MATHEMATICAL SCIENCES

Undergraduate Program Information

In addition to meeting University and College requirements, students earning a Bachelor of Science in Mathematics must fulfill the core departmental requirements and choose from one of six concentrations:

- General,
- Applied Mathematics,
- Actuarial Science and Insurance,
- Foundations,
- Secondary Mathematics Education or
- Probability and Statistics.

Students must earn a grade of C- or better in all departmental and nondepartmental courses for any degree in the Department of Mathematical Sciences.

Math Sequence Information and Recommendations

Some students may be able to bypass one or more courses in the calculus sequence MATH 1511G Calculus and Analytic Geometry I - MATH 1521G Calculus and Analytic Geometry II - MATH 2530G Calculus III. The calculus sequence, MATH 1531 Introduction to Higher Mathematics, and MATH 2415 Introduction to Linear Algebra provide knowledge that is basic to further work, and students are advised to complete them or their equivalent as early as possible.

Students planning to enter a graduate program in Mathematics should select the General Emphasis. In any case, such students are strongly advised to take both MATH 3110 Introduction to Modern Algebra and MATH 3120 Introduction to Analysis, since these courses are required by most programs, and should take as many as possible of the following courses

Prefix	Title	Credits
MATH 4340	Abstract Algebra I: Groups and Rings	3
MATH 4350	Advanced Linear Algebra	3
MATH 4360	Introduction to Real Analysis I	3
MATH 4365	Introduction to Real Analysis II	3

Graduate Program Information

The Department of Mathematical Sciences offers graduate instruction leading to the Master of Science degree, and Doctor of Philosophy degree. Possible areas of study are various topics in pure mathematics and applied mathematics, statistics and mathematics education. Students may also pursue an interdisciplinary program of study. Most graduate students in Mathematical Sciences are supported either through teaching assistantships, research assistantships, fellowships, or job opportunities at nearby teaching or research units.

For more information on our programs and facilities, and to learn more about the research interests of the faculty, please see our web site at https://math.nmsu.edu/, phone us at (575) 646-3901, or write to:

Graduate Secretary
Department of Mathematical Sciences
NMSU
Las Cruces, NM 88003-8001
Email: gradcomm@nmsu.edu

Students applying for regular admission to graduate study in mathematics are expected to have 24 credits of upper-division courses in mathematics and statistics, including three-credit proof based courses in modern analysis and in modern algebra. Students who do not meet these requirements may be admitted with deficiencies and allowed to complete the requirements at New Mexico State University.

Applications must be submitted online, see http://prospective.nmsu.edu/graduate/apply/ (http://admissions.nmsu.edu/apply/). The minimum application to be admitted as a regular graduate student in mathematics includes:

1. a completed Graduate School admission application
2. complete transcripts of all undergraduate and graduate work
3. application fee
4. three letters of recommendation from professors, employers, or others who are qualified to judge potential for graduate work in mathematics
5. a one-page statement of educational objectives

Although GRE subject test scores are not required for admission, applicants are encouraged to submit them, if available. The test scores may be used to help allocate available teaching assistantships among entering students.

To ensure full consideration for admission, candidates should submit their applications by the following deadlines.

Application Deadlines-Domestic Applicants

Semester	Admission Only	Admission/Financial Aid
Fall	July 1	February 1
Spring/Summer	October 1	October 1

Application Deadlines-International Applicants

Semester	Admission Only	Admission/Financial Aid
Fall	February 1	February 1
Spring/Summer	October 1	October 1

Degrees for the Department

Bachelor Degree(s) & Supplemental Major(s)

- Applied Mathematics - Supplemental Major (https://catalogs.nmsu.edu/nmsu/arts-sciences/mathematical-sciences/applied-mathematics-supplemental-major/)
- Mathematics (Actuarial Science and Insurance) - Bachelor of Science (https://catalogs.nmsu.edu/nmsu/arts-sciences/mathematical-sciences/mathematics-actuarial-science-insurance-bachelor-science/)
- Mathematics (Applied Mathematics) - Bachelor of Science (https://catalogs.nmsu.edu/nmsu/arts-sciences/mathematical-sciences/applied-mathematics-bachelor-science/)
- Mathematics (Computational Mathematics) - Bachelor of Science (https://catalogs.nmsu.edu/nmsu/arts-sciences/mathematical-sciences/mathematics-computational-mathematics-bachelor-science/)
- Mathematics (Foundations) - Bachelor of Science (https://catalogs.nmsu.edu/nmsu/arts-sciences/mathematical-sciences/foundations-bachelor-science/)

- Mathematics (General Mathematics) - Bachelor of Science (https://catalogs.nmsu.edu/nmsu/arts-sciences/mathematical-sciences/general-bachelor-science/)
- Mathematics (Physics) - Bachelor of Science (https://catalogs.nmsu.edu/nmsu/arts-sciences/mathematical-sciences/mathematics-physics-bachelor-science/)
- Mathematics (Probability and Statistics) - Bachelor of Science (https://catalogs.nmsu.edu/nmsu/arts-sciences/mathematical-sciences/mathematics-probability-statistics-bachelor-science/)
- Mathematics (Secondary Mathematics Education) - Bachelor of Science (https://catalogs.nmsu.edu/nmsu/arts-sciences/mathematical-sciences/secondary-math-education-bachelor-science/)

Master Degree(s)

- Mathematics - Master of Science (https://catalogs.nmsu.edu/nmsu/graduate-school/mathematics-master-science/)

Doctoral Degree(s)

- Mathematics - Doctor of Philosophy (https://catalogs.nmsu.edu/nmsu/graduate-school/mathematics-doctor-philosophy/)

Minors for the Department

- Mathematics - Undergraduate Minor (https://catalogs.nmsu.edu/nmsu/arts-sciences/mathematical-sciences/mathematics-undergraduate-minor/)
- Mathematics -Graduate Minor (https://catalogs.nmsu.edu/nmsu/graduate-school/mathematics-graduate-minor/)

Professor, John Harding, Department Head

Professors Ballyk, Bezhanishvili, DeBlassie, Fouli, Harding, Lakey, Olberding; ***Associate Professors*** Contreras, Tian; ***Assistant Professors*** Bhattacharya, Boyle, De Chenne, DiPasquale, Li, Oprisan, Shapirovskiy; ***College Associate Professors*** O'Rourke, Villaverde; ***College Assistant Professors*** Archuleta, Cruz Quinones, Hoang, Letterhos, Rocks; ***College Instructors*** Reece.

J. Harding Department Head, Ph.D. Ph.D. (McMaster)– applications of topological methods to ordered structures; M. Ballyk, Ph.D. (McMaster)– mathematical biology and ecology; G. Bezhanishvili, Ph.D. (Tokyo Institute of Technology)– topology, algebra, and categories in logic; P. Bhattacharya, Ph.D. (Indiana)– algebraic topology; K. Boyle, Ph.D. (Oregon)– topology; A. Contreras, Ph.D. (Indiana)– analysis and applied mathematics; D. DeBlassie, Ph.D. (MIT)– probability; A. De Chenne, Ph.D. (Oregon State)– mathematics education, combinatorial reasoning, computation education in mathematics; M. DiPasquale, Ph.D. (Illinois)– computational commutative algebra and algebraic geometry; L. Fouli, Ph.D. (Purdue)– commutative algebra; J. Lakey, Ph.D. (Maryland)– applied harmonic analysis; B. Li, Ph.D. (Waterloo)– functional analysis, operator theory and operator algebras; B. Olberding, Ph.D. (Wesleyan)– commutative algebra, valuation theory and module theory; A. Oprisan, Ph.D. (Texas–Arlington)– statistics, probability, and data science; I. Shapirovskiy, *Ph.D.* (IITP, Moscow, Russia) *– foundations; J. Tian, Ph.D. (California–Riverside)– applied mathematics, mathematical biology, and biostatistics.*

Mathematics Courses

MATH 1130G. Survey of Mathematics
3 Credits (3)

This course will develop students' ability to work with and interpret numerical data, to apply logical and symbolic analysis to a variety of problems, and/or to model phenomena with mathematical or logical reasoning. Topics include financial mathematics used in everyday life situations, statistics, and optional topics from a wide array of authentic contexts.
Prerequisite: Adequate scoring on the Mathematics Placement Exam, or any ACT/SAT and GPA combination that is considered equivalent, or a C- or better in CCDM 113 N or CCDM 114 N.

Learning Outcomes

1. Construct and analyze graphs and/or data sets: Gather and organize information; Understand the purpose and use of various graphical representations such as tables, line graphs, tilings, networks, bar graphs, etc.; Interpret results through graphs, lists, tables, sequences, etc.; Draw conclusions from data or various graphical representations.
2. Use and solve various kinds of equations: Understand the purpose of and use appropriate formulas within a mathematical application; Solve equations within a mathematical application; Check answers to problems and determine the reasonableness of results.
3. Understand and write mathematical explanations using appropriate definitions and symbols: Translate mathematical information into symbolic form; Define mathematical concepts in the student's own words; Use basic mathematical skills to solve problems.
4. Demonstrate problem solving skills within the context of mathematical applications; Show an understanding of a mathematical application both orally and in writing; Choose an effective strategy to solve a problem; Gather and organize relevant information for a given application.

MATH 1134. Fundamentals of Elementary Mathematics I
3 Credits (3)

Numbers and the four operations of arithmetic. Understanding and comparing multiple representations of numbers and operations, in particular how these representations build from whole numbers to integers to fractions and decimals. Applying properties of numbers and operations in contextual situations. Reasoning, communicating, and problem solving with numbers and operations. Applications to ratio, and connections with algebra. Taught primarily through student activities and investigations. Restricted to: EDUC,EPAR,E ED,ECED majors.
Prerequisite: C- or better in ENGL 1110G; adequate scoring on the Mathematics Placement Exam, or any ACT/SAT and GPA combination that is considered equivalent, or a C- or better in MATH 1215.

Learning Outcomes

1. As future elementary teachers you will be teaching mathematics to children.
2. In order to teach a subject well you need not only to know the material that you will teach, but you need to know more than what you will teach, and know it well,in order to be able to answer questions, understand student reasoning, give alternate explanations when your students do not understand something, and be able to adjust to changes in the mathematical curriculum.
3. Furthermore, even if you hope to teach a given grade, you should be prepared to teach a variety of grades since what a person ends up teaching is often not what they planned to do.
4. We will explore ideas of arithmetic in a way to help you improve your mathematical ability, gain confidence in your ability, introduce to you different ideas and models, and to see a variety of mathematical activities that are appropriate for people of all ages.

