

# Graduate Certificate: High-Performance Computing for Scientific Applications

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COLLEGE OF SCIENCE AND TECHNOLOGY

Learn more about the graduate certificate in High-Performance Computing for Scientific Applications.

## About the Certificate

The graduate certificate in High-Performance Computing for Scientific Applications is designed to serve working professionals who need academic credentials for career advancement. Students are introduced to a portfolio of knowledge and experience that enables them to tackle problems using high-performance computing by:

- obtaining a fundamental understanding of the mathematical foundations and structure of numerical methods and parallel computing;
- becoming proficient in using hardware, algorithms, and programming;
- effectively applying high-performance computing to a variety of real-world problems, across multiple application fields; and
- gaining knowledge and skills applicable to academia, industry, and government.

**Campus Location:** Main

**Full-Time/Part-Time Status:** The graduate certificate can be completed on a part-time basis.

**Non-Matriculated Student Policy:** Students can take up to 9 credits on a non-matriculated basis. When they complete 9 credits, they must declare their intention to complete the graduate certificate in High-Performance Computing for Scientific Applications by completing and submitting the "Non-Degree Seeking Student Request to Exceed 9 Credits of Graduate Coursework for Certificate Program," found in TUportal under the Tools tab within "University Forms."

## Admission Requirements and Deadlines

**Bachelor's Degree in Discipline/Related Discipline:** All applicants must present credentials that are the equivalent of the appropriate baccalaureate degree at Temple University.

## Certificate Requirements

*Number of Credits Required to Complete the Certificate:* 13-14<sup>1</sup>

*Required Courses:*

Code	Title	Credit Hours
MATH 5061	Fundamentals of Computer Programming for Scientists and Engineers	4
MATH 5062	High Performance Computer Programming for Scientific Modeling	3
MATH 5063	Introduction to High-Performance Computing Technology for Scientists	4
MATH 5066	Mathematical Methods for High Performance Computing	3
Total Credit Hours		14

<sup>1</sup> Students may replace any *one* course on the list with a graduate-level course approved by the advisor. If a 3-credit graduate course is substituted for a 4-credit core course, then the certificate may be completed in 13 credits.

**GPA Required to be Awarded the Certificate:** 3.0 minimum

## Contacts

### Certificate Program Web Address:

<https://www.temple.edu/academics/degree-programs/high-performance-computing-for-scientific-applications-certificate-graduate-st-hpc-grad>

### Department Information:

Dept. of Mathematics  
638 Wachman Hall  
1805 N. Broad Street  
Philadelphia, PA 19122-6094

cst.psm@temple.edu  
215-204-7842

## Submission Address for Application Materials:

<https://cst.temple.edu/academics/graduate-programs/apply-now>

## Department Contacts:

*Graduate Chairperson:*  
Yury Grabovsky, Ph.D.  
grad.math@temple.edu  
215-204-1650

*Chairperson:*  
Irina Mitrea, Ph.D.  
mathematics@temple.edu  
215-204-4650

## Courses

### **MATH 5000. Special Topics in Math. 3 Credit Hours.**

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may be repeated for additional credit.

### **MATH 5001. Linear Algebra. 3 Credit Hours.**

Vector spaces and subspaces over the real and complex numbers; linear independence and bases; linear mappings; dual and quotient spaces; fields and general vector spaces; polynomials, ideals and factorization of polynomials; determinant; Jordan canonical form. Fundamentals of multilinear algebra.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

### **MATH 5003. Professional Development Seminar. 1 Credit Hour.**

This class advances intentional Professional Development by creating an online professional profile and portfolio that allows employers to determine the strength of a student's candidacy for a specific job. Students develop an online professional profile, attend a Professional Development Workshop and write a White paper which demonstrates analytical and technical writing skills on a topic of interest to the student. The White Paper proposes a change in any STEM area where a lack of efficiency in a process, or gap in knowledge, in an area of research, exists. Finally, students organize a networking event by inviting speakers, hiring managers and graduate students in CST.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Degree Restrictions:** Must be enrolled in one of the following Degrees: Prof Science Masters.

