# MATHEMATICS (MATH)

**MATH100. INTRODUCTORY TOPICS FOR CALCULUS. 3.0 Semester Hrs.**
(S) An introduction and/or review of topics which are essential to the background of an undergraduate student at CSM. This course serves as a preparatory course for the Calculus curriculum and includes material from Algebra, Trigonometry, Mathematical Analysis, and Calculus. Topics include basic algebra and equation solving, solutions of inequalities, trigonometric functions and identities, functions of a single variable, continuity, and limits of functions. Does not apply toward undergraduate degree or GPA. 3 hours lecture; 3 semester hours.

**MATH111. CALCULUS FOR SCIENTISTS AND ENGINEERS I. 4.0 Semester Hrs.**
(I, II, S) First course in the calculus sequence, including elements of plane geometry. Functions, limits, continuity, derivatives and their application. Definite and indefinite integrals; Prerequisite: precalculus. 4 hours lecture; 4 semester hours. Approved for Colorado Guaranteed General Education transfer. Equivalency for GT-MA1.

**MATH112. CALCULUS FOR SCIENTISTS AND ENGINEERS II. 4.0 Semester Hrs.**
Equivalent with MATH122,
Vectors, applications and techniques of integration, infinite series, and an introduction to multivariate functions and surfaces. 4 hours lecture; 4 semester hours. Approved for Colorado Guaranteed General Education transfer. Equivalency for GT-MA1. Prerequisite: Grade of C- or better in MATH111.

**MATH122. CALCULUS FOR SCIENTISTS AND ENGINEERS II HONORS. 4.0 Semester Hrs.**
Equivalent with MATH112,
Same topics as those covered in MATH112 but with additional material and problems. Prerequisite: Grade of C- or better in MATH111.

**MATH198. SPECIAL TOPICS. 6.0 Semester Hrs.**
(I, II) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once. Prerequisite: none. Variable credit; 1 to 6 credit hours. Repeatable for credit under different titles.

**MATH199. INDEPENDENT STUDY. 1-6 Semester Hr.**
(I, II) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit; 1 to 6 credit hours. Repeatable for credit.

**MATH201. INTRODUCTION TO STATISTICS. 3.0 Semester Hrs.**
Equivalent with MATH323,
This course is an introduction to Statistics, including fundamentals of experimental design and data collection, the summary and display of data, propagation of error, interval estimation, hypothesis testing, and linear regression with emphasis on applications to science and engineering. Prerequisite: MATH111.
**Course Learning Outcomes**

- Choose appropriate descriptive statistics and graphical displays to summarize a data set.
- Distinguish between commonly used random variables and sampling distributions in order to identify the appropriate statistical tools based on the context of a given problem.
- Identify, formulate, and evaluate appropriate tools for statistical inference based on the context of a given problem.
- Disseminate/Communicate statistical analysis.

**MATH213. CALCULUS FOR SCIENTISTS AND ENGINEERS III. 4.0 Semester Hrs.**
Multivariable calculus, including partial derivatives, multiple integrals, and vector calculus. 4 hours lecture; 4 semester hours. Approved for Colorado Guaranteed General Education transfer. Equivalency for GT-MA1. Prerequisites: Grade of C- or better in MATH112 or MATH122. Corequisites: CSCI128 or CSCI102.

**MATH223. CALCULUS FOR SCIENTISTS AND ENGINEERS III HONORS. 4.0 Semester Hrs.**
Same topics as those covered in MATH213 but with additional material and problems. Prerequisite: MATH112 with a grade of B- or higher, MATH112 with a grade of B- or higher.

**MATH225. DIFFERENTIAL EQUATIONS. 3.0 Semester Hrs.**
Classical techniques for first and higher order equations and systems of equations. Laplace transforms. Phase-plane and stability analysis of non-linear equations and systems. Applications from physics, mechanics, electrical engineering, and environmental sciences. Prerequisites: Grade of C- or better in MATH112 or MATH122. Corequisites: CSCI128 or CSCI102. 3 hours lecture; 3 semester hours.

**MATH235. DIFFERENTIAL EQUATIONS HONORS. 3.0 Semester Hrs.**
Same topics as those covered in MATH225 but with additional material and problems. 3 hours lecture; 3 semester hours. Prerequisite: Grade of B- or better in MATH112 or MATH 113 or MATH122.

**MATH298. SPECIAL TOPICS. 1-6 Semester Hr.**
(I, II) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once. Prerequisite: none. Variable credit; 1 to 6 credit hours. Repeatable for credit under different titles.

**MATH299. INDEPENDENT STUDY. 1-6 Semester Hr.**
(I, II) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit; 1 to 6 credit hours. Repeatable for credit.

**MATH300. FOUNDATIONS OF ADVANCED MATHEMATICS. 3.0 Semester Hrs.**
(WI) This course is an introduction to communication in mathematics. This writing intensive course provides a transition from the Calculus sequence to theoretical mathematics curriculum in CSM. Topics include logic and recursion, techniques of mathematical proofs, reading and writing proofs. 3 hours lecture; 3 semester hours. Prerequisite: MATH112 or MATH122.
**Course Learning Outcomes**

- Apply the rules of logic in order to construct proofs. In particular, students should be able to work symbolically with connectives and quantifiers to produce logically valid, correct and clear arguments.
- Apply abstract definitions and previous results (from areas such as set theory, discrete mathematics, introductory analysis, or introductory abstract algebra) as well as create intuition-forming examples or counterexamples in order to prove or disprove a conjecture.
- Construct direct and indirect proofs and proofs by induction and determine the appropriateness of each type in a particular setting

(such as set theory, discrete mathematics, introductory analysis, or introductory abstract algebra).
- Write solutions to problems and proofs of theorems that meet rigorous standards based on content, organization and coherence, argument and support, and style and mechanics.
- Analyze and critique proofs with respect to logic and correctness.