5. Everything we study will be done with the aim of developing your ability to relate to the mathematics of elementary school and to help children develop mathematical understanding.

MATH 1215. Intermediate Algebra
3 Credits (3)
A study of linear and quadratic functions, and an introduction to polynomial, absolute value, rational, radical, exponential, and logarithmic functions. A development of strategies for solving single-variable equations and contextual problems.
Prerequisite: Adequate scoring on the Mathematics Placement Exam, or any ACT/SAT and GPA combination that is considered equivalent, or a C- or better in CCDM 113 N or CCDM 114 N.
Learning Outcomes
1. Students will build on their knowledge of linear and quadratic functions and will begin to build an understanding of absolute value, polynomial, rational, power, radical, exponential and logarithmic functions in the following contexts: Demonstrate appropriate use of basic function language and notation; Convert between equivalent forms of algebraic expressions; Solve single-variable equations of the types listed above; Interpret and communicate algebraic solutions graphically and numerically; Demonstrate contextual problem-solving skills that include setting up and solving problems, and interpreting solutions in context; Apply appropriate problem solving methods from among algebraic, graphical, and numerical.

MATH 1217. General Supplemental Instruction I
1 Credit (2P)
Collaborative workshop for students enrolled in Intermediate Algebra.
Corequisite: MATH 1215.
Learning Outcomes
1. Intermediate Algebra Workshop provides time for students to work on problems from Intermediate Algebra under the guidance of their instructor.

MATH 1220G. College Algebra
3 Credits (3)
The study of equations, functions and graphs, reviewing linear and quadratic functions, and concentrating on polynomial, rational, exponential and logarithmic functions. Emphasizes algebraic problem solving skills and graphical representation of functions.
Prerequisite: Adequate scoring on the Mathematics Placement Exam, or any ACT/SAT and GPA combination that is considered equivalent, or a C- or better in MATH 1215.
Learning Outcomes
1. Use function notation; perform function arithmetic, including composition; find inverse functions.
2. Identify functions and their transformations given in algebraic, graphical, numerical, and verbal representations, and explain the connections between these representations.
3. Graph and interpret key feature of functions, e.g., intercepts, leading term, end behavior, asymptotes.
4. Solve equations algebraically to answer questions about graphs, and use graphs to estimate solutions to equations.
5. Solve contextual problems by identifying the appropriate type of function given the context and creating a formula based on the information given.
6. Communicate mathematical information using proper notation and verbal explanations.

MATH 1221. General Supplemental Instruction II
1 Credit (1+2P)
Collaborative workshop for students enrolled in College Algebra.
Corequisite: MATH 1220G.
Learning Outcomes
1. College Algebra Workshop provides time for students to work on problems from College Algebra under the guidance of their instructor.

MATH 1250G. Trigonometry & Pre-Calculus
4 Credits (3+2P)
Trigonometry & Pre-Calculus includes the study of functions in general with emphasis on the elementary functions: algebraic, exponential, logarithmic, trigonometric and inverse trigonometric functions. Topics include rates of change, limits, systems of equations, conic sections, sequences and series, trigonometric equations and identities, complex number, vectors, and applications.
Prerequisite: Adequate scoring on the Mathematics Placement Exam, or any ACT/SAT and GPA combination that is considered equivalent, or a C- or better in MATH 1220G.
Learning Outcomes
1. (Trigonometry) Students will be able to define and evaluate the trigonometric functions as functions of angle in both degree and radian measure using the definitions in terms of x, y, and r; as the ratio of sides of a right triangle; using the unit circle; using reference angles, commonly used (0 o, 30 o, 45 o, 60 o, 90o) angles and using a calculator.
2. (Trigonometry) Students will be able to solve right triangles. They will be able to draw a sketch in an applied problem when necessary.
3. (Trigonometry) Students will be able to solve non-right triangles using the law of sines and the law of cosines.
4. (Trigonometry) Students will be able to prove trigonometric identities and apply addition and subtraction, doubleangle, half-angle and power reduction formulas.
5. (Trigonometry) Students will be able to graph the six trigonometric functions, their transformations and their inverses.
6. (Trigonometry) Students will be able to use algebraic methods, including the use of identities and inverses, to solve trigonometric equations and demonstrate connections to graphical and numerical representations of the solutions.
7. (Trigonometry) Students will be able to add and subtract vectors in two dimensions. They will be able to use the dot product to project one vector onto another and to determine the angle between two vectors. They will be able to solve a variety of word problems using vectors.
8. (Trigonometry) Students will be able to work with polar coordinates; this includes graphing in polar coordinates and transforming an equation with polar coordinates into one with rectangular coordinates, and vice versa.
9. (Trigonometry) Students will be to work with the trigonometric form of complex numbers, including using De Moivre's formula. 1
10. (Pre-Calculus) Functions: Reinforce recognizing a function from its graph and from its algebraic expression; Reinforce identification of a one-to-one function graphically and from its algebraic expression; Reinforce identification of inverse functions graphically and algebraically; Reinforce combining functions arithmetically and compositionally; Be able to calculate the average rate of change of a function using the difference quotient and depict it graphically; Be able to find a limiting value of a function and be able to identify and use the notation that describes this. 1

11. (Pre-Calculus) Graphing: Reinforce using key characteristics of functions to graph them; Be able to graph conic sections from their key characteristics such as foci, eccentricity and asymptotes; Be able to identify all functions mentioned from their graphs, describing their key aspects. 1
12. (Pre-Calculus) Solving: Exponential/Logarithmic equations using the rules of exponents and logarithms; Systems of linear equations by elimination; Non-linear systems algebraically and graphically. 1
13. (Pre-Calculus) Applications: Modeling with functions with an emphasis on exponential and logarithmic functions, growth and decay. 1
14. (Pre-Calculus) Sequences and series: Understand the concept and notation of a sequence; Understand the concept and notation of a series; Be able to find limits of basic sequences; Be able to find sums of basic series.

MATH 1350G. Introduction to Statistics
3 Credits (3)
This course discusses the fundamentals of descriptive and inferential statistics. Students will gain introductions to topics such as descriptive statistics, probability and basic probability models used in statistics, sampling and statistical inference, and techniques for the visual presentation of numerical data. These concepts will be illustrated by examples from a variety of fields.
Prerequisite: Adequate scoring on the Mathematics Placement Exam, or any ACT/SAT and GPA combination that is considered equivalent, or a C- or better in MATH 1215 or higher.
Learning Outcomes
1. Explain the general concepts of statistics: Explain and evaluate statistics used in the real world (from a news article, research project, etc.); Use statistical vocabulary appropriately; Distinguish between descriptive and inferential statistics; Distinguish between qualitative and quantitative data; Distinguish between populations and samples, and parameters and statistics; Give examples of independent and dependent variables.
2. Presentation and description of data: Present data graphically using histograms, frequency curves and other statistical graphs; Interpret graphs of data, including histograms and shapes of distributions.
3. Summarize data using measures of central tendency and variation: Calculate and interpret the mean, median, and mode to describe data; Calculate and interpret range, variance, and standard deviation to describe data.
4. Present the concepts of probability: Interpret basic probabilities; Calculate probabilities using compound probability rules and the binomial distribution; Calculate probabilities using the standard normal distribution and relate them to areas under the curve; Determine if the binomial distribution can be approximated with the normal distribution; Describe the relationship between the sampling distribution and the population distribution; Use the central limit theorem to approximate the probability distribution and calculate probabilities.
5. Compute point and interval estimates: Determine the confidence interval for a parameter; Interpret the confidence level and margin of error; Determine whether a statistical technique is appropriate under stated conditions.
6. Perform hypothesis tests: Determine whether a statistical test is appropriate under stated conditions; Identify null and alternative hypothesis; Perform and interpret statistical tests (e.g. z-test, t-test, one-tailed and two-tailed, one-sample, two-sample) and determine whether data is statistically significant; State the conclusion of a hypothesis test; Interpret a p-value as compared to a significance level; Explain why a test can lead us to reject a null hypothesis, not accept one; Distinguish between Type I and Type II errors.
7. Analyze data using regression and correlation: Explain the difference between correlation and causation; Construct and interpret scatter plots; Calculate and interpret the linear correlation coefficient; Determine and use the equation of a least-squares regression line between two variables to make predictions; Interpret the meaning of the coefficient of determination.
8. Optional topics: Inter-quartile range, box-plots, stem-and-leaf plots; Combinations and permutations; The Poisson distribution; Statistical power; Chi-square; Analysis of variance.

MATH 1430G. Applications of Calculus I
3 Credits (2+2P)
An algebraic and graphical study of derivatives and integrals, with an emphasis on applications to business, social science, economics and the sciences.
Prerequisite: Adequate scoring on the Mathematics Placement Exam, or any ACT/SAT and GPA combination that is considered equivalent, or a C- or better in MATH 1220G or higher.
Learning Outcomes
1. Find limits algebraically and graphically, and use limits to analyze continuity.
2. Find the derivative of a function by applying appropriate techniques (limit of the difference quotient, general derivative rules, product rule, quotient rule, chain rule, and higher order derivatives).
3. Perform implicit differentiation. Use implicit differentiation to solve related rate application problems.
4. Use the derivative to describe the rate of change and slope of a curve in general and at particular points. Compare and contrast average rates of change to instantaneous rates of change.
5. Find the maxima, minima, points of inflections, and determine concavity of a function by applying the first and second derivatives. Use these results to sketch graphs of functions and to solve optimization problems in context.
6. Find the antiderivative and indefinite integral functions to include integration by substitution. Apply the Fundamental Theorem of Calculus in computing definite integrals of functions.
7. Approximate the area under the curve using Riemann sums.
8. Use the integral to determine the area under a curve and to find the accumulated value of a function in context.
9. Solve contextual problems by identifying the appropriate type of function given the context, creating a formula based on the information given, applying knowledge of algebra and calculus, and interpreting the results in context. 1
10. Communicate mathematical information using proper notation and verbal explanations.