**College Restrictions:** Must be enrolled in one of the following Colleges: Science & Technology.

**Repeatability:** This course may not be repeated for additional credits.

### **MATH 5005. Ethics in Computing. 2 Credit Hours.**

This course will examine the social, legal, and privacy issues applying to scientific data. Students will be given the opportunity to discuss contemporary case studies, in addition to NIH-sanctioned online training modules (Responsible Conduct in Research). The case-study based approach used in class will expose students to ethics of database management and security, open-access and open-source philosophies, the ethics of collecting, storing, and disseminating data.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Degree Restrictions:** Must be enrolled in one of the following Degrees: Prof Science Masters.

**College Restrictions:** Must be enrolled in one of the following Colleges: Science & Technology.

**Repeatability:** This course may not be repeated for additional credits.

**MATH 5011. Algebra and Functions for Teaching. 3 Credit Hours.**

This class will broaden and deepen our understanding of algebra and functions and their many applications. We will begin with an examination of the concept of function generally and then look at examples. We will consider the usefulness of functions, both in modeling real phenomena and in solving equations. We will carefully develop more advanced concepts from basic principles and logic as we proceed from polynomial functions to rational, radical, exponential, logarithmic, and trigonometric functions. As we do this, we will explore non-traditional teaching techniques and tools such as the practice of inquiry-based learning and the appropriate use of technology. We will also utilize and discuss the eight Mathematical Practice Standards set forth in the Common Core State Standards.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**Pre-requisites:**

MATH 1042|Minimum Grade of C|May not be taken concurrently.

**MATH 5012. Introduction to Mathematical Modeling for Teaching. 3 Credit Hours.**

In this course, mathematics will be discussed as the language of science. Many students do not have an adequate picture of mathematics: they see it either as a dry formal list of formulas or a dull study of numbers. Mathematics is in fact a network of intriguing and profound ideas that are deeply connected to reality. As a language, mathematics provides penetrating techniques of thought that allow us to analyze physical reality and to look for answers or solutions to some of the most intriguing real-life questions. Students will be asked to read the material in advance and come prepared for class discussion. The in-class activities will be conducted in an inquiry-minded fashion.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**Pre-requisites:**

MATH 1042|Minimum Grade of C|May not be taken concurrently.

**MATH 5013. Geometry for Teaching. 3 Credit Hours.**

This class will provide a deep and complete picture of the underlying concepts needed to teach high school geometry. We'll start by learning about the basic axiomatic method, which is fundamental to all of mathematics. We'll learn about the rigid transformations (reflections, rotations, and translations) and the important role that they can play in defining congruence more generally. We'll finish by looking at some important examples of non-Euclidean geometry, where Euclid's famous parallel postulate does not hold.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**Pre-requisites:**

MATH 1042|Minimum Grade of C|May not be taken concurrently.

**MATH 5014. Probability Theory and Applications for Teaching. 3 Credit Hours.**

Probability is a fundamental topic with applications in nearly every aspect of life. The goal for this course is to equip the student with a large and diverse set of tools with which to tackle a wide variety of problems, both theory and application based. We will focus on the ideas behind the important topics e.g. conditioning, averages, binomial distribution, and explain their origins and applications. This will equip the student to teach their own students this material with an emphasis on the "why", which is essential to maintaining attentiveness.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**Pre-requisites:**

MATH 1042|Minimum Grade of C|May not be taken concurrently.

**MATH 5015. Modern Algebra for Teaching. 3 Credit Hours.**

Students will understand the integers and polynomial rings over a field as being specific examples of rings. The idea of quotient spaces will be emphasized with the particular examples of the integers modulo  $n$  and factor rings of polynomial rings illustrating and introducing the concept. Moreover, the ability to read and to construct well-written and correct mathematical proofs on these topics is an overarching goal of the course. Written communication skills will also be emphasized.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**Pre-requisites:**

MATH 2111|Minimum Grade of C|May not be taken concurrently.

