr. 3. Alt. S., offered even-numbered years. Prereq: MATH 607

Study of extremal graph problems and methods. Topics include canonical Ramsey theory, generalizations of Turan's theorem, Szemeredi's regularity lemma, random graph theory.

# MATH 610: Seminar

Cr. arr.

# MATH 615: General Theory of Algebraic Structures I

(3-0) Cr. 3. Alt. F., offered even-numbered years.

Prereq: MATH 504

First semester of full-year course. Subalgebras, homomorphisms, congruence relations, and direct products. Lattices and closure operators. Varieties and quasivarieties of algebras, free algebras, Birkhoff's theorems, clones, Mal'cev conditions. Advanced topics.

# MATH 616: General Theory of Algebraic Structures II

(3-0) Cr. 3. Alt. S., offered odd-numbered years. *Prereq: MATH 615* Continuation of MATH 615.

# MATH 617: Category Theory

(3-0) Cr. 3. Alt. F., offered odd-numbered years. *Prereq: MATH 504* Categories and functors and their applications.

# MATH 618: Representation Theory

(3-0) Cr. 3. Alt. S., offered even-numbered years. *Prereq: MATH 504* Representations of algebraic structures. Content varies by semester.

# MATH 624: Manifolds, Tensors and Differential Geometry

(3-0) Cr. 3. Alt. S., offered odd-numbered years. Prereq: MATH 501 or MATH 515

Topics selected from: Geometry of curves and surfaces. Manifolds, coordinate systems. Tangent and cotangent vectors, vector fields. Tensors, differential forms, Riemannian metrics. Connections, covariant differentiation, curvature tensors. Applications to physics and engineering.

# MATH 633: Functional Analysis

(3-0) Cr. 3. Alt. F., offered odd-numbered years. *Prereq: MATH 515* 

Fundamental theory of normed linear spaces and algebras, such as topology and continuity, duality and spectral theory, emphasizing aspects that provide a framework for the study of the spectrum of an operator, analytic function theory, and modern operator theory.

# MATH 641: Foundations of Probability Theory

(Cross-listed with STAT). (3-0) Cr. 3. F.

Prereq: MATH 414 or MATH 501 or equivalent course.

Sequences and set theory; Lebesgue measure, measurable functions. Absolute continuity of functions, integrability and the fundamental theorem of Lebesgue integration. General measure spaces, probability measure, extension theorem and construction of Lebesgue-Stieljes measures on Euclidean spaces. Measurable transformations and random variables, induced measures and probability distributions. General integration and expectation, Lp-spaces and integral inequalities. Uniform integrability and absolute continuity of measures. Probability densities and the Radon-Nikodym theorem. Product spaces and Fubini-Tonelli theorems.

# MATH 642: Advanced Probability Theory

(Cross-listed with STAT). (3-0) Cr. 3. S.

Prereq: STAT 641, or STAT 543 and MATH 515.

Probability spaces and random variables. Kolmogorov's consistency theorem. Independence, Borel-Cantelli lemmas and Kolmogorov's 0 -1 Law. Comparing types of convergence for random variables. Sums of independent random variables, empirical distributions, weak and strong laws of large numbers. Convergence in distribution and its characterizations, tightness, characteristic functions, central limit theorems and Lindeberg-Feller conditions. Conditional probability and expectation. Discrete parameter martingales and their properties and applications.

# MATH 645: Advanced Stochastic Processes

(Cross-listed with STAT). (3-0) Cr. 3. S.

Weak convergence. Random walks and Brownian motion. Martingales. Stochastic integration and Ito's Formula. Stochastic differential equations and applications.

#### MATH 646: Mathematical Modeling of Complex Physical Systems

(Cross-listed with PHYS). (3-0) Cr. 3. S.

Modeling of the dynamics of complex systems on multiple scales: Classical and dissipative molecular dynamics, stochastic modeling and Monte-Carlo simulation; coarse grained nonlinear dynamics, interface propagation and spatial pattern formation.

### MATH 655: Partial Differential Equations I

(3-0) Cr. 3. F.

### Prereq: MATH 515 or MATH 519

Study of model problems of elliptic, parabolic and hyperbolic types, first order equations, conservation laws, transform methods, introduction to linear partial differential equations of arbitrary order, fundamental solutions.

#### MATH 656: Partial Differential Equations II

(3-0) Cr. 3. S.

Prereq: MATH 655

Sobolev spaces, general theory of second order linear elliptic, parabolic and hyperbolic partial differential equations, first order linear hyperbolic systems, variational methods, fixed point methods.

### MATH 666: Finite Element Methods

(3-0) Cr. 3. Alt. F., offered even-numbered years. *Prereq: MATH 516 or MATH 520 or MATH 561 or MATH 656* Weak and variational formulations of elliptic problems; weak derivatives and Sobolev spaces; Lax-Milgram theorem, Bramble-Hilbert lemma; examples of finite element spaces; polynomial approximation theory; error estimates for finite element methods; implementation issues; mixed finite element methods for Stokes problems; applications.

#### MATH 680: Advanced Topics

Cr. 3. Repeatable.

MATH 680A: Advanced Topics: Algebra Cr. 3. Repeatable.

MATH 680B: Advanced Topics: Analysis Cr. 3. Repeatable.

MATH 680C: Advanced Topics: Applied Mathematics Cr. 3. Repeatable.

MATH 680D: Advanced Topics: Combinatorics Cr. 3. Repeatable.

MATH 680E: Advanced Topics: Differential Equations Cr. 3. Repeatable.

MATH 680F: Advanced Topics: Linear Algebra Cr. 3. Repeatable.

MATH 680G: Advanced Topics: Logic and Foundations Cr. 3. Repeatable.

MATH 680H: Advanced Topics: Number Theory Cr. 3. Repeatable.

MATH 680I: Advanced Topics: Numerical Analysis Cr. 3. Repeatable.

MATH 680J: Advanced Topics: Optimization Cr. 3. Repeatable. MATH 680K: Advanced Topics: Probability Cr. 3. Repeatable.

MATH 680L: Advanced Topics: Topology Cr. 3. Repeatable.

MATH 699: Research Cr. arr. Repeatable.