**MATH301. INTRODUCTION TO ANALYSIS. 3.0 Semester Hrs.**
Equivalent with MATH401,
This course is a first course in real analysis that lays out the context and motivation of analysis in terms of the transition from power series to those less predictable series. The course is taught from a historical perspective. It covers an introduction to the real numbers, sequences and series and their convergence, real-valued functions and their continuity and differentiability, sequences of functions and their pointwise and uniform convergence, and Riemann-Stieltjes integration theory. 3 hours lecture; 3 semester hours. Prerequisite: MATH300.

**MATH307. INTRODUCTION TO SCIENTIFIC COMPUTING. 3.0 Semester Hrs.**
Equivalent with CSCI407,MATH407,
This course is designed to introduce scientific computing to scientists and engineers. Students in this course will be taught various numerical methods and programming techniques to solve basic scientific problems. Emphasis will be made on implementation of various numerical and approximation methods to efficiently simulate several applied mathematical models. 3 hours lecture; 3 semester hours. Prerequisite: MATH213 or MATH223; CSCI102 or CSCI128 or CSCI200. Co-requisite: MATH225 or MATH235.

**MATH310. INTRODUCTION TO MATHEMATICAL MODELING. 3.0 Semester Hrs.**
An introduction to modeling and communication in mathematics. A writing intensive course providing a transition from the core math sequence to the upper division AMS curriculum. Topics include a variety of mathematical and statistical modeling techniques. Students will formulate and solve applied problems and will present results orally and in writing. In addition, students will be introduced to the mathematics software that will be used in upper division courses. Prerequisite: MATH201, MATH213, MATH225; CSCI128.
**Course Learning Outcomes**

- Formulate and investigate mathematical and statistical models
- Identify mulitple types of models and techniques
- Communicate the results of a modeling study in writing and orally

**MATH324. STATISTICAL MODELING. 3.0 Semester Hrs.**
Linear regression, analysis of variance, and design of experiments, focusing on the construction of models and evaluation of their fit. Techniques covered will include stepwise and best subsets regression, variable transformations, and residual analysis. Emphasis will be placed on the analysis of data with statistical software. Prerequisite: MATH201.

**MATH332. LINEAR ALGEBRA. 3.0 Semester Hrs.**
Systems of linear equations, matrices, determinants and eigenvalues. Linear operators. Abstract vector spaces. Applications selected from linear programming, physics, graph theory, and other fields. Prerequisite: CSCI128; MATH112, MATH122, or PHGN100.

**MATH334. INTRODUCTION TO PROBABILITY. 3.0 Semester Hrs.**
An introduction to the theory of probability essential for problems in science and engineering. Topics include axioms of probability, combinatorics, conditional probability and independence, discrete and continuous probability density functions, expectation, jointly distributed random variables, Central Limit Theorem, laws of large numbers. 3 hours lecture, 3 semester hours. Prerequisite: CSCI128 or CSCI102; MATH213, MATH223.

**MATH335. INTRODUCTION TO MATHEMATICAL STATISTICS. 3.0 Semester Hrs.**
An introduction to the theory of statistics essential for problems in science and engineering. Topics include sampling distributions, methods of point estimation, methods of interval estimation, significance testing for population means and variances and goodness of fit, linear regression, analysis of variance. 3 hours lecture, 3 semester hours. Prerequisite: MATH334.

**MATH342. HONORS LINEAR ALGEBRA. 3.0 Semester Hrs.**
Same topics as those covered in MATH332 but with additional material and problems as well as a more rigorous presentation. 3 hours lecture; 3 semester hours. Prerequisite: MATH213, MATH223.

**MATH398. SPECIAL TOPICS. 6.0 Semester Hrs.**
(I, II) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once. Prerequisite: none. Variable credit; 1 to 6 credit hours. Repeatable for credit under different titles.

**MATH399. INDEPENDENT STUDY. 0.5-6 Semester Hr.**
(I, II) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit; 1 to 6 credit hours. Repeatable for credit.

**MATH408. COMPUTATIONAL METHODS FOR DIFFERENTIAL EQUATIONS. 3.0 Semester Hrs.**
This course is designed to introduce computational methods to scientists and engineers for developing differential equations based computer models. Students in this course will be taught various numerical methods and programming techniques to simulate systems of nonlinear ordinary differential equations. Emphasis will be on implementation of various numerical and approximation methods to efficiently simulate several systems of nonlinear differential equations. Prerequisite: MATH307. 3 hours lecture, 3 semester hours.