**MATH 5016. Mathematical Analysis for Teaching. 3 Credit Hours.**

This course will start with a discussion of the basic topology of the real line and the creation of the basic tools using the completeness axiom. From there, the course will proceed to sequences and series, limits, continuity, differentiation, Riemann integration, and Taylor series representations of functions.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**Pre-requisites:**

MATH 2043|Minimum Grade of C|May not be taken concurrently.

**MATH 5017. Number Theory and Proof for Teaching. 3 Credit Hours.**

In this course, we encounter and explore fundamental ideas in number theory. Basic properties of the integers and their two principal operations, addition and multiplication, will form the starting point of our study. Along the way, the course will introduce some basic logic and the rigorous notion of mathematical proof, including mathematical induction, in the context of number theory. Through this elementary foundation, students will experience the richness of mathematics: proof going back as far as Euclid, examples of elementary yet still unproven conjectures, and results that are easy to state and understand but require extremely complicated proofs.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**Pre-requisites:**

MATH 1042|Minimum Grade of C|May not be taken concurrently.

**MATH 5041. Concepts of Analysis I. 3 Credit Hours.**

Advanced calculus in one and several real variables. Topics include topology of metric spaces, continuity, sequences and series of numbers and functions, convergence, including uniform convergence. Ascoli and Stone-Weierstrass theorems. Integration and Fourier series. Inverse and implicit function theorems, differential forms, Stokes theorem.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**MATH 5042. Concepts of Analysis II. 3 Credit Hours.**

Advanced calculus in one and several real variables. Topics include topology of metric spaces, continuity, sequences and series of numbers and functions, convergence, including uniform convergence. Ascoli and Stone-Weierstrass theorems. Integration and Fourier series. Inverse and implicit function theorems, differential forms, Stokes theorem.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**Pre-requisites:**

MATH 5041|Minimum Grade of B-|May not be taken concurrently.

**MATH 5043. Introduction to Numerical Analysis. 3 Credit Hours.**

Roots of nonlinear equations, errors, their source and propagation, linear systems, approximation and interpolation of functions, numerical integration.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**MATH 5044. Introduction to Numerical Analysis II. 3 Credit Hours.**

This course will cover the following topics: Analysis and numerical solutions of ordinary differential equations, Runge-Kutta, multistep, and Taylor series methods; deferred correction; convergence and stability; stiff problems.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**MATH 5045. Ordinary Differential Equations. 3 Credit Hours.**

Existence and uniqueness theorems, continuous and smooth dependence on parameters, linear differential equations, asymptotic behavior of solutions, isolated singularities, nonlinear equations, Sturm-Liouville problems, numerical solution of ODEs.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**MATH 5061. Fundamentals of Computer Programming for Scientists and Engineers. 4 Credit Hours.**

Scientists and engineers use computers for a multitude of purposes. Even with ready-to-use applications, some amount of computer programming is commonly required to adapt to changing technology while attaining the rigorous standards of each specific discipline. This course focuses on fundamental computer programming constructs, introducing the languages Python, C++ and Fortran. Through lectures and intensive exercises students will learn to implement fundamental mathematical constructs and solve basic programming problems relevant to scientific applications. The course briefly reviews also the Linux environment, its software development tools and language interoperability. For each programming language, the course focuses on constructs and syntax designed for performance and numerical accuracy, in connection with methods from applied science, mathematics and engineering. The students taking the course are expected to have sufficient mathematical maturity, as evidenced, for example, by having completed an undergraduate Calculus sequence. The majority of the grade is determined by a mid-term and a final exam, both including a combination of questionnaires and supervised programming assignments.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**MATH 5062. High Performance Computer Programming for Scientific Modeling. 3 Credit Hours.**

This course will provide theory and hands-on experience programming high performance computers for the solution of scientific modeling problems. This includes in particular problems arising from the discretizations of differential equations. Topics covered include domain decomposition and mesh partitioning, quantifying the computation and communication cost, communication avoidance methods, Monte Carlo methods, multithreading, benchmarking and optimization of the parallel computations.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**Pre-requisites:**

MATH 5061|Minimum Grade of B-|May not be taken concurrently.