MATH 1435. Applications of Calculus I
3 Credits (3)
Intuitive differential calculus with applications to engineering.
Prerequisite(s): C- or better in MATH 1250G.
Learning Outcomes
1. Find limits algebraically and graphically, and use limits to analyze continuity.
2. Find the derivative of a function by applying appropriate techniques (limit of the difference quotient, general derivative rules, product rule, quotient rule, chain rule, and higher order derivatives).

3. Learn derivative rules for polynomial, exponential, logarithmic, trigonometric and inverse trigonometric functions.
4. Perform implicit differentiation. Use implicit differentiation to solve related rate application problems.
5. Find the maxima, minima, points of inflections, and determine concavity of a function by applying the first and second derivatives. Use these results to sketch graphs of functions and to solve optimization problems in context.
6. Find partial derivatives and find maxima, minima in three dimensions.
7. Find the linear approximation of a function.
8. Find Maclaurin and Taylor series.
9. Find limits via L'Hospital's rule. 1
10. Communicate mathematical information using proper notation and verbal explanations.

MATH 1440. Applications of Calculus II
3 Credits (3)
Topics in this second course of Applications of Calculus include functions of several variables, techniques of integration, an introduction to basic differential equations, and other applications.
Prerequisites: C or better in MATH 1435 or in MATH 1521G, or in MATH 1521H.
Learning Outcomes
1. Find definite and indefinite integrals using integration by parts, integral tables, and numerical integration.
2. Analyze multivariable functions using partial derivatives and double integrals, and apply these techniques to applications such as optimization, least squares, and volumes.
3. Solve differential equations graphically, numerically, and algebraically using separation of variables, and apply differential equations in context.
4. Apply differentiation and integration to other areas, for example to Taylor polynomials and Taylor series, probability, trigonometric functions, etc.

MATH 1511G. Calculus and Analytic Geometry I
4 Credits (4)
Limits and continuity, theory and computation of derivatives, applications of derivatives, extreme values, critical points, derivative tests, L'Hopital's Rule.
Prerequisite: Adequate scoring on the Mathematics Placement Exam, or any ACT/SAT and GPA combination that is considered equivalent, or a C- or better in MATH 1250G.
Learning Outcomes
1. The goals are to present the concepts of calculus, stressing techniques, applications, and problem solving, and emphasizing numerical aspects such as approximations and order of magnitude.
2. Overall, the goals are to illustrate the power of calculus as a tool for modeling situations arising in physics, science, engineering and other fields.
3. In fulfillment of these goals, this and later courses will stress topics such as polynomial approximation, setting up integrals, as well as the use of appropriate technology.

MATH 1511H. Calculus and Analytic Geometry I Honors
4 Credits (4)
Limits and continuity, theory and computation of derivatives, applications of derivatives, extreme values, critical points, derivative tests, L'Hopital's Rule. This is an Honors version of MATH 1511G. It is taught with MATH 1511G with differentiated assignments.
Prerequisite: Adequate scoring on the Mathematics Placement Exam, or any ACT/SAT and GPA combination that is considered equivalent, or a C- or better in MATH 1250G or higher.
Learning Outcomes
1. The goals are to present the concepts of calculus, stressing techniques, applications, and problem solving, and emphasizing numerical aspects such as approximations and order of magnitude.
2. Overall, the goals are to illustrate the power of calculus as a tool for modeling situations arising in physics, science, engineering and other fields.
3. In fulfillment of these goals, this and later courses will stress topics such as polynomial approximation, setting up integrals, as well as the use of appropriate technology.
4. Gain a deeper understanding of the mathematics behind Limits and Derivatives and be able to use mathematical ideas (such as the Intermediate Value Theorem, the Mean Value Theorem, and the Extreme Value Theorem) in applied contexts.

MATH 1521G. Calculus and Analytic Geometry II
4 Credits (4)
Riemann sums, the definite integral, antiderivatives, fundamental theorems, techniques of integration, applications of integrals, improper integrals, Taylor polynomials, sequences and series, power series and Taylor series.
Prerequisite: C- or better in MATH 1511G.
Learning Outcomes
1. Recognize the interplay between Riemann sums and definite integrals.
2. Use the Fundamental Theorem of Calculus to compute definite and indefinite integrals.
3. Demonstrate an understand of the relationship between the derivative and the definite integral.
4. Evaluate integrals numerically using standard rules (midpoint, trapezoid, Simpson's).
5. Evaluate integrals analytically using standard methods (substitution, integration by parts, trigonometric substitution and identities, inverse functions and partial fractions.
6. Use integration to solve problems in geometry, physics, science, engineering and other fields.
7. Use appropriate methods such as L'Hopital's Rule to evaluate improper integrals.
8. Approximate functions using Taylor polynomials.
9. Apply standard tests to determine convergence or divergence of sequences and series. 1
10. Find a power series representation for a function and determine where it converges. 1
11. Identify and evaluate first order differential equations.

MATH 1521H. Calculus and Analytic Geometry II Honors
4 Credits (4)
A more advanced treatment of the material of MATH 1521G with additional topics. Consent of Instructor required. Restricted to Las Cruces campus only.
Learning Outcomes
1. Recognize the interplay between Riemann sums and definite integrals.
2. Use the Fundamental Theorem of Calculus to compute definite and indefinite integrals.

3. Demonstrate an understand of the relationship between the derivative and the definite integral.
4. Evaluate integrals numerically using standard rules (midpoint, trapezoid, Simpson's).
5. Evaluate integrals analytically using standard methods (substitution, integration by parts, trigonometric substitution and identities, inverse functions and partial fractions.
6. Use integration to solve problems in geometry, physics, science, engineering and other fields.
7. Use appropriate methods such as L'Hopital's Rule to evaluate improper integrals.
8. Approximate functions using Taylor polynomials.
9. Apply standard tests to determine convergence or divergence of sequences and series. 1
10. Find a power series representation for a function and determine where it converges. 1
11. Identify and evaluate first order differential equations.

MATH 1531. Introduction to Higher Mathematics
3 Credits (3)
Logic; sets, relations, and functions; introduction to mathematical proofs.
Prerequisite(s): C- or better in MATH 1521G or MATH 1521H.
Learning Outcomes
1. The primary objective of this course is to serve as a bridge between the calculus courses you have taken, where the focus is on computations and solving problems, to more abstract mathematics courses.
2. In particular, we will discuss logical reasoning, definitions, proofs, and certain basic building blocks such as sets, functions, and relations.
3. By the end of the course, you should be able to understand and construct well-written proofs of basic mathematical arguments involving simple properties of the real numbers, integers, sets, functions, and relations using universal and existential quantifiers, absolute values and inequalities, modular arithmetic, and proof by induction.

MATH 1531H. Introduction to Higher Mathematics Honors
3 Credits (3)
Logic; sets, relations, and functions; introduction to mathematical proofs. A more advanced treatment of the material of MATH 1531 with additional topics and/or assignments. Consent of Instructor required. Restricted to Las Cruces campus only.
Prerequisite: C- or better in MATH 1521G or MATH 1521H.
Learning Outcomes
1. The primary objective of this course is to serve as a bridge between the calculus courses you have taken, where the focus is on computations and solving problems, to more abstract mathematics courses.
2. In particular, we will discuss logical reasoning, definitions, proofs, and certain basic building blocks such as sets, functions, and relations.
3. By the end of the course, you should be able to understand and construct well-written proofs of basic mathematical arguments involving simple properties of the real numbers, integers, sets, functions, and relations using universal and existential quantifiers, absolute values and inequalities, modular arithmetic, and proof by induction.
4. Since this is an honors course, you should be able to understand higher-level properties of the mathematical objects and ideas arising in the class. You should also be able to write, edit, revise, and ultimately construct well-written proofs and mathematical arguments.

MATH 1996. Topics in Mathematics
1-3 Credits
Topics to be announced in the Schedule of Classes. Maximum of 3 credits per semester. Total credit not to exceed 6 credits. Community Colleges only.
Prerequisite: consent of instructor.
Learning Outcomes
1. Varies

MATH 2134G. Fundamentals of Elementary Math II
3 Credits (3)
Geometry and measurement. Multiple approaches to solving problems and understanding concepts in geometry. Analyzing and constructing two- and three-dimensional shapes. Measurable attributes, including angle, length, area, and volume. Understanding and applying units and unit conversions. Transformations, congruence, and symmetry. Scale factor and similarity. Coordinate geometry and connections with algebra. Reasoning and communicating about geometric concepts. Taught primarily through student activities and investigations.
Prerequisite: C- or better in MATH 1134.
Learning Outcomes
1. The primary objectives are mathematical: to understand some of the basic concepts of geometry, and measurement with an appropriate level of rigor; to appreciate the historical, cultural and educational contributions and potential applications in real life situations; and to gain problem solving skills using these concepts.
2. The secondary goal is to appreciate the importance of this material in the elementary school curriculum.

MATH 2350G. Statistical Methods
3 Credits (3)
Exploratory data analysis. Introduction to probability, random variables and probability distributions. Concepts of Central Limit Theorem and Sampling Distributions such as sample mean and sample proportion. Estimation and hypothesis testing single population parameter for means and proportions and difference of two population parameters for means and proportions. Analysis categorical data for goodness of fit. Fitting simple linear regression model and inference for regression parameters. Analysis of variance for several population means. Techniques in data analysis using statistical packages.
Prerequisite: Adequate scoring on the Mathematics Placement Exam, or any ACT/SAT and GPA combination that is considered equivalent, or a C- or better in MATH 1215 or higher.
Learning Outcomes
1. Summarize Data through graphs and Descriptive statistics: Define qualitative and quantitative data; Provide examples of a population, a sample, independent and dependent variables, parameters and statistics; Construct and interpret histograms, stem plots, bar charts, and boxplot; Summarize distributions with numerical measures such as mean, median, standard deviation, percentiles, interquartile range.
2. Present the concepts of probability: Explain related to probability axioms (e.g. mutually exclusive events and independent events); Apply applications of probability rules; Apply Conditional probability and Bayes Rule.
3. Distinguish between discrete and continuous random variables: Calculate probabilities using Binomial and Poisson distributions; Calculate probabilities using the standard normal distribution by finding the area underneath the curve.