**MATH431. MATHEMATICAL BIOLOGY. 3.0 Semester Hrs.**
This course will discuss methods for building and solving both continuous and discrete mathematical models. These methods will be applied to population dynamics, epidemic spread, pharmacokinetics and modeling of physiologic systems. Modern Control Theory will be introduced and used to model living systems. Some concepts related to self-organizing systems will be introduced. Prerequisite: MATH307, MATH310 or BIOL300, and MATH332 or MATH342.
**Course Learning Outcomes**

- Describe the assumptions and implementations of some of the classical models of mathematical biology in your own words.
- Derive models for biological phenomena including both discrete and continuous classes of models.
- Solve models using both analytical and numerical techniques.
- Apply techniques for model analysis and interpret results.
- Generate and professionally communicate novel results in mathematical biology.

**MATH432. SPATIAL STATISTICS. 3.0 Semester Hrs.**
Modeling and analysis of data observed in a 2- or 3-dimensional region. Random fields, variograms, covariances, stationarity, nonstationarity, kriging, simulation, Bayesian hierarchical models, spatial regression,

SAR, CAR, QAR, and MA models, Geary/Moran indices, point processes, K-function, complete spatial randomness, homogeneous and inhomogeneous processes, marked point processes. Prerequisite: MATH324, MATH332, MATH335.

**MATH433. TIME SERIES AND ITS APPLICATIONS. 3.0 Semester Hrs.**
Equivalent with BELS331,BELS433,MACS433,MATH331,
Exploratory Analysis of Time Series, Stationary Time Series, Autocorrelation and Partial Autocorrelation, Autoregressive Moving Average (ARMA) Models, Forecasting, Estimation, ARIMA Models for Nonstationary Data, Multiplicative Seasonal ARIMA Models, The Spectral Density, Periodogram and Discrete Fourier Transform, Spectral Estimation, Multiple Series and Cross-Spectra, Linear Filters, Long Memory ARMA and Fractional Differencing, GARCH Models, Threshold Models, Regression with Autocorrelated Errors, Lagged Regression, Multivariate ARMAX Models. Prerequisite: MATH324, MATH335.
**Course Learning Outcomes**

- This course is designed to be useful for students facing the analysis of time-correlated data in the physical, biological, and social sciences.

**MATH436. ADVANCED STATISTICAL MODELING. 3.0 Semester Hrs.**
Modern methods for constructing and evaluating statistical models. Topics include generalized linear models, generalized additive models, hierarchical Bayes methods, and resampling methods. Time series models, including moving average, autoregressive, and ARIMA models, estimation and forecasting, confidence intervals. 3 hours lecture; 3 semester hours. Prerequisite: MATH332, MATH324.
**Course Learning Outcomes**

- Fit and interpret standard and weighted linear models
- Fit and interpret ANOVA models
- Fit and interpret generalized linear models
- Fit models to time series data
- Perform diagnostic tests on statistical models

**MATH437. MULTIVARIATE ANALYSIS. 3.0 Semester Hrs.**
Introduction to applied multivariate techniques for data analysis. Topics include principal components, cluster analysis, MANOVA and other methods based on the multivariate Gaussian distribution, discriminant analysis, classification with nearest neighbors. 3 hours lecture; 3 semester hours. Prerequisite: MATH335 or MATH201, MATH332 or MATH342, MATH324.

**MATH438. STOCHASTIC MODELS. 3.0 Semester Hrs.**
(II) An introduction to stochastic models applicable to problems in engineering, physical science, economics, and operations research. Markov chains in discrete and continuous time, Poisson processes, and topics in queuing, reliability, and renewal theory. Prerequisite: MATH332, MATH334.

**MATH439. SURVIVAL ANALYSIS. 3.0 Semester Hrs.**
Basic theory and practice of survival analysis. Topics include survival and hazard functions, censoring and truncation, parametric and non-parametric inference, hypothesis testing, the proportional hazards model, model diagnostics. 3 hours lecture; 3 semester hours. Prerequisite: MATH335.

**MATH440. PARALLEL SCIENTIFIC COMPUTING. 3.0 Semester Hrs.**
Equivalent with CSCI440,
This course is designed to facilitate students' learning of high-performance computing concepts and techniques to efficiently perform large-scale mathematical modelling and data analysis using modern high-performance architectures (e.g. multi-core processors, multiple processors, and/or accelerators). Emphasis will be placed on analysis and implementation of various scientific computing algorithms in high-level languages using their interfaces for parallel or accelerated computing. Use of scripting to manage HPC workflows is included. Prerequisite: MATH307, CSCI200.

**MATH454. COMPLEX ANALYSIS. 3.0 Semester Hrs.**
The complex plane. Analytic functions, harmonic functions. Mapping by elementary functions. Complex integration, power series, calculus of residues. Conformal mapping. Prerequisite: MATH225 or MATH235 and MATH213 or MATH223. 3 hours lecture, 3 semester hours.

**MATH455. PARTIAL DIFFERENTIAL EQUATIONS. 3.0 Semester Hrs.**
Linear partial differential equations, with emphasis on the classical second-order equations: wave equation, heat equation, Laplace's equation. Separation of variables, Fourier methods, Sturm-Liouville problems. Prerequisites: MATH225 or MATH235 and MATH213 or MATH223. 3 hours lecture; 3 semester hours.

**MATH457. INTEGRAL EQUATIONS. 3.0 Semester Hrs.**
This is an introductory course on the theory and applications of integral equations. Abel, Fredholm and Volterra equations. Fredholm theory: small kernels, separable kernels, iteration, connections with linear algebra and Sturm-Liouville problems. Applications to boundary-value problems for Laplace's equation and other partial differential equations. Prerequisites: MATH332 or MATH342, and MATH455. 3 hours lecture; 3 semester hours.