**MATH 5063. Introduction to High-Performance Computing Technology for Scientists. 4 Credit Hours.**

This course is an introduction to the technology used in Linux clusters and supercomputers dedicated to calculations in applied science and engineering. The basic architecture of modern computers (processing units, memory, storage, operating system) is briefly reviewed, emphasizing the role and performance impact of each element in numerical computation. The core of the course focuses on setup and management of computer hardware specialized for scientific computing, and on its impact on commonly used strategies and methods for scientific computation. The material is organized in a combination of lectures and hands-on exercises, using computer hardware hosted at local facilities as well as virtualized resources. The majority of the grade is determined by a mid-term and a final exam, both including a combination of questionnaires and identification of the most efficient solution to common numerical problems.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**Pre-requisites:**

MATH 5061|Minimum Grade of B-|May be taken concurrently.

**MATH 5066. Mathematical Methods for High Performance Computing. 3 Credit Hours.**

This course presents mathematical methods for the solution of a variety of discrete and algebraic problems which are at the core of many scientific and engineering applications. The methods covered are especially tailored for high performance computing. Topics include large matrix computations, graphs and networks, fast Fourier transforms, geometric and algebraic multi-grid methods, and constrained optimization.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**Pre-requisites:**

(MATH 5061|Minimum Grade of B-|May not be taken concurrently)

AND (MATH 5062|Minimum Grade of B-|May not be taken concurrently)

AND (MATH 5063|Minimum Grade of B-|May not be taken concurrently)

**MATH 8001. Candidates Seminar. 1 to 3 Credit Hour.**

Challenging problems from many different areas of mathematics are posed and discussed.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may be repeated for additional credit.

**MATH 8002. Candidates Seminar. 1 to 3 Credit Hour.**

Challenging problems from many different areas of mathematics are posed and discussed.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may be repeated for additional credit.

**MATH 8003. Number Theory. 3 Credit Hours.**

This is an introduction to the ideas and techniques of number theory, elementary, analytic, and algebraic. The object of the course is to demonstrate how real and complex analysis and modern algebra can be applied to classical problems in number theory. References: H. Rademacher, "Lectures on elementary number theory"; H. Davenport, "Multiplicative number theory"; Rosen and Ireland, "A classical introduction to algebraic number theory."

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**MATH 8004. Number Theory. 3 Credit Hours.**

This is an introduction to the ideas and techniques of number theory, elementary, analytic, and algebraic. The object of the course is to demonstrate how real and complex analysis and modern algebra can be applied to classical problems in number theory. References: H. Rademacher, "Lectures on elementary number theory"; H. Davenport, "Multiplicative number theory"; Rosen and Ireland, "A classical introduction to algebraic number theory."

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**MATH 8007. Introduction to Methods in Applied Mathematics I. 3 Credit Hours.**

This is the first semester of a two-semester general overview of mathematical concepts and tools for applied mathematics. Topics to be covered include modeling and derivation of equations of continuum mechanics; solution methods for linear PDE in special domains, such as Fourier and Laplace transforms as well as Green's functions; calculus of variations and control theory.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**MATH 8008. Introduction to Methods in Applied Mathematics II. 3 Credit Hours.**

This is the second semester of a two-semester general overview of mathematical concepts and tools for applied mathematics. Topics to be covered include dynamical systems and bifurcation theory; asymptotic analysis and perturbation theory; systems of hyperbolic conservation laws. Material is largely independent of MATH 8007.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**MATH 8011. Abstract Algebra I. 3 Credit Hours.**

Groups, rings, modules, fields; Galois theory; linear algebra.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**MATH 8012. Abstract Algebra II. 3 Credit Hours.**

Groups, rings, modules, fields; Galois theory; linear algebra.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**Pre-requisites:**

MATH 8011|Minimum Grade of B-|May not be taken concurrently.