4. Explain the Central Limit Theorem: Introduce the concept of a sampling distribution; Discuss the distribution of the sample mean and sample proportion under repeated sampling; Generate and interpret a sampling distribution using repeated sampling; Determine if the Binomial and Poisson distribution can be approximated with the normal distribution.
5. Estimate a population parameter: Determine confidence interval for population mean, proportion, difference of means, and difference of proportions; Interpret the confidence interval and margin of error; Explain the dependence of margin of error on sample size and confidence level.
6. Perform hypothesis tests for population parameters (population mean, proportion, difference of means, and difference of proportions); Describe the logic and framework of the inference of hypothesis testing; Make a decision using a p-value and draw an appropriate conclusion; Distinguish between Type I and Type II errors; Explain power of the test.
7. Perform Hypothesis Tests for Categorical data: Determine and analyze Chi-square test for Independence; Determine and analyze Chi-square test for Goodness of fit.
8. Analyze data using regression and correlation: Construct scatterplots and analyze the scatter plots; Calculate the linear correlation coefficient and determine whether a linear relationship exists between two variables; Fit the least-squares regression line between two variables; Predict the response variable from the regression line; Apply statistical inference to regression parameters.
9. Perform analysis of variance: State hypotheses for the test of several population means; Construct the AVOVA Table; Explain the significance of multiple comparisons. 1
10. Demonstrate the appropriate use of technology (e.g., Excel, an appropriate graphing calculator or other software (Minitab, SAS)

MATH 2415. Introduction to Linear Algebra
3 Credits (3)
Systems of equations, matrices, vector spaces and linear transformations. Applications to computer science.
Prerequisite(s): Grade of C- or better in MATH 1521G or MATH 1521H.
Learning Outcomes

1. Use row reduction and echelon forms of a matrix to solve linear systems of equations.
2. Use matrix operations, inverse matrices, and matrix factorizations to solve matrix equations.
3. Study the properties of vector spaces and subspaces (e.g., the null and column spaces of a matrix); linear transformations, isomorphisms and kernels; linear independence, bases, and dimension.
4. Apply appropriate matrix manipulations to perform a change of basis.
5. Understand determinants and their properties.
6. Find eigenvalues and eigenvectors and use them to diagonalize matrices.
7. Understand inner product spaces and apply them to real-world problems.

MATH 2530G. Calculus III
3 Credits (3)
Continuation of Calculus II including multivariate and vector calculus, level curves and surfaces, partial derivatives, gradient, directional derivatives, tangent planes, optimization, multiple integrals in Cartesian, cylindrical and spherical coordinate systems.
Prerequisite: Grade of C- or better in MATH 1521G or MATH 1521H.
Learning Outcomes

1. Use vector notation correctly.
2. Perform vector operations, including dot product, cross product, differentiation and integration, and demonstrate their geometric interpretations.
3. Perform operations on vector valued functions and functions of a parameter.
4. Identify and graph the equations of cylinders and quadratic surfaces in 3-dimensional space.
5. Determine the domain of continuity of a vector valued function and of a function of multiple variables.
6. Compute partial derivatives, generally and at a point, and sketch their graphical representation on a surface in space.
7. Recognize when the chain rule is needed when differentiating functions of multiple variables, parametric equations and vector valued functions, and be able to use the chain rule in these situations.
8. Compute curvature of a parameterized vector representation of a curve in 2- and 3-dimensional space and be able to explain its meaning.
9. Compute the unit tangent and unit normal vectors to a curve and be able to sketch them with the curve. 1
10. Computationally move among position vector, velocity vector, speed, and acceleration vectors; recognize and demonstrate their use as applied to motion in space. 1
11. Determine the equation of the tangent plane to a surface at a point. 1
12. Use the tangent plane to a surface to approximate values on the surface and estimate error in approximation using differentials 1
13. Compute directional derivatives and represent them graphically relative to the inherent surface. 1
14. Compute the gradient vector; represent it graphically relative to the inherent surface and use it to maximize or minimize rate of change of the function. 1
15. Locate local and global maxima and minima of a function. 1
16. Use Lagrange multipliers to maximize output with one or two constraints. 1
17. Compute arc length and be able to explain its derivation as a limit. 1
18. Calculate double and triple integrals independently and with their geometric representations as surfaces, areas and volumes. 1
19. Calculate iterated integrals in polar, cylindrical and spherical coordinate systems.

MATH 2992. Directed Study
1-3 Credits
May be repeated for a maximum of 6 credits. Graded S/U.
Prerequisite: consent of the instructor.
Learning Outcomes

1. Varies

MATH 3110. Introduction to Modern Algebra
3 Credits (3)
Elements of abstract algebra, including groups, rings and fields.
Prerequisite: C or better in MATH 1531 and MATH 2415.
Learning Outcomes

1. Varies.

MATH 3120. Introduction to Analysis
3 Credits (3)
Development of the real numbers, a rigorous treatment of sequences, limits, continuity, differentiation, and integration.

Prerequisite: C- or better in MATH 1531 or MATH 1531H.

Learning Outcomes

1. Understand the Axiom of Completeness and be able to work with suprema and infima.
2. Know the basic definitions of sequences and be able to understand and construct rigorous epsilon-N proofs.
3. Understand the properties of convergent sequences and be able to construct related proofs.
4. Know the basic definitions of limits and be able to understand and construct epsilon-delta proofs.
5. Be familiar with the basic properties and topology of the reals.

MATH 3130. Introduction to Geometry
3 Credits (3)
Building on ideas from high school geometry, an introduction to the axiomatic method, transformation groups, and non-Euclidean geometry.
Prerequisite: C- or better in MATH 1531 (or MATH 1531H) and MATH 2415.

Learning Outcomes

1. Demonstrate the ability to make conjectures in geometry, refine conjectures, and prove or refute conjectures.
2. Understand how transformations of the plane can be used to define and apply the concepts of congruence and similarity in Euclidean geometry.
3. Solve problems in geometry using different approaches (axioms, coordinates, transformations), and explain how the different approaches are related.
4. Compare the definitions and theorems of Euclidean geometry with the corresponding definitions and theorems in non-Euclidean geometry.

MATH 3140. Introduction to Numerical Methods
3 Credits (3)
Basic numerical methods for interpolation, approximation, locating zeros of functions and integration; numerical linear algebra. Computer-oriented methods will be emphasized. Student must also have some programming experience in order to enroll.
Prerequisite: C- or better in one of MATH 2415, M E 228, or E E 200.

Learning Outcomes

1. Understand the limitations, advantages, and disadvantages of common numerical methods and how they are used to obtain approximate solutions.
2. Apply numerical methods to obtain approximate solutions to mathematical problems.
3. Analyze and evaluate the accuracy of common numerical methods.
4. Write efficient, well-documented code to implement numerical methods.

MATH 3160. Introduction to Ordinary Differential Equations
3 Credits (3)
Introduction to differential equations and dynamical systems with emphasis on modeling and applications. Basic analytic, qualitative and numerical methods. Equilibria and bifurcations. Linear systems with matrix methods, real and complex solutions.
Prerequisite: C or better in MATH 1521G or MATH 1521H or B or better in MATH 1440.

Learning Outcomes

1. Solve basic linear and nonlinear linear first order equations using appropriate methods (both explicit and qualitative).
2. Model both linear and nonlinear physical entities such as population, income growth, mixing and cooling, as well as systems of physical entities such as predator/prey models and electric circuits.
3. Classify higher order equations as homogeneous/nonhomogeneous and linear/nonlinear.
4. Solve second order homogeneous and nonhomogeneous linear equations using appropriate techniques.
5. Solve differential equations using Laplace Transforms.
6. Solve systems of linear equations using basic matrix methods.

MATH 3997. Directed Readings
1-3 Credits
A selection of readings and reports in the mathematical sciences, the breadth and depth of which is deemed to fit the needs of the student. May be repeated up to 3 credits.
Prerequisite: consent of instructor.

MATH 400. Undergraduate Research
1-3 Credits
May be repeated for a maximum of 6 credits. Graded S/U.
Prerequisite: consent of faculty member.

MATH 4110V. Great Theorems in Mathematics
3 Credits (3)
This course examines some significant mathematical achievements from antiquity to the modern era. Evolution of notions and methods in geometry, number theory, algebra, and calculus will be supplemented by cultural and biographical history, placing mathematics in a broad human context.
Prerequisite: Grade of C- or higher in MATH 1531, or grade of B or higher in any upper-division math or stat course, or consent of instructor.

Learning Outcomes

1. At the end of this course, students will be able to: Describe the history of the development of some key mathematical concepts.
2. Describe the connections between mathematical ideas in different historical periods and places.
3. Recognize the role of abstraction and logic in the progress of mathematics.
4. Describe the contribution of mathematics to culture and science in different historical eras.
5. Determine if a mathematical conjecture is correct and provide rigorous written mathematical justification.
6. Provide sound, complete and clear mathematical arguments involving simple calculations, geometric constructions, and/or written mathematical proofs.
7. Communicate mathematical ideas, both written and orally.

MATH 4210. Complex Variables
3 Credits (3)
A first course in complex function theory, with emphasis on applications.
Prerequisite: C- or better in both MATH 3160 and MATH 2530G.

Learning Outcomes

1. Define analytic function, the Cauchy-Riemann equations, and harmonic functions.
2. Recognize elementary analytic functions such as the exponential function, trigonometric functions, and branches of the logarithmic function and their properties.
3. Understand mapping by elementary functions, linear fractional transformations, and powers.

4. Compute line integrals, making appropriate use of the Cauchy-Goursat Theorem, the Cauchy Integral Formula, and Morera's Theorem.
5. Relate complex power series (including Laurent series) to their singularities (removable singularities, poles, and essential singularities).
6. Evaluate improper integrals using the Residue Theorem.

MATH 4220. Fourier Series and Boundary Value Problems
3 Credits (3)
Fourier series and methods of solution of the boundary value problems of applied mathematics.
Prerequisite: C- or better in MATH 3160.
Learning Outcomes
1. Learn the standard boundary/initial value problems for the partial differential equations of mathematical physics: wave equation, heat equation, Laplace's equation and Poisson's equation.
2. Be able to use the method of separation of variables to solve the boundary/initial value problems.
3. In learning the method, understand orthogonal sets of functions, eigenvalues, eigenfunctions, Fourier series, generalized Fourier series.
4. Understand Fourier integrals, Fourier transforms and their applications.