**MATH458. ABSTRACT ALGEBRA. 3.0 Semester Hrs.**
This course is an introduction to the concepts of contemporary abstract algebra and applications of those concepts in areas such as physics and chemistry. Topics include groups, subgroups, isomorphisms and homomorphisms, rings, integral domains and fields. Prerequisites: MATH300. 3 hours lecture; 3 semester hours.

**MATH459. ASYMPTOTICS. 3.0 Semester Hrs.**
Equivalent with MATH559,
Asymptotic methods are used to find approximate solutions to problems when exact solutions are unavailable or too complicated to be useful. A broad range of asymptotic methods is developed, covering algebraic problems, integrals and differential equations. Prerequisites: MATH213 and MATH225. 3 hours lecture; 3 semester hours.
**Course Learning Outcomes**

- Use asymptotic methods to solve algebraic problems.
- Use asymptotic methods to estimate integrals
- Use asymptotic methods to solve differential equations.

**MATH470. MATHEMATICAL MODELING OF SPATIAL PROCESSES IN BIOLOGY. 3.0 Semester Hrs.**
(II) This course is an introduction to mathematical modeling of spatial processes in biology. The emphasis is on partial differential equation models from a diverse set of biological topics such as cellular homeostasis, muscle dynamics, neural dynamics, calcium handling, epidemiology, and chemotaxis. We will survey a variety of models and analyze their results in the context of the biology. Mathematically, we will examine the diffusion equation, advection equation, and combinations of the two that include reactions. There will be a significant computational component to the course including bi-weekly computational labs; students will solve the model equations and perform computations using MATLAB. Prerequisite: MATH431, MATH455 or equivalent courses and familiarity with MATLAB.
**Course Learning Outcomes**

- Describe classical spatial-temporal models in mathematical biology including diffusion-reaction, advection-reaction, and advection-diffusion-reaction
- Derive partial differential equations models for spatial-temporal phenomena
- Implement analytical and numerical techniques to solve and analyze spatial-temporal models
- Assimilate current literature, extend it in a final project that advances the field, and communicate results professionally and effectively

**MATH472. MATHEMATICAL AND COMPUTATIONAL NEUROSCIENCE. 3.0 Semester Hrs.**
This course will focus on mathematical and computational techniques applied to neuroscience. Topics will include nonlinear dynamics, hysteresis, the cable equation, and representative models such as Wilson-Cowan, Hodgkin-Huxley, and FitzHugh-Nagumo. Applications will be motivated by student interests. In addition to building basic skills in applied math, students will gain insight into how mathematical sciences can be used to model and solve problems in neuroscience; develop a variety of strategies (computational, theoretical, etc.) with which to approach novel mathematical situations; and hone skills for communicating mathematical ideas precisely and concisely in an interdisciplinary context. In addition, the strong computational component of this course will help students to develop computer programming skills and apply appropriate technological tools to solve mathematical problems. 3 hours lecture; 3 semester hours. Prerequisite: MATH431.
**Course Learning Outcomes**

- Describe the classical models of mathematical neuroscience including Hodgkin-Huxley, Wilson-Cowan, and FitzHugh-Nagumo
- Implement analytical and numerical techniques to analyze models at different spatial and temporal scales;
- Apply concepts from nonlinear dynamics including phase plane analysis, bifurcation theory, and model reduction techniques to analyze models in neuroscience.
- Assimilate current literature, extend it in a final project that advances the field, and communicate results professionally and effectively.

**MATH482. STATISTICS PRACTICUM (CAPSTONE). 3.0 Semester Hrs.**
This is the capstone course in the Statistics option. Students will apply statistical principles to data analysis through advanced work, leading to a written report and an oral presentation. Choice of project is arranged between the student and the individual faculty member who will serve as advisor. Prerequisite: MATH335, MATH324, MATH436.
**Course Learning Outcomes**

- Gain hands-on data analysis experience on a substantial problem seeing it all the way through.
- Communicate effectively with clients, who might have limited statistical background.
- Develop well-documented and reproducible code.
- Document results in a technical report and potentially co-author a scientific publication.

**MATH484. MATHEMATICAL AND COMPUTATIONAL MODELING (CAPSTONE). 3.0 Semester Hrs.**
This is the capstone course in the Computational and Applied Mathematics option. Students will apply computational and applied mathematics modeling techniques to solve complex problems in biological, engineering and physical systems. Mathematical methods and algorithms will be studied within both theoretical and computational contexts. The emphasis is on how to formulate, analyze and use nonlinear modeling to solve typical modern problems. Prerequisite: MATH431, MATH307, MATH455.
**Course Learning Outcomes**

- Construct, interpret, and critique fundamental models of physical, chemical, and biological systems throughout the fundamental and applied sciences.
- Utilize computational tools, such as MATLAB, to simulate behavior arising from mathematical models
- Describe and interpret, via oral and written means, pertinent information obtained from mathematical analysis and simulation in order to draw scientific conclusions concerning applied model

**MATH491. UNDERGRADUATE RESEARCH. 1-3 Semester Hr.**
(I) (WI) Individual investigation under the direction of a department faculty member. Written report required for credit. Variable - 1 to 3 semester hours. Repeatable for credit to a maximum of 12 hours.