**MATH 8013. Numerical Linear Algebra I. 3 Credit Hours.**

The syllabus includes iterative methods, classical methods, nonnegative matrices. Semi-iterative methods. Multigrid methods. Conjugate gradient methods. Preconditioning. Domain decomposition. Direct Methods. Sparse Matrix techniques. Graph theory. Eigenvalue Problems.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**MATH 8014. Numerical Linear Algebra II. 3 Credit Hours.**

The syllabus includes iterative methods, classical methods, nonnegative matrices. Semi-iterative methods. Multigrid methods. Conjugate gradient methods. Preconditioning. Domain decomposition. Direct Methods. Sparse Matrix techniques. Graph theory. Eigenvalue Problems.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**Pre-requisites:**

MATH 8013|Minimum Grade of B-|May not be taken concurrently.

**MATH 8023. Numerical Differential Equations I. 3 Credit Hours.**

Analysis and numerical solution of ordinary and partial differential equations. Elliptic, parabolic and hyperbolic systems. Constant and variable coefficients. Finite difference methods. Finite element methods. Convergence analysis. Practical applications.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**MATH 8024. Numerical Differential Equations II. 3 Credit Hours.**

Analysis and numerical solution of ordinary and partial differential equations. Elliptic, parabolic and hyperbolic systems. Constant and variable coefficients. Finite difference methods. Finite element methods. Convergence analysis. Practical applications.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**Pre-requisites:**

MATH 8023|Minimum Grade of B-|May not be taken concurrently.

**MATH 8031. Probability Theory. 3 Credit Hours.**

With a rigorous approach the course covers the axioms, random variables, expectation and variance. Limit theorems are developed through characteristic functions.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**MATH 8032. Stochastic Processes. 3 Credit Hours.**

Random sequences and functions; linear theory; limit theorems; Markov processes; branching processes; queuing processes.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**Pre-requisites:**

MATH 8031|Minimum Grade of B-|May not be taken concurrently.

**MATH 8041. Real Analysis I. 3 Credit Hours.**

The syllabus coincides with the syllabus for the Ph.D. Examination in Real Analysis.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**MATH 8042. Real Analysis II. 3 Credit Hours.**

The syllabus coincides with the syllabus for the Ph.D. Examination in Real Analysis.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**Pre-requisites:**

MATH 8041|Minimum Grade of B-|May not be taken concurrently.

**MATH 8051. Functions of a Complex Variable I. 3 Credit Hours.**

Analytic functions. Conformal mapping. Analytic continuation. Topics in univalent functions, elliptic functions, Riemann surfaces, analytic number theory. Nevanlinna theory, several complex variables.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**MATH 8052. Functions of a Complex Variable II. 3 Credit Hours.**

Analytic functions. Conformal mapping. Analytic continuation. Topics in univalent functions, elliptic functions, Riemann surfaces, analytic number theory. Nevanlinna theory, several complex variables.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**Pre-requisites:**

MATH 8051|Minimum Grade of B-|May not be taken concurrently.

**MATH 8061. Differential Geometry and Topology I. 3 Credit Hours.**

Elementary theory of smooth manifolds. Singular cohomology and DeRham's theorem. Fundamental group and covering spaces. Hodge theory.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**MATH 8062. Differential Geometry and Topology II. 3 Credit Hours.**

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**Pre-requisites:**

MATH 8061|Minimum Grade of B-|May not be taken concurrently.