MATH 4230. Applied Linear Algebra
3 Credits (3)
An application-driven course, whose topics may include the four fundamental subspaces, inner products, orthogonality, diagonalization, and complex matrices. Applications may include factorization, least squares, data compression, singular value decomposition, and discrete Fourier transform.
Prerequisite: C- or better in one of MATH 2415, E E 200, or M E 228.
Learning Outcomes
1. Understand higher-level linear algebra concepts for which matrix linear algebra is the basic tool.
2. Understand how to apply higher-level linear algebra concepts to problems that arise in real-world applications.

MATH 4310. Introduction to Topology
3 Credits (3)
Topological spaces: general spaces and specific examples such as metric spaces, Hausdorff spaces and/or normed vector spaces; separation axioms; continuity, compactness, connectedness; related theorems. Crosslisted with: MATH 5310.
Prerequisite: MATH 3120.

MATH 4320. Logic and Set Theory
3 Credits (3)
Propositional and first order logic; axioms, proofs, models. Semantic and syntactic consequence. Soundness, completeness, compactness, and Loewenheim –Skolem theorems. The Zermelo-Fraenkel axioms for set theory. Well orderings, ordinals, cardinals, the axiom of choice, and the von Neumann hierarchy.
Learning Outcomes
1. Define the fundamental notions of set theory (ordinals, cardinals) and apply transfinite induction/recursion to construct proofs.
2. Explain the Axiom of Choice and relate set-theoretic and logical techniques to topics in algebra and analysis.
3. Construct formal proofs in first-order logic and distinguish between semantic and syntactic consequence.
4. Prove the Completeness and Compactness theorems of first-order logic and apply metatheorems (Löwenheim–Skolem) to analyze formal theories and their models.

MATH 4330. Elementary Number Theory
3 Credits (3)
Covers primes, congruences and related topics.
Prerequisite: Grade of C or better in MATH 3110 or consent of instructor.

MATH 4340. Abstract Algebra I: Groups and Rings
3 Credits (3)
Group theory, including cyclic groups, homomorphisms, cosets, quotient groups and Lagrange's theorem. Introduction to rings: ring homomorphisms, ideals, quotient rings, polynomial rings, and principal ideal domains. Taught with MATH 5340.
Prerequisite(s): MATH 3110 or consent of instructor.

MATH 4350. Advanced Linear Algebra
3 Credits (3)
Rigorous treatment of vector spaces and linear transformations including canonical forms, spectral theory, inner product spaces and related topics.
Prerequisite: Grade of C or better in MATH 3110.
Learning Outcomes
1. Apply the fundamental properties of abstract vector spaces to solve algebraic problems.
2. Define and evaluate linear independence, bases, and dimension within abstract vector spaces.
3. Construct matrix representations for linear transformations between vector spaces.
4. Compute determinants, eigenvalues, and eigenvectors of linear operators.
5. Prove theorems regarding direct sums, kernels (null spaces), and ranges of linear transformations.
6. Apply the properties of adjoint operators to solve problems in inner product spaces.

MATH 4360. Introduction to Real Analysis I
3 Credits (3)
Rigorous discussion of the real numbers for topics introduced in calculus: limits and continuity, followed by differentiation, integration, and series of functions.
Prerequisite: Grade of C- or better in MATH 3120 or consent of instructor.
Learning Outcomes
1. Understand two-sided limits, one-sided limits, limits at infinity, continuity and uniform continuity for functions on the real line.
2. Understand derivatives, differentiability theorems, the Mean Value Theorem, Taylor's Theorem, L'hospital's Rule and the Inverse Function Theorem for functions on the real line.
3. Understand integration on the real line: the Riemann integral, Riemann sums, the Fundamental Theorem of Calculus and improper Riemann integrals.
4. Understand sequences and infinite series of functions, including uniform convergence, limit supremum, limit infimum, power series and analytic functions.

MATH 4365. Introduction to Real Analysis II
3 Credits (3)
Extension of the ideas of Math 4360 to higher dimensions and more general contexts (metric spaces, differentiability on higher dimensional Euclidean space, integration on higher dimensional Euclidean space).
Prerequisite: C- or better in MATH 4360 or consent of instructor.

Learning Outcomes

1. Understand the algebraic structure, including planes and linear transformations, of Euclidean spaces.
2. Understand the fundamental notions of metric spaces: limits of functions, interior/closure/boundary of sets, compact sets, connected sets, continuous functions and the Stone-Weierstrass Theorem.
3. Understand derivatives, differentials, tangent planes, the Chain Rule, the Mean Value Theorem, Taylor's Formula and the Inverse Function Theorem for functions on n-dimensional Euclidean space.
4. Apply the Ascoli Theorem for relative compactness of sets of continuous functions on a compact metric space.

MATH 454. Logic and Set Theory
3 Credits (3)
Propositional and first order logic; axioms, proofs, models. Semantic and syntactic consequence. Soundness, completeness, compactness, and Loewenheim –Skolem theorems. The Zermelo-Fraenkel axioms for set theory. Well orderings, ordinals, cardinals, the axiom of choice, and the von Neumann hierarchy. Crosslisted with: MATH 524.
Prerequisite(s): C- or better in MATH 331 or MATH 332, or consent of instructor.

MATH 455. Elementary Number Theory
3 Credits (3)
Covers primes, congruences and related topics.
Prerequisite: grade of C or better in MATH 331 or consent of instructor.

MATH 456. Abstract Algebra I: Groups and Rings
3 Credits (3)
Group theory, including cyclic groups, homomorphisms, cosets, quotient groups and Lagrange's theorem. Introduction to rings: ring homomorphisms, ideals, quotient rings, polynomial rings, and principal ideal domains. Crosslisted with: MATH 526.
Prerequisite(s): MATH 331 or consent of instructor.

MATH 491. Introduction to Real Analysis I
3 Credits (3)
Rigorous discussion of the real numbers for topics introduced in calculus: limits and continuity, followed by differentiation, integration, and series of functions.
Prerequisite: Grade of C- or better in MATH 332 or consent of instructor.

Learning Outcomes

1. Understand two-sided limits, one-sided limits, limits at infinity, continuity and uniform continuity for functions on the real line.
2. Understand derivatives, differentiability theorems, the Mean Value Theorem, Taylor's Theorem, L'hospital's Rule and the Inverse Function Theorem for functions on the real line.
3. Understand integration on the real line: the Riemann integral, Riemann sums, the Fundamental Theorem of Calculus and improper Riemann integrals.
4. Understand sequences and infinite series of functions, including uniform convergence, limit supremum, limit infimum, power series and analytic functions.

MATH 492. Introduction to Real Analysis II
3 Credits (3)
Extension of the ideas of Math 491 to higher dimensions and more general contexts (metric spaces, differentiability on higher dimensional Euclidean space, integration on higher dimensional Euclidean space).
Prerequisite: C- or better in MATH 491 or consent of instructor.

Learning Outcomes

1. Understand the algebraic structure, including planes and linear transformations, of Euclidean spaces.
2. Understand the fundamental notions of metric spaces: limits of functions, interior/closure/boundary of sets, compact sets, connected sets, continuous functions and the Stone-Weierstrass Theorem.
3. Understand derivatives, differentials, tangent planes, the Chain Rule, the Mean Value Theorem, Taylor's Formula and the Inverse Function Theorem for functions on n-dimensional Euclidean space.
4. Understand integration on n-dimensional Euclidean space: Jordan regions, Riemann integration on Jordan Regions, iterated integrals and change of variables.

MATH 498. Directed Reading
1-6 Credits
May be repeated for a maximum of 6 credits. Graded S/U.

MATH 4991. Undergraduate Research
1-3 Credits
May be repeated for a maximum of 6 credits. Graded S/U.

MATH 4996. Special Topics
1-3 Credits (1-3)
Specific subjects to be announced in the Schedule of Classes. May be used to fulfill a course requirement for the mathematics major. May be repeated up to 99 credits.

Learning Outcomes

1. Analyze concepts in the selected topic area.
2. Apply mathematical methods to solve complex problems within the topic area.
3. Communicate findings from the topic area in written and oral formats.

MATH 4997. Directed Reading
1-6 Credits
May be repeated for a maximum of 6 credits. Graded S/U.

MATH 5110. Fundamentals of Elementary Mathematics I
3 Credits (3+1P)
Topics from real numbers, geometry, measurement, and algorithms, incorporating calculator technology. Intended for K-8 teachers. As part of course students mentor MATH 1134 undergraduates. Does not fulfill degree requirements for M.S. in mathematics.

MATH 512. Fundamentals of Elementary Mathematics II
3 Credits (3+1P)
Real numbers, geometry, and statistics, incorporating calculator technology. Intended for K-8 teachers. Students serve as mentors to MATH 2134G undergraduates. Does not fulfill degree requirements for M.S. in mathematics.

MATH 5120. History and Theories of Mathematics Education
3 Credits (3)
A study of the history of the mathematics taught in American schools, including an examination of authentic original textbooks and the changes in their content and the approach to the subject over time, together with writings of people who have influenced the development and changes of mathematics education. Theories of learning mathematics, and current issues in mathematics education.
Prerequisite(s): Restricted to graduate students.

MATH 5130. Algebra with Connections
3 Credits (3)
Connections between Algebra and other K-12 curriculum strands, especially Geometry and Probability / Data Analysis. Apply algebraic

modeling and reasoning to a variety of mathematical problem solving situations. Does not fulfill requirements for degrees in mathematics.
Prerequisite(s): Admittance into the MC2-LIFT program.

MATH 5140. From Number to Algebra
3 Credits (3)
The progression from Number to Algebra in the K-12 curriculum as a concrete-to-abstract progression. Key concepts considered across the grade levels include the different uses of variables, equivalence in different contexts, patterns, and ratios. Does not fulfill requirements for degrees in mathematics. Consent of instructor required.
Prerequisite(s): Admittance into the MC2-LIFT program.

MATH 5150. Data Analysis with Applications
3 Credits (3)
Statistical concepts and terminology in professional uses of data by teachers, such as standardized test score reports and educational research; visual displays of data; measures of variation and central tendency; consideration of how K-12 topics in Data Analysis are developed from one grade level to the next. Does not fulfill requirements for degrees in mathematics. Consent of instructor required.
Prerequisite(s): Admittance into the MC2-LIFT program.