**MATH498. SPECIAL TOPICS. 1-6 Semester Hr.**
(I, II) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once. Prerequisite: none. Variable credit; 1 to 6 credit hours. Repeatable for credit under different titles.

**MATH499. INDEPENDENT STUDY. 0.5-6 Semester Hr.**
(I, II) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit; 1 to 6 credit hours. Repeatable for credit.

**MATH500. LINEAR VECTOR SPACES. 3.0 Semester Hrs.**
(I) Finite dimensional vector spaces and subspaces: dimension, dual bases, annihilators. Linear transformations, matrices, projections, change of basis, similarity. Determinants, eigenvalues, multiplicity. Jordan form. Inner products and inner product spaces with orthogonality and completeness. Prerequisite: MATH301, MATH332. 3 hours lecture; 3 semester hours.
**Course Learning Outcomes**

- to be completed at a later date

**MATH501. APPLIED ANALYSIS. 3.0 Semester Hrs.**
(II) Fundamental theory and tools of applied analysis. Students in this course will be introduced to Banach, Hilbert, and Sobolev spaces; bounded and unbounded operators defined on such infinite dimensional spaces; and associated properties. These concepts will be applied to understand the properties of differential and integral operators occurring in mathematical models that govern various biological, physical and engineering processes. Prerequisites: MATH301 or equivalent.
**Course Learning Outcomes**

- 1) Show that a set or function is Lebesgue measurable. 2) Be able to describe Lp spaces and their properties. 3) Apply the Banach fixed point theorem. 4) Find the weak derivative of a function. 5) Solve problems involving metric spaces and their properties. 6) Solve problems involving fundamental definitions and theorems of Banach and Hilbert spaces.

**MATH503. FUNCTIONAL ANALYSIS. 3.0 Semester Hrs.**
(II) Properties of metric spaces, normed spaces and Banach spaces, inner product and Hilbert spaces. Fundamental theorems for normed and

Banach spaces with applications. Orthogonality and orthonormal systems on Hilbert spaces with applications to approximation theory. Compact, bounded and unbounded operators. Duality, adjoint, self-adjoint, Hilbert-adjoint operators. Spectral analysis of linear operators. Applications to differential and integral equations. 3 hours lecture; 3 semester hours.
**Course Learning Outcomes**

- No change

**MATH506. COMPLEX ANALYSIS II. 3.0 Semester Hrs.**
(II) Analytic functions. Conformal mapping and applications. Analytic continuation. Schlicht functions. Approximation theorems in the complex domain. Taught every other year. Prerequisite: MATH454. 3 hours lecture; 3 semester hours.
**Course Learning Outcomes**

- no change

**MATH510. ORDINARY DIFFERENTIAL EQUATIONS AND DYNAMICAL SYSTEMS. 3.0 Semester Hrs.**
(I) Topics to be covered: basic existence and uniqueness theory, systems of equations, stability, differential inequalities, Poincare-Bendixon theory, linearization. Other topics from: Hamiltonian systems, periodic and almost periodic systems, integral manifolds, Lyapunov functions, bifurcations, homoclinic points and chaos theory. Offered even years. 3 hours lecture; 3 semester hours. Prerequisite: MATH225 or MATH235 and MATH332 or MATH342 and MATH301.
**Course Learning Outcomes**

- no change

**MATH514. APPLIED MATHEMATICS I. 3.0 Semester Hrs.**
(II) The course focuses on the application of mathematical ideas and methods for solving problems in the applied sciences and engineering. Topics include dimensional analysis, regular and singular perturbation methods, boundary layer analysis, kinetics. Other topics may include variational calculus, boundary value problems and integral equations, and discrete models. Where applicable, there will be numerical approaches to complement the analytic ones.
**Course Learning Outcomes**

- No change

**MATH515. APPLIED MATHEMATICS II. 3.0 Semester Hrs.**
(II) The course focuses on the application of mathematical ideas and methods for solving problems in the applied sciences and engineering. Topics include non-numerical techniques for dealing with partial differential equations, wave phenomena, continuum mechanics, conservation laws, and transform methods.
**Course Learning Outcomes**

- no change

**MATH530. INTRODUCTION TO STATISTICAL METHODS. 3.0 Semester Hrs.**
(I,II) Review of probability, random variables, and discrete and continuous probability models. Descriptive statistics and graphical representations. General theory of Confidence intervals and hypothesis testing. Inferences for mean and variance of a single population. Inferences for means and variances for two populations. Inferences for proportions and count data.
**Course Learning Outcomes**

**MATH531. THEORY OF LINEAR MODELS. 3.0 Semester Hrs.**
(II) Statistical framework for estimation and inference based on multiple regression, including distribution theory for sums of squares statistics and estimators. Principles of analysis of variance (ANOVA), multiple comparisons, and experimental design. Also included are some relevant topics in multivariate analysis and asymptotic, large sample theory. Prerequisites. MATH332 and MATH534.