**MATH 8107. Mathematical Modeling for Science, Engineering, and Industry. 3 Credit Hours.**

In this course, students work in groups on projects that arise in industry, engineering, or in other disciplines of science. In addition to being advised by the course instructors, in all projects an external partner is present. The problems are formulated in non-mathematical language, and the final results need to be formulated in a language accessible to the external partner. This means in particular that the mathematical and computational methods must be selected or created by the students themselves. Students disseminate their progress and achievements in weekly presentations, a mid-term and a final project report, and a final presentation. Group work with and without the instructors' involvement is a crucial component in this course.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**Pre-requisites:**

(MATH 8007|Minimum Grade of B-|May not be taken concurrently)

AND (MATH 8008|Minimum Grade of B-|May not be taken concurrently)

**MATH 8141. Partial Differential Equations I. 3 Credit Hours.**

The classical theory of partial differential equations. Elliptic, parabolic, and hyperbolic operations.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**MATH 8142. Partial Differential Equations II. 3 Credit Hours.**

The classical theory of partial differential equations. Elliptic, parabolic, and hyperbolic operations.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**Pre-requisites:**

MATH 8141|Minimum Grade of B-|May not be taken concurrently.

**MATH 8161. Topology. 3 Credit Hours.**

Point set topology through the Urysohn Metrization Theorem; fundamental group and covering spaces. Differential forms; the DeRham groups.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**Pre-requisites:**

MATH 5041|Minimum Grade of B-|May not be taken concurrently.

**MATH 8200. Topics in Applied Mathematics. 3 Credit Hours.**

Variable topics, such as control theory and transform theory, will be treated.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may be repeated for additional credit.

**MATH 8210. Topics in Applied Mathematics II. 3 Credit Hours.**

Variable topics, such as control theory and transform theory, will be treated.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may be repeated for additional credit.

**MATH 8700. Topics Computer Program. 3 Credit Hours.**

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may be repeated for additional credit.

**MATH 8710. Topics Computer Program. 3 Credit Hours.**

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may be repeated for additional credit.

**MATH 8985. Teaching in Higher Education. 1 to 3 Credit Hour.**

This course is required for any student seeking Temple's Teaching in Higher Education Certificate. The course focuses on the research on learning theory and the best teaching practices, with the aim of preparing students for effective higher education teaching. All educational topics will be considered through the lens of teaching mathematics and quantitative thinking.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may be repeated for a total of 3 credit.

**MATH 9000. Topics in Number Theory I. 3 Credit Hours.**

Analytic and algebraic number theory. Classical results and methods and special topics such as partition theory, asymptotic, Zeta functions, transcendence, modular functions.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may be repeated for additional credit.

**MATH 9003. Modular Functions. 3 Credit Hours.**

This course focuses upon the modular group and its subgroups, the corresponding fundamental region and their invariant functions. Included will be a discussion of the basic properties of modular forms and their construction by means of Eisenstein and Poincaré series and theta series. Other topics: the Hecke correspondence between modular forms and Dirichlet series with functional equations, the Petersen inner product, the Hecke's operators. Emphasis will be placed upon applications to number theory. References: M. Knopp, "Modular functions in analytic number theory"; J. Lehner, "A short course in automorphic forms"; B. Schoeneberg, "Elliptic modular forms."

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**MATH 9004. Modular Functions. 3 Credit Hours.**

This course focuses upon the modular group and its subgroups, the corresponding fundamental region and their invariant functions. Included will be a discussion of the basic properties of modular forms and their construction by means of Eisenstein and Poincaré series and theta series. Other topics: the Hecke correspondence between modular forms and Dirichlet series with functional equations, the Petersen inner product, the Hecke's operators. Emphasis will be placed upon applications to number theory. References: M. Knopp, "Modular functions in analytic number theory"; J. Lehner, "A short course in automorphic forms"; B. Schoeneberg, "Elliptic modular forms."

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**MATH 9005. Combinatorial Mathematics. 3 Credit Hours.**

Topics include: Enumeration, Trees, Graphs, Codes, Matchings, Designs, Chromatic Polynomials, Coloring, Networks.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**MATH 9010. Topics in Number Theory II. 3 Credit Hours.**

Analytic and algebraic number theory. Classical results and methods and special topics such as partition theory, asymptotic, Zeta functions, transcendence, modular functions.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may be repeated for additional credit.