MATH 5160. From Measurement to Geometry
3 Credits (3)
The progression from Measurement to Geometry in the K-12 curriculum as a concrete-to abstract progression. Important concepts such as angle, length, and area progress from concrete, measurable situations to more abstract problems which require reasoning and proof. Does not fulfill requirements for degrees in mathematics. Consent of instructor required.
Prerequisite(s): Admittance into the MC2-LIFT program.

MATH 517. Complex Variables
3 Credits (3)
Same as MATH 471 with additional work for graduate students.

MATH 5170. Using Number Throughout the Curriculum
3 Credits (3)
Understand number concepts more deeply by seeing many examples of those concepts applied in other content strands. Develop mathematical knowledge and understanding to build a repertoire of ways for students to practice and review basic number skills and concepts as part of later, more advanced courses. Does not fulfill requirements for degrees in mathematics. Consent of instructor required.
Prerequisite(s): Admittance into the MC2-LIFT program.

MATH 518. Fourier Series and Boundary Value Problems
3 Credits (3)
Same as MATH 472 with additional work for graduate students.

MATH 5180. Geometry with Connections
3 Credits (3)
Connections between Geometry and other K-12 curriculum strands, especially Algebra and Probability / Data Analysis. Address key attributes of geometric concepts by considering their connections within and across grade levels. Does not fulfill requirements for degrees in mathematics.
Prerequisite: Admittance into the MC2-LIFT program.

MATH 5210. Complex Variables
3 Credits (3)
Same as MATH 4210 with additional work for graduate students.
Learning Outcomes

1. Define analytic function, the Cauchy-Riemann equations, and harmonic functions.
2. Recognize elementary analytic functions such as the exponential function, trigonometric functions, and branches of the logarithmic function and their properties.
3. Understand mapping by elementary functions, linear fractional transformations, and powers.
4. Compute line integrals, making appropriate use of the Cauchy-Goursat Theorem, the Cauchy Integral Formula, and Morera's Theorem.
5. Relate complex power series (including Laurent series) to their singularities (removable singularities, poles, and essential singularities).
6. Evaluate improper integrals using the Residue Theorem.

MATH 5220. Fourier Series and Boundary Value Problems
3 Credits (3)
Same as MATH 4220 with additional work for graduate students.
Learning Outcomes

1. Derive the partial differential equations of physics: wave equation, heat equation, Laplace's equation, and Poisson's equation, including boundary/initial values.
2. Use the method of separation of variables to solve the boundary/initial value problems.
3. Recognize the role of orthogonal sets of functions, eigenvalues, eigenfunctions, Fourier series, generalized Fourier series in the method of separation of variables.
4. Compute Fourier integrals and Fourier transforms, and apply them to physical problems.

MATH 527. Introduction to Real Analysis I
3 Credits (3)
Same as MATH 491 with additional work for graduate students.
Learning Outcomes

1. Understand two-sided limits, one-sided limits, limits at infinity, continuity and uniform continuity for functions on the real line.
2. Understand derivatives, differentiability theorems, the Mean Value Theorem, Taylor's Theorem, L'hospital's Rule and the Inverse Function Theorem for functions on the real line.
3. Understand integration on the real line: the Riemann integral, Riemann sums, the Fundamental Theorem of Calculus and improper Riemann integrals.
4. Understand sequences and infinite series of functions, including uniform convergence, limit supremum, limit infimum, power series and analytic functions.

MATH 528. Introduction to Real Analysis II
3 Credits (3)
Same as MATH 492 with additional work for graduate students.
Learning Outcomes

1. Understand the algebraic structure, including planes and linear transformations, of Euclidean spaces.
2. Understand the fundamental notions of metric spaces: limits of functions, interior/closure/boundary of sets, compact sets, connected sets, continuous functions and the Stone-Weierstrass Theorem.
3. Understand derivatives, differentials, tangent planes, the Chain Rule, the Mean Value Theorem, Taylor's Formula and the Inverse Function Theorem for functions on n-dimensional Euclidean space.

4. Understand integration on n-dimensional Euclidean space: Jordan regions, Riemann integration on Jordan Regions, iterated integrals and change of variables.

MATH 5310. Introduction to Topology
3 Credits (3)
Topological spaces: general spaces and specific examples such as metric spaces, Hausdorff spaces and/or normed vector spaces; separation axioms; continuity, compactness, connectedness; related theorems. Crosslisted with: MATH 4310.
Learning Outcomes
1. Define the topology induced from a total ordering or metric.
2. Construct new topological spaces by taking subspaces, products, and quotients.
3. Compare different topologies on the same set to determine which is finer.
4. Determine whether a function is continuous with respect to a particular topology.
5. Classify topological spaces based on fundamental properties (connectedness, compactness, Hausdorff).
6. Construct examples and counter-examples of topological spaces satisfying a given set of properties.

MATH 5320. Logic and Set Theory
3 Credits (3)
Same as MATH 4320 with additional assignments for graduate students.

MATH 5330. Elementary Number Theory
3 Credits (3)
Same as MATH 4330 with additional assignments for graduate students.
Learning Outcomes
1. Apply various properties of the integers to solve number theory problems.
2. Analyze the properties of number theoretic functions.
3. Construct proofs using the concept of a congruence.
4. Solve certain types of Diophantine equations using number theoretic methods.
5. Explain how number theory is related to and used in modern cryptography.

MATH 5340. Abstract Algebra I: Groups and Rings
3 Credits (3)
Same as MATH 4340 with additional work for graduate students. Taught with MATH 4340.
Prerequisite: MATH 5350 or consent of instructor.
Learning Outcomes
1. Apply the fundamental properties of groups to solve abstract algebra problems and analyze the structure of rings.
2. Construct subgroups and factor groups of given groups.
3. Prove key theorems related to cyclic groups, Sylow groups, and permutation groups.
4. Prove that certain algebraic structures are isomorphic using homomorphism properties.
5. Determine group structures based on analyzing information about their subgroups.

MATH 5350. Advanced Linear Algebra
3 Credits (3)
Same as MATH 4350 with additional work for graduate students.
Learning Outcomes
1. Apply the fundamental properties of abstract vector spaces to solve algebraic problems.
2. Define and evaluate linear independence, bases, and dimension within abstract vector spaces.
3. Construct matrix representations for linear transformations between vector spaces.
4. Compute determinants, eigenvalues, and eigenvectors of linear operators.
5. Prove theorems regarding direct sums, kernels (null spaces), and ranges of linear transformations.
6. Apply the properties of adjoint operators to solve problems in inner product spaces.

MATH 5360. Introduction to Real Analysis I
3 Credits (3)
Same as MATH 4360 with additional work for graduate students.
Learning Outcomes
1. Understand two-sided limits, one-sided limits, limits at infinity, continuity and uniform continuity for functions on the real line.
2. Understand derivatives, differentiability theorems, the Mean Value Theorem, Taylor's Theorem, L'hospital's Rule and the Inverse Function Theorem for functions on the real line.
3. Understand integration on the real line: the Riemann integral, Riemann sums, the Fundamental Theorem of Calculus and improper Riemann integrals.
4. Understand sequences and infinite series of functions, including uniform convergence, limit supremum, limit infimum, power series and analytic functions.

MATH 5365. Introduction to Real Analysis II
3 Credits (3)
Same as MATH 4365 with additional work for graduate students.
Learning Outcomes
1. Understand the algebraic structure, including planes and linear transformations, of Euclidean spaces.
2. Understand the fundamental notions of metric spaces: limits of functions, interior/closure/boundary of sets, compact sets, connected sets, continuous functions and the Stone-Weierstrass Theorem.
3. Understand derivatives, differentials, tangent planes, the Chain Rule, the Mean Value Theorem, Taylor's Formula and the Inverse Function Theorem for functions on n-dimensional Euclidean space.
4. Apply the Ascoli Theorem for relative compactness of sets of continuous functions on a compact metric space.

MATH 5410. Complex Analysis
3 Credits (3)
Rigorous treatment of complex differentiation and integration, properties of analytic functions, series and Cauchy's integral representations.
Prerequisite: MATH 3120.
Learning Outcomes
1. Analyze the definitions and properties of analytic functions (the Cauchy-Riemann equations, harmonic functions).
2. Explain and apply Cauchy's Integral Theorem/Formula, primitive functions, Liouville's Theorem and the Maximum Modulus Principle.
3. Construct Taylor/Laurent series, analyze their convergence, and (where applicable) classify isolated singularities (poles, essential).
4. Prove the Residue Theorem and use it to compute line integrals and improper real integrals.

5. Analyze such concepts as the Argument Principle, Rouche's Theorem, Jordan's Lemma, the Schwarz Lemma, and Montel's Theorem.

MATH 5420. Topology I
3 Credits (3)
Connectedness and compactness of topological spaces, introduction to the quotient topology, elementary homotopy theory, the fundamental group, the Seifert-van Kampen theorem.
Prerequisite(s): MATH 5350 and MATH 5365, or consent of instructor.
Learning Outcomes
1. Formulate explicit homotopies between functions and construct homotopy equivalences between topological spaces.
2. Construct standard examples of manifolds and CW-complexes.
3. Prove basic properties of the fundamental groups of topological spaces.
4. Calculate fundamental groups of topological spaces using the Van Kampen Theorem.
5. Construct the covering space corresponding to a particular subgroup.
6. Determine when a group action on a space is a deck transformation action and compute the corresponding base space.

MATH 5425. Topology II
3 Credits (3)
Covering spaces and their classification, singular homology, degree theory, Brouwer's fixed point theorem, CW-complexes and cellular homology, and other applications.
Prerequisite(s): MATH 5420 or consent of instructor.
Learning Outcomes
1. Define singular chain complexes and singular homology.
2. Prove basic properties such as functoriality and homotopy invariance of singular homology groups.
3. Define and calculate cellular homology groups of CW-complexes using degree theory.
4. Prove geometric theorems (Brouwer's Fixed-point Theorem) using properties of homology groups.
5. Calculate singular homology groups of CW-Complexes using the singular/cellular equivalence.

MATH 5428. Topics in Topology
3 Credits
Topics in modern topology. The material covered will reflect current research topics in the field and may vary each time the course is offered. To be taken up to 3 times. May be repeated up to 9 credits.
Learning Outcomes
1. Gain knowledge of advanced methods in the area of topology.
2. Develop potential to explore literature in the area of topology.
3. Develop potential to conduct supervised research in the area of topology.