**MATH532. SPATIAL STATISTICS. 3.0 Semester Hrs.**
Modeling and analysis of data observed on a 2 or 3-dimensional surface. Random fields, variograms, covariances, stationarity, nonstationarity, kriging, simulation, Bayesian hierarchical models, spatial regression, SAR, CAR, QAR, and MA models, Geary/Moran indices, point processes, K-function, complete spatial randomness, homogeneous and inhomogeneous processes, marked point processes, spatio-temporal modeling. Course is offered every other year on even years. Prerequisites: MATH324 or equivalent.
**Course Learning Outcomes**

- no change

**MATH533. TIME SERIES AND ITS APPLICATIONS. 3.0 Semester Hrs.**
Exploratory Analysis of Time Series, Stationary Time Series, Autocorrelation and Partial Autocorrelation, Autoregressive Moving Average (ARMA) Models, Forecasting, Estimation, ARIMA Models for Nonstationary Data, Multiplicative Seasonal ARIMA Models, The Spectral Density, Periodogram and Discrete Fourier Transform, Spectral Estimation, Multiple Series and Cross-Spectra, Linear Filters, Long Memory ARMA and Fractional Differencing, GARCH Models, Threshold Models, Regression with Autocorrelated Errors, Lagged Regression, Multivariate ARMAX Models. Prerequisite: MATH 324, MATH335.

**MATH534. MATHEMATICAL STATISTICS I. 3.0 Semester Hrs.**
(I) The basics of probability, discrete and continuous probability distributions, sampling distributions, order statistics, convergence in probability and in distribution, and basic limit theorems, including the central limit theorem, are covered. Prerequisite: none. 3 hours lecture; 3 semester hours.

**MATH535. MATHEMATICAL STATISTICS II. 3.0 Semester Hrs.**
(II) The basics of hypothesis testing using likelihood ratios, point and interval estimation, consistency, efficiency, sufficient statistics, and some nonparametric methods are presented. Prerequisite: MATH534 or equivalent. 3 hours lecture; 3 semester hours.

**MATH536. ADVANCED STATISTICAL MODELING. 3.0 Semester Hrs.**
(II) Modern extensions of the standard linear model for analyzing data. Topics include generalized linear models, generalized additive models, mixed effects models, and resampling methods. Offered every two years on odd years. 3 hours lecture; 3 semester hours. Prerequisite: MATH335, MATH324.
**Course Learning Outcomes**

- no change

**MATH537. MULTIVARIATE ANALYSIS. 3.0 Semester Hrs.**
(I) Introduction to applied multivariate representations of data for use in data analysis. Topics include introduction to multivariate distributions; methods for data reduction, such as principal components; hierarchical and model-based clustering methods; factor analysis; canonical correlation analysis; multidimensional scaling; and multivariate hypothesis testing.

**MATH538. STOCHASTIC MODELS. 3.0 Semester Hrs.**
(II) An introduction to the mathematical principles of stochastic processes. Discrete- and continuous-time Markov processes, Poisson processes, Brownian motion. 3 hours lecture; 3 semester hours.
**Course Learning Outcomes**

- no change

**MATH539. SURVIVAL ANALYSIS. 3.0 Semester Hrs.**
(I) Basic theory and practice of survival analysis. Topics include survival and hazard functions, censoring and truncation, parametric and non-parametric inference, the proportional hazards model, model diagnostics. Offered on odd years. Prerequisite: MATH335, MATH535. 3 hours lecture; 3 semester hours.
**Course Learning Outcomes**

- no change

**MATH540. PARALLEL SCIENTIFIC COMPUTING. 3.0 Semester Hrs.**
This course is designed to facilitate students' learning of high-performance computing concepts and techniques to efficiently perform large-scale mathematical modelling and data analysis using modern high-performance architectures (e.g. multi-core processors, multiple processors, and/or accelerators). Emphasis will be placed on analysis and implementation of various scientific computing algorithms in high-level languages using their interfaces for parallel or accelerated computing. Use of scripting to manage HPC workflows is included. Additional emphasis will be placed on design of parallel algorithms and implementation optimization in assignments. Prerequisites: MATH307 and CSCI200.
**Course Learning Outcomes**

- no change

**MATH547. SCIENTIFIC VISUALIZATION. 3.0 Semester Hrs.**
Equivalent with CSCI547,
Scientific visualization uses computer graphics to create visual images which aid in understanding of complex, often massive numerical representation of scientific concepts or results. The main focus of this course is on techniques applicable to spatial data such as scalar, vector and tensor fields. Topics include volume rendering, texture based methods for vector and tensor field visualization, and scalar and vector field topology. Students will learn about modern visualization techniques by reading and discussing research papers and implementing one of the algorithms described in the literature.

**MATH550. NUMERICAL SOLUTION OF PARTIAL DIFFERENTIAL EQUATIONS. 3.0 Semester Hrs.**
(I) Numerical methods for solving partial differential equations. Explicit and implicit finite difference methods; stability, convergence, and consistency. Alternating direction implicit (ADI) methods. Weighted residual and finite element methods. Prerequisites: MATH225 or MATH235 and MATH332 or MATH342.

**MATH551. COMPUTATIONAL LINEAR ALGEBRA. 3.0 Semester Hrs.**
(II) Numerical analysis of algorithms for solving linear systems of equations, least squares methods, the symmetric eigenproblem, singular value decomposition, conjugate gradient iteration. Modification of algorithms to fit the architecture. Error analysis, existing software packages. 3 hours lecture; 3 semester hours. Prerequisite: MATH332, MATH 307.