**MATH 9011. Homological Algebra. 3 Credit Hours.**

Students will learn fundamental notions of homological algebra such as chain complexes, Abelian categories, derived functors, and spectral sequences. A portion of this course is also devoted to rudiments of category theory. Students will learn how to apply constructions of homological algebra and category theory to questions from abstract algebra, topology and deformation theory.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**Pre-requisites:**

(MATH 8011|Minimum Grade of B-|May not be taken concurrently)

AND (MATH 8012|Minimum Grade of B-|May not be taken concurrently)

**MATH 9012. Representation Theory I. 3 Credit Hours.**

This is the first semester of a two-semester course on the principal methods and results of algebraic representation theory. The course will start with an introduction to the fundamental notions, tools and general results of representation theory in the setting of associative algebras. This will be followed by a thorough coverage of the classical representation theory of finite groups over an algebraically closed field of characteristic zero. If time permits, then the semester will conclude with a brief introductory discussion of the representation theory of the general linear group.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**Pre-requisites:**

(MATH 8011|Minimum Grade of B-|May not be taken concurrently)

AND (MATH 8012|Minimum Grade of B-|May not be taken concurrently)

**MATH 9013. Representation Theory II. 3 Credit Hours.**

This is the second part of a two-semester course sequence on the principal methods and results of algebraic representation theory. The main focus will be on representations of finite-dimensional Lie algebras, with particular emphasis on the case of semisimple Lie algebras. Time permitting, the course will conclude with an introduction to the representation theory of Hopf algebras.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**Pre-requisites:**

MATH 9012|Minimum Grade of B-|May not be taken concurrently.

**MATH 9014. Commutative Algebra and Algebraic Geometry I. 3 Credit Hours.**

This is the first semester of a two-semester course on the fundamental concepts of commutative algebra and classical as well as modern algebraic geometry. Topics for the first semester include: ideals of commutative rings, modules, Noetherian and Artinian rings, Noether normalization, Hilbert's Nullstellensatz, rings of fractions, primary decomposition, discrete valuation rings and the rudiments of dimension theory.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**Pre-requisites:**

(MATH 8011|Minimum Grade of B-|May not be taken concurrently)

AND (MATH 8012|Minimum Grade of B-|May not be taken concurrently)

**MATH 9015. Commutative Algebra and Algebraic Geometry II. 3 Credit Hours.**

This is the second semester of a two-semester course on the fundamental concepts of commutative algebra and classical as well as modern algebraic geometry. Topics for the second semester include: affine and projective varieties, morphisms of algebraic varieties, birational equivalence, and basic intersection theory. In the second semester, students will also learn about schemes, morphisms of schemes, coherent sheaves, and divisors.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**Pre-requisites:**

MATH 9014|Minimum Grade of B-|May not be taken concurrently.

**MATH 9021. Riemannian Geometry. 3 Credit Hours.**

The main goal of this one-semester course is to provide a solid introduction to the two central concepts of Riemannian Geometry, namely, geodesics and curvature and their relationship. After taking this course, students will have an intimate acquaintance with the tools and concepts that are needed for pursuing research in Riemannian Geometry or applying its ideas to other fields of mathematics such as analysis, topology, and algebraic geometry. The topics covered include Riemannian metrics, Riemannian connections, geodesics, curvature (sectional, Ricci, and scalar curvatures), the Jacobi equation, the second fundamental form, and global results such as the Gauss-Bonnet Theorem, the theorems of Hopf-Rinow and Hadamard, variations of energy, the theorems of Bonnet-Myers and of Synge-Weinstein, and the Rauch comparison theorem.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**Pre-requisites:**

(MATH 8061|Minimum Grade of B-|May not be taken concurrently)

AND (MATH 8062|Minimum Grade of B-|May be taken concurrently)

**MATH 9023. Knot Theory and Low-Dimensional Topology I. 3 Credit Hours.**

This is the first semester of a year-long course surveying the modern theory of knots and providing an introduction to some fundamental results and techniques of low-dimensional topology. The course will start at the very beginning of knot theory; it will then proceed to several classical knot invariants (Alexander, Jones, HOMFLY polynomials). The first semester will also touch on braid groups and mapping class groups, and use these groups to show that every (closed, orientable) 3-manifold can be constructed via knots.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**Pre-requisites:**