MATH 5430. Mathematical Structures in Logic
3 Credits (3)
Lattices, distributive lattices, Boolean algebras, Heyting algebras. Lindenbaum-Tarski algebras of classical and intuitionistic logics. Representation theorems. Modal logics and their algebraic counterparts. Kripke semantics. Goedel translation.
Prerequisite: MATH 5320.
Learning Outcomes
1. Explain the basic theory of posets and lattices and apply closure operators, ideals, and completions to solve related problems.
2. Analyze the basic theory of distributive lattices, Boolean algebras, and Heyting algebras, and construct related algebraic structures (homomorphisms, subalgebras).
3. Illustrate the connections between various algebraic systems and the propositional logics they model, and translate statements between an algebraic structure and its dual space.
4. Explain the theoretical motivation for various modal logics and relate properties of modal algebras with their corresponding dual frames.

MATH 5435. Universal Algebra and Model Theory
3 Credits (3)
Universal algebra, homomorphisms, subalgebras, products, congruences. Varieties and class operators. Free algebras and Birkhoff's theorem. Ultraproducts and Los's theorem. Congruence distributive varieties and Jonsson's theorem. Universal classes and quasi-varieties.
Prerequisite: MATH 5320.
Learning Outcomes
1. Analyze standard examples of universal algebras arising from logic, algebra, and linear algebra.
2. Construct and manipulate homomorphisms, subalgebras, products, and congruences within universal algebraic systems.
3. Apply the relationships between equations, free algebras, and varieties to characterize algebraic classes.
4. Classify subdirectly irreducible algebras within various varieties.
5. Apply Jonsson's lemma and Los's theorem to solve complex problems related to varieties.
6. Relate the theory of varieties to broader concepts and special cases within model theory.

MATH 5438. Topics in Foundations
3 Credits
Topics in modern foundations. The material covered will reflect current research topics in the field and may vary each time the course is offered. To be taken up to 3 times. May be repeated up to 9 credits.
Learning Outcomes
1. Gain knowledge of advanced methods in the area of foundations.
2. Develop potential to explore literature in the area of foundations.
3. Develop potential to conduct supervised research in the area of foundations.

MATH 5440. Partial Differential Equations I
3 Credits (3)
The basic equations of mathematical physics. Laplace, Heat and Wave Equations. The method of characteristics, introduction to conservation laws, special solutions.
Prerequisite(s): MATH 5220 and MATH 5365 or consent of instructor.
Learning Outcomes
1. Formulate the basic equations of mathematical physics from physical principles and classify them (elliptic, parabolic, hyperbolic).
2. Apply analytical techniques (separation of variables, Fourier series) to solve the Heat and Wave equations.
3. Solve boundary and initial value problems for classical Partial Differential Equations (PDEs).
4. Interpret special solutions of PDEs in applied contexts.
5. Evaluate the stability and uniqueness of solutions to PDEs.

MATH 5445. Partial Differential Equations II
3 Credits (3)

Sobolev spaces theory: basic definitions and properties, embedding theorems, weak solutions of boundary value problems and variational methods for partial differential equations.
Prerequisite(s): MATH 5460 or consent of instructor.
Learning Outcomes

1. Define and apply key concepts in Sobolev space theory.
2. Apply embedding theorems to analyze function spaces.
3. Formulate and solve boundary value problems for PDEs using weak solutions.
4. Apply variational methods to analyze solutions of partial differential equations.

MATH 5450. Abstract Algebra II: Fields, Rings and Modules
3 Credits (3)
Topics covered include field extensions; algebraic closure; polynomials rings; irreducibility criteria; Noetherian rings; algebraic sets; Nullstellensatz; modules; applications to linear algebra.
Prerequisite(s): MATH 5340 or consent of instructor.
Learning Outcomes

1. Apply factorization properties of rings (UFD, PID, ED) to solve algebraic problems.
2. Apply irreducibility criteria to univariate polynomials over various fields.
3. Construct field extensions and determine their key properties.
4. Analyze the structure and basic properties of modules.
5. Apply the structure theorem for modules over a PID to classify modules.
6. Compute the rational canonical form of a matrix.

MATH 5453. Module Theory and Homological Algebra
3 Credits (3)
Introductory concepts of homological algebra, including projective, injective and flat modules; projective and injective resolutions; exactness of functors; homology of chain complexes; derived functors.
Prerequisite(s): MATH 5450 or consent of instructor.

MATH 5455. Introduction to Commutative Algebra and Algebraic Geometry
3 Credits (3)
Introduction to the basic notions and techniques of modern algebraic geometry, including the necessary commutative algebra foundation. Topics likely to include algebraic and projective varieties, Nullstellensatz, morphisms, rational and regular functions, local properties. Other topics may include Noether normalization, dimension theory, singularities, sheaves, schemes, Grobner bases.
Prerequisite(s): MATH 5450 or consent of instructor.

MATH 5458. Topics in Algebra
3 Credits
Topics in modern algebra. The material covered will reflect current research topics in the field and may vary each time the course is offered. To be taken up to 3 times. May be repeated up to 9 credits.
Learning Outcomes

1. Gain knowledge of advanced methods in the area of algebra.
2. Develop potential to explore literature in the area of algebra.
3. Develop potential to conduct supervised research in the area of algebra.

MATH 5460. Measure and Integration
3 Credits (3)
Measure spaces, measurable functions, extension and decomposition theorems for measures, integration on measure spaces, absolute continuity, iterated integrals.
Prerequisite: MATH 5365 or consent of instructor.
Learning Outcomes

1. Define key concepts in measure theory and distinguish between them.
2. Apply extension and decomposition theorems to determine the structure of measures.
3. Construct the Lebesgue integral on general measure spaces.
4. Compare the Lebesgue integral to the Riemann integral using concrete examples.
5. Evaluate and manipulate iterated integrals using absolute continuity and Fubini's theorem.

MATH 5463. Real Analysis
3 Credits (3)
Differentiation, Lp spaces, Banach spaces, measure and topology, other selected topics.
Prerequisite: MATH 5460.
Learning Outcomes

1. Analyze the topological structure, duality properties, and important inequalities of Lp spaces.
2. Apply concepts from measure theory and topology to analyze the behavior of functions and sets in real analysis.
3. Evaluate differentiability and integrability using advanced real analysis techniques.
4. Distinguish between pointwise and norm-based convergence of function sequences.
5. Solve problems involving the completeness, continuity, and compactness of Banach spaces.

MATH 5465. Introduction to Functional Analysis
3 Credits (3)
Banach spaces. The three basic principles: uniform boundedness principle, closed graph/open mapping theorems, Hahn-Banach theorem.
Prerequisite: MATH 5463, or consent of instructor.
Learning Outcomes

1. Define and analyze the structure of normed and Banach spaces.
2. Apply the Hahn-Banach Theorem to investigate the properties of dual spaces.
3. Apply the Uniform Boundedness Principle, the Open Mapping Theorem, and the Closed Graph Theorem to solve problems in functional analysis.
4. Define the properties of compact and self-adjoint operators.
5. Apply spectral theory to analyze self-adjoint operators.

MATH 5468. Topics in Analysis
3 Credits
Topics in modern analysis. The material covered will reflect current research topics in the field and may vary each time the course is offered. To be taken up to 3 times. May be repeated up to 9 credits.
Learning Outcomes

1. Gain knowledge of advanced methods in the area of analysis.
2. Develop potential to explore literature in the area of analysis.
3. Develop potential to conduct supervised research in the area of analysis.

MATH 563. Algebra with Connections
3 Credits (3)

Connections between Algebra and other K-12 curriculum strands, especially Geometry and Probability / Data Analysis. Apply algebraic modeling and reasoning to a variety of mathematical problem solving situations. Does not fulfill requirements for degrees in mathematics. Consent of instructor required.
Prerequisite(s): Admittance into the MC2-LIFT program.

MATH 564. From Number to Algebra
3 Credits (3)
The progression from Number to Algebra in the K-12 curriculum as a concrete-to-abstract progression. Key concepts considered across the grade levels include the different uses of variables, equivalence in different contexts, patterns, and ratios. Does not fulfill requirements for degrees in mathematics. Consent of instructor required.
Prerequisite(s): Admittance into the MC2-LIFT program.

MATH 567. From Measurement to Geometry
3 Credits (3)
The progression from Measurement to Geometry in the K-12 curriculum as a concrete-to abstract progression. Important concepts such as angle, length, and area progress from concrete, measurable situations to more abstract problems which require reasoning and proof. Does not fulfill requirements for degrees in mathematics. Consent of instructor required.
Prerequisite(s): Admittance into the MC2-LIFT program.

MATH 581. Abstract Algebra II: Fields, Rings and Modules
3 Credits (3)
Topics covered include field extensions; algebraic closure; polynomials rings; irreducibility criteria; Noetherian rings; algebraic sets; Nullstellensatz; modules; applications to linear algebra.
Prerequisite(s): MATH 526 or consent of instructor.

MATH 582. Module Theory and Homological Algebra
3 Credits (3)
Introductory concepts of homological algebra, including projective, injective and flat modules; projective and injective resolutions; exactness of functors; homology of chain complexes; derived functors.
Prerequisite(s): MATH 581 or consent of instructor.

MATH 583. Introduction to Commutative Algebra and Algebraic Geometry
3 Credits (3)
Introduction to the basic notions and techniques of modern algebraic geometry, including the necessary commutative algebra foundation. Topics likely to include algebraic and projective varieties, Nullstellensatz, morphisms, rational and regular functions, local properties. Other topics may include Noether normalization, dimension theory, singularities, sheaves, schemes, Grobner bases.
Prerequisite(s): MATH 581 or consent of instructor.

MATH 593. Measure and Integration
3 Credits (3)
Measure spaces, measurable functions, extension and decomposition theorems for measures, integration on measure spaces, absolute continuity, iterated integrals.
Prerequisite: MATH 528 or consent of instructor.

MATH 5996. Special Topics
1-3 Credits
Specific subjects to be announced in the Schedule of Classes. May be for unlimited credit with approval of the department.
Learning Outcomes
1. Analyze advanced concepts in the selected topic area.
2. Apply specialized mathematical methods to solve complex problems within the topic area.
3. Critique current research and developments in the topic area.
4. Communicate findings from the topic area in professional written and oral formats.