**MATH552. KERNEL-BASED APPROXIMATION METHODS. 3.0 Semester Hrs.**
Positive definite kernels play an important role in many different areas of mathematics, science and engineering. We put these kernels into perspective, both historically, as well as scientifically via connections to related fields such as analysis, approximation theory, the theory of integral equations, mathematical physics, probability theory and statistics, geostatistics, statistical or machine learning, and various kinds of engineering or physics applications. None of these fields is given a thorough theoretical treatment. Instead, these topics are presented via their relation to positive definite kernels. Prerequisite: Graduate level mathematical maturity and confidence to build on elements from (computational) linear algebra, functional analysis, and Gaussian processes, such as eigenvalues, eigenfunctions, orthogonality, change of basis, Sturm-Liouville theory, Green?s kernels, maximum likelihood estimation, Bayesian statistics, and convex optimization.
**Course Learning Outcomes**

- This course is designed to be useful for students interested in fitting multidimensional data (as arises, for example in many machine learning tasks) or numerically solving partial differential equations.

**MATH557. INTEGRAL EQUATIONS. 3.0 Semester Hrs.**
This is an introductory course on the theory and applications of integral equations. Abel, Fredholm and Volterra equations. Fredholm theory: small kernels, separable kernels, iteration, connections with linear algebra and Sturm-Liouville problems. Applications to boundary-value problems for Laplace's equation and other partial differential equations. Offered even years. Prerequisite: MATH332 or MATH342 and MATH455. 3 hours lecture; 3 semester hours.
**Course Learning Outcomes**

- no change

**MATH559. ASYMPTOTICS. 3.0 Semester Hrs.**
Equivalent with MATH459,
(I) Exact methods for solving mathematical problems are not always available: approximate methods must be developed. Often, problems involve small parameters, and this can be exploited so as to derive approximations: these are known as asymptotic approximations. Many techniques for constructing asymptotic approximations have been devised. The course develops such approximations for algebraic problems, the evaluation of integrals, and the solutions of differential equations. Emphasis is placed on effective methods and, where possible, rigorous analysis. Prerequisites: Calculus and ordinary differential equations. 3 hours lecture; 3 semester hours.
**Course Learning Outcomes**

- 1. Use asymptotic methods to solve algebraic problems
- 2. Use asymptotic methods to estimate integrals
- 3. Use asymptotic methods to solve differential equations.

**MATH560. INTRODUCTION TO KEY STATISTICAL LEARNING METHODS I. 3.0 Semester Hrs.**
Part one of a two-course series introducing statistical learning methods with a focus on conceptual understanding and practical applications. Methods covered will include Introduction to Statistical Learning, Linear Regression, Cross validation, Basis Expansions, Regularization, Non linear Models, Model Assessment and Selection. Prerequisite: MATH530 or DSCI530.
**Course Learning Outcomes**

- Understand what statistical learning is, how it is done and how it relates to real-world problems.
- Understand the concepts, assumptions and applicability of linear regression and gain the practical skills to be able to apply regression analysis to real-world data.
- Understand the concepts, assumptions and applicability of classification and gain the practical skills to be able to apply classification analysis to real-world data.
- Understand what resampling methods are, how they work and in which situations they can be used. Apply resampling methods to real-world problems.
- Understand what basis expansions are, how they work and in which situations they can be applied. Address real-world problems with basis expansion solutions.
- Understand what regularization methods are, why they can be useful and how to apply them in the context of regression and classification problems.
- Gain knowledge of multiple ways to diagnose and assess statistical models and how to select among different models.

**MATH561. INTRODUCTION TO KEY STATISTICAL LEARNING METHODS II. 3.0 Semester Hrs.**
Part two of a two course series introducing statistical learning methods with a focus on conceptual understanding and practical applications. Methods covered will include Classification, Bootstrap, Tree-based Methods, Support Vector Machines, Unsupervised Learning. Prerequisite: MATH560 or DSCI560.
**Course Learning Outcomes**

- Gain knowledge of a variety of nonlinear modeling approaches including polynomial regression, regression splines, smoothing splines, local regression and generalized additive models. Understand when to apply these methods and gain practical knowledge doing so with real-world data.
- Gain knowledge of tree-based approaches, including regression and classification trees, bagging, random forests, and boosting. Be able to compare them to linear models and know when to apply them and do so with real-world data.
- Know what support vector machines are, when to apply them and how they compare to other classification methods. Test them with real-world data for two and more classes.
- Understand the conceptual basis of neural networks, for which types of problems they are useful and what potential drawbacks are. Build a neural network for real-world data.
- Gain an overview of unsupervised methods including Principal Components Analysis and different clustering methods. Apply these methods to solve real-world problems.