MATH 5997. Directed Reading
1-6 Credits
Readings. May be repeated for a maximum of 6 credits. Consent of instructor required. Graded: S/U.
Learning Outcomes
1. Summarize key concepts from assigned mathematical literature in a written report.
2. Critique mathematical arguments presented in advanced texts.
3. Synthesize information from multiple mathematical sources to form a coherent overview.
4. Communicate understanding of the assigned readings through a written report or oral presentation.

MATH 5999. Master's Thesis
1-15 Credits
Thesis. May be repeated up to 99 credits.
Learning Outcomes
1. Formulate a significant mathematical research problem suitable for a Master's thesis.
2. Apply appropriate mathematical methods to investigate the research problem.
3. Interpret research results in the context of existing mathematical literature.
4. Produce a Master's thesis meeting scholarly standards.
5. Defend the Master's thesis in an oral examination.

MATH 6991. Doctoral Research
1-15 Credits
Research. May be repeated up to 88 credits.
Learning Outcomes
1. Identify and refine an original doctoral research problem into a testable hypothesis or clear objectives.
2. Design a rigorous research plan for the doctoral research.
3. Implement the initial stages of the rigorous research plan.
4. Evaluate initial research findings within the academic context.
5. Communicate research progress and results through appropriate scholarly formats (written paper, oral presentation).

MATH 6996. Special Topics
1-15 Credits
Selected topics. May be repeated up to 88 credits.
Learning Outcomes
1. Integrate advanced mathematical theories to solve problems related to the selected topic.
2. Solve complex problems requiring specialized mathematical tools.
3. Critique research trends and debates in the topic area.
4. Present an advanced analysis of the topic area through written and oral communication.

MATH 7000. Doctoral Dissertation
1-15 Credits
Dissertation. May be repeated up to 88 credits.
Learning Outcomes
1. Conduct original research advancing knowledge in mathematics.
2. Apply rigorous methodologies to address complex research questions.

3. Integrate research findings into the scholarly literature through a publishable paper.
4. Produce a doctoral dissertation meeting professional standards.
5. Defend the doctoral dissertation in an oral examination.

Statistics Courses

STAT 3110. Statistics for Engineers and Scientists
3 Credits (3)
Modern probability and statistics with applications to the engineering sciences.
Prerequisite: C - or better in MATH 1521G or MATH 1521H.
Learning Outcomes
1. Apply probability concepts and statistical methods to analyze data relevant to engineering and scientific problems.
2. Interpret descriptive statistics, probability distributions, and inferential techniques in context-specific applications.
3. Construct confidence intervals and perform hypothesis tests to support decision-making in engineering contexts.
4. Use statistical software and tools to model, visualize, and communicate results from experimental and observational data.

STAT 4210. Probability: Theory and Applications
3 Credits (3)
Basic probability distributions including binomial, normal; random variables, expectation; laws of large numbers; central limit theorem.
Prerequisite(s): C- or better in MATH 2530G and C- or better in at least one-3000 level MATH or STAT course.
Learning Outcomes
1. Be able to compute discrete probabilities using combinatorial methods.
2. Understand and use conditional probability, independence and Bayes' Formula to compute probabilities.
3. Demonstrate understanding and use of discrete and continuous random variables including Bernoulli, Binomial, Poisson, Geometric, Normal, Exponential and Gamma.
4. Understand joint and conditional probability distributions and use them to compute probabilities.
5. Learn about basic limit theorems such as the Central Limit Theorem and the Laws of Large Numbers.

STAT 4220. Statistics: Theory and Applications
3 Credits (3)
Point and interval estimation; sufficiency; hypothesis testing; regression; analysis of variance; chi-square tests.
Prerequisite: C- or better in STAT 4210.
Learning Outcomes
1. Explain and apply the principles of point and interval estimation, including properties such as unbiasedness and consistency.
2. Analyze statistical models using concepts of sufficiency and likelihood to support inference procedures.
3. Conduct and interpret hypothesis tests, including those based on regression, ANOVA, and chi-square methods.
4. Evaluate the appropriateness of statistical techniques for real-world data and communicate results effectively in applied contexts.

STAT 5210. Probability: Theory and Applications
3 Credits (3)
Same as STAT 4210 with additional work for graduate students.
Learning Outcomes
1. Be able to compute discrete probabilities using combinatorial methods.
2. Understand and use conditional probability, independence and Bayes' Formula to compute probabilities.
3. Demonstrate understanding and use of discrete and continuous random variables including Bernoulli, Binomial, Poisson, Geometric, Normal, Exponential and Gamma.
4. Understand joint and conditional probability distributions and use them to compute probabilities.
5. Learn about basic limit theorems such as the Central Limit Theorem and the Laws of Large Numbers.

STAT 5220. Statistics: Theory and Applications
3 Credits (3)
Same as STAT 4220 with additional work for graduate students.
Learning Outcomes
1. Explain and apply the principles of point and interval estimation, including properties such as unbiasedness and consistency.
2. Analyze statistical models using concepts of sufficiency and likelihood to support inference procedures.
3. Conduct and interpret hypothesis tests, including those based on regression, ANOVA, and chi-square methods.
4. Evaluate the appropriateness of statistical techniques for real-world data and communicate results effectively in applied contexts.

STAT 5230. Elementary Stochastic Processes
3 Credits (3)
Markov chains, Poisson processes, Brownian motion, branching processes, and queuing processes, with applications to the physical, biological, and social sciences.
Prerequisite: STAT 5210 or consent of instructor.
Learning Outcomes
1. Apply conditional expectation and generating functions to analyze simple stochastic processes.
2. Describe and distinguish among key stochastic processes (Markov chains, Poisson processes).
3. Apply stochastic models to evaluate problems in the physical, biological, and social sciences.
4. Evaluate the long-term behavior of stochastic processes using transition probabilities and limiting distributions.
5. Analyze the Brownian motion process and its fundamental properties.

STAT 5310. Foundations of Probability
3 Credits (3)
Probability spaces, expectation and conditional expectation, limit theorems and laws of large numbers.
Prerequisite: MATH 5460.
Learning Outcomes
1. Define an abstract probability space via measure theory, regarding expectation as abstract integration and study its properties such as linearity and monotonicity.
2. Study the convergence of random variables and Weak and Strong Laws of Large Numbers.
3. Compare and employ almost sure convergence, convergence in probability, convergence in Lp, and convergence in distribution to analyze the behavior of sequences of random variables.
4. Define the weak convergence of probability measures, apply it to characterize the weak convergence on the set of real numbers, and study Central Limit Theorems.

5. Introduce the concept of stochastic process, define martingales and study the martin-gale convergence theorems.

STAT 5320. Advanced Topics in Stochastic Processes
3 Credits (3)
Markov processes, martingales, Brownian motion, the Ito calculus, stochastic differential equations.
Prerequisite: STAT 5310.
Learning Outcomes
1. Analyze the structure and behavior of continuous-time Markov processes and martingales.
2. Derive the fundamental properties of Brownian motion and explain its role in stochastic modeling.
3. Apply Ito calculus to solve stochastic differential equations in theoretical contexts.
4. Formulate stochastic differential equations from applied problems.
5. Explain and apply the Feynman-Kac formula, the martingale problem, and the Girsanov formula.
6. Evaluate stochastic models arising in various disciplines.
7. Interpret the solutions of stochastic models using advanced probability theory.

STAT 5330. Continuous Multivariate Analysis
3 Credits (3)
Theory and applications of the multivariate normal distribution.
Prerequisite: STAT 5220, or consent of instructor.
Learning Outcomes
1. Explain the theoretical foundations and properties of the multivariate normal distribution.
2. Apply principal component analysis and linear discriminant analysis to solve multivariate problems.
3. Evaluate the structure and relationships among multiple continuous variables using matrix-based statistical methods.
4. Interpret results from multivariate analyses in real-world applications.
5. Communicate findings from multivariate analyses clearly in a written report.

STAT 5335. Linear Models
3 Credits (3)
Core topics include distribution of quadratic forms, theory of regression, analysis of variance and covariance in linear models. Advanced topics chosen from random and mixed linear models, generalized linear, growth curve, and nonlinear models, quartile and copula regression. May be repeated up to 6 credits.
Prerequisite: STAT 5330.
Learning Outcomes
1. Analyze linear models using the distribution of quadratic forms and the theory of least squares estimation.
2. Apply regression, ANOVA, and ANCOVA models to determine relationships among variables.
3. Evaluate the assumptions and limitations of linear modeling frameworks (random and mixed effects models).
4. Explain the theory behind generalized linear models, nonlinear models, and quantile regression.
5. Assess the applicability of advanced modeling techniques to complex data sets.

STAT 5340. Advanced Theory of Statistics I
3 Credits (3)
Testing hypotheses, probability and sufficiency, uniformly most powerful tests, unbiasedness, invariance, and minimax principle.
Prerequisite: STAT 5220 or consent of instructor.
Learning Outcomes
1. Explain foundational concepts in statistical inference (hypothesis testing, sufficiency).
2. Construct statistical tests using criteria such as unbiasedness and invariance.
3. Analyze the properties of statistical tests using the minimax principle.
4. Apply the Neyman-Pearson lemma to derive uniformly most powerful (UMP) tests.
5. Evaluate the theoretical properties of statistical procedures.
6. Justify the use of statistical procedures in complex inference problems based on theoretical properties.

STAT 5345. Advanced Theory of Statistics II
3 Credits (3)
Estimation of parameters; unbiased estimators; equivariance; Bayes properties; large sample theory and optimality.
Prerequisite: STAT 5340 or consent of instructor.
Learning Outcomes
1. Analyze methods for estimating parameters and their properties (unbiased, consistent, efficient).
2. Apply the principles of equivariance to construct and evaluate estimators.
3. Construct and evaluate Bayes estimators in various contexts.
4. Evaluate estimators using large sample theory and asymptotic optimality criteria.
5. Compare classical and Bayesian approaches to estimation.
6. Justify the selection of estimation methods based on theoretical and practical considerations.

STAT 5348. Topics in Probability and Statistics
3 Credits
Topics in modern probability and statistics. The material covered will reflect current research topics in the field and may vary each time the course is offered. To be taken up to 3 times. May be repeated up to 9 credits.
Learning Outcomes
1. Gain knowledge of advanced methods in the areas of probability and statistics.
2. Develop potential to explore literature in the areas of of probability and statistics.
3. Develop potential to conduct supervised research in the areas of of probability and statistics.

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