**MATH570. MATHEMATICAL MODELING OF SPATIAL PROCESSES IN BIOLOGY. 3.0 Semester Hrs.**
(II) This course is an introduction to mathematical modeling of spatial processes in biology. The emphasis is on partial differential equation models from a diverse set of biological topics such as cellular homeostasis, muscle dynamics, neural dynamics, calcium handling, epidemiology, and chemotaxis. We will survey a variety of models and analyze their results in the context of the biology. Mathematically, we will examine the diffusion equation, advection equation, and combinations of the two that include reactions. There will be a significant computational component to the course including bi-weekly computational labs; students will solve the model equations and perform computations using MATLAB.
**Course Learning Outcomes**

- 1. Describe classical spatial-temporal models in mathematical biology including diffusion-reaction, advection-reaction, and advection-diffusion-reaction
- 2. Derive partial differential equations models for spatial-temporal phenomena
- 3. Implement analytical and numerical techniques to solve and analyze spatial-temporal models
- 4. Assimilate current literature, extend it in a final project that advances the field, and communicate results professionally and effectively

**MATH572. MATHEMATICAL AND COMPUTATIONAL NEUROSCIENCE. 3.0 Semester Hrs.**
(II) This course will focus on mathematical and computational techniques applied to neuroscience. Topics will include nonlinear dynamics, hysteresis, the cable equation, and representative models such as Wilson-Cowan, Hodgkin-Huxley, and FitzHugh-Nagumo. Applications will be motivated by student interests. In addition to building basic skills in applied math, students will gain insight into how mathematical sciences can be used to model and solve problems in neuroscience; develop a variety of strategies (computational, theoretical, etc.) with which to approach novel mathematical situations; and hone skills for communicating mathematical ideas precisely and concisely in an interdisciplinary context. In addition, the strong computational component of this course will help students to develop computer programming skills and apply appropriate technological tools to solve mathematical problems. Prerequisite: MATH331. 3 hours lecture; 3 semester hours.
**Course Learning Outcomes**

- Describe the classical models of mathematical neuroscience including Hodgkin-Huxley, Wilson-Cowan, and FitzHugh-Nagumo
- Implement analytical and numerical techniques to analyze models at different spatial and temporal scales
- Apply concepts from nonlinear dynamics including phase plane analysis, bifurcation theory, and model reduction techniques to analyze models in neuroscience
- Assimilate current literature, extend it in a final project that advances the field, and communicate results professionally and effectively

**MATH582. STATISTICS PRACTICUM. 3.0 Semester Hrs.**
(II) This is the capstone course in the Statistics Option. The main objective is to apply statistical knowledge and skills to a data analysis problem, which will vary by semester. Students will gain experience in problem-solving; working in a team; presentation skills (both orally and written); and thinking independently. 3 hours lecture and discussion; 3 semester hours. Prerequisite: MATH 201 or 530 and MATH 324 or 531.

**MATH588. INTRODUCTION TO QUANTITATIVE AND COMPUTATIONAL RESEARCH. 1.0 Semester Hr.**
Students will be expected to use applied mathematics and statistics principles to critically analyze research results in published literature and place them in the context of related literature. Skills to be developed and discussed include critical review of the literature and oral defense of these reviews.
**Course Learning Outcomes**

- Critically analyze and evaluate research articles in applied mathematics and statistics

- Develop written syntheses that interpret, compare, and contrast multiple studies
- Effectively communicate these syntheses in the form of oral presentations
- Identify and describe effective communication styles in both research articles and oral presentations
- Identify knowledge gaps based on a synthesis of research articles and formulate new research questions/directions/applications

**MATH589. APPLIED MATHEMATICS AND STATISTICS TEACHING SEMINAR. 1.0 Semester Hr.**
(I) An introduction to teaching issues and techniques within the AMS department. Weekly, discussion-based seminars will cover practical issues such as lesson planning, grading, and test writing. Issues specific to the AMS core courses will be included. 1 hour lecture; 1.0 semester hour.

**MATH598. SPECIAL TOPICS. 6.0 Semester Hrs.**
(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

**MATH599. INDEPENDENT STUDY. 0.5-6 Semester Hr.**
(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/experience and maximums vary by department. Contact the Department for credit limits toward the degree.

**MATH691. GRADUATE SEMINAR. 1.0 Semester Hr.**
(I) Presentation of latest research results by guest lecturers, staff, and advanced students. Prerequisite: none. 1 hour seminar; 1 semester hour. Repeatable for credit to a maximum of 12 hours.

**MATH692. GRADUATE SEMINAR. 1.0 Semester Hr.**
Equivalent with CSCI692,
(II) Presentation of latest research results by guest lecturers, staff, and advanced students. Prerequisite: none. 1 hour seminar; 1 semester hour. Repeatable for credit to a maximum of 12 hours.

**MATH693. WAVE PHENOMENA SEMINAR. 1.0 Semester Hr.**
(I, II) Students will probe a range of current methodologies and issues in seismic data processing, with emphasis on under lying assumptions, implications of these assumptions, and implications that would follow from use of alternative assumptions. Such analysis should provide seed topics for ongoing and subsequent research. Topic areas include: Statistics estimation and compensation, deconvolution, multiple suppression, suppression of other noises, wavelet estimation, imaging and inversion, extraction of stratigraphic and lithologic information, and correlation of surface and borehole seismic data with well log data. Prerequisite: none. 1 hour seminar; 1 semester hour.

**MATH698. SPECIAL TOPICS. 6.0 Semester Hrs.**
(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

**MATH699. INDEPENDENT STUDY. 0.5-6 Semester Hr.**
(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/experience and maximums vary by department. Contact the Department for credit limits toward the degree.

**MATH707. GRADUATE THESIS / DISSERTATION RESEARCH CREDIT. 1-15 Semester Hr.**
(I, II, S) GRADUATE THESIS/DISSERTATION RESEARCH CREDIT Research credit hours required for completion of a Masters-level thesis or Doctoral dissertation. Research must be carried out under the direct supervision of the student's faculty advisor. Variable class and semester hours. Repeatable for credit.