(MATH 8061|Minimum Grade of B-|May not be taken concurrently)

AND (MATH 8062|Minimum Grade of B-|May not be taken concurrently)

**MATH 9024. Knot Theory and Low-Dimensional Topology II. 3 Credit Hours.**

This is the second semester of a year-long course surveying the modern theory of knots and providing an introduction to some fundamental results and techniques of low-dimensional topology. This course will continue the development of knot invariants begun during the first semester, in particular exploring the connection between knots and braid groups. It will also use Dehn surgery techniques to extend construct quantum invariants of closed 3-dimensional manifolds. Finally, the course will survey several results in 4-dimensional topology and their connection to knot theory.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**Pre-requisites:**

MATH 9023|Minimum Grade of B-|May not be taken concurrently.

**MATH 9031. Advanced Probability Theory. 3 Credit Hours.**

This course is a continuation of MATH 8031 and is based on measure theory. It covers advanced topics in probability theory: martingales, Brownian motion, Markov chains, continuous time Markov processes, ergodic theory and their applications.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**MATH 9041. Functional Analysis I. 3 Credit Hours.**

Topics covered include Banach and Hilbert spaces, Banach-Steinhaus theorem, Hahn-Banach theorem, Stone-Weierstrass theorem, Operator theory, self-adjointness, compactness. Also covered are Sobolev spaces, embedding theorems, Schwartz distributions, Paley-Wiener theory. If time permits, Banach and C algebras will be covered.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**Pre-requisites:**

(MATH 8041|Minimum Grade of B-|May not be taken concurrently)

AND (MATH 8042|Minimum Grade of B-|May not be taken concurrently)

**MATH 9042. Functional Analysis II. 3 Credit Hours.**

Topics covered include: Banach and Hilbert spaces, Banach-Steinhaus theorem, Hahn-Banach theorem, Stone-Weierstrass theorem, Operator theory, self-adjointness, compactness. Also covered are Sobolev spaces, embedding theorems, Schwartz distributions, Paley-Wiener theory. If time permits, Banach and C algebras will be covered.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**Pre-requisites:**

MATH 9041|Minimum Grade of B-|May not be taken concurrently.

**MATH 9043. Calculus of Variations. 3 Credit Hours.**

First variation and Euler-Lagrange equations. Null-Lagrangians and the Caratheodory's "Royal Road". Geodesic coverings, the eikonal and the Hamilton-Jacobi equation. Second variation and Jacobi's theory of conjugate points. Strong variations and Weierstrass E-function. Hamiltonian formalism and convex duality. Hilbert's invariant integral.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**MATH 9044. Harmonic Analysis. 3 Credit Hours.**

A year long course to explore the real-variable techniques developed in Harmonic Analysis to study smoothness properties of functions and the behavior of certain spaces under the action of some operators. These techniques are also essential in many applications to PDE's and several complex variables. Offered every two years.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**MATH 9051. Several Complex Variables I. 3 Credit Hours.**

Holomorphic functions of several complex variables, domains of holomorphy, pseudoconvexity, analytic varieties, CR manifolds.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**Pre-requisites:**

(MATH 8051|Minimum Grade of B-|May not be taken concurrently)

AND (MATH 8052|Minimum Grade of B-|May not be taken concurrently)

**MATH 9052. Several Complex Variables II. 3 Credit Hours.**

Holomorphic functions of several complex variables, domains of holomorphy, pseudoconvexity, analytic varieties, CR manifolds.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**Pre-requisites:**

MATH 9051|Minimum Grade of B-|May not be taken concurrently.

**MATH 9053. Harmonic Analysis. 3 Credit Hours.**

A year long course to explore the real-variable techniques developed in Harmonic Analysis to study smoothness properties of functions and the behavior of certain spaces under the action of some operators. These techniques are also essential in many applications to PDE's and several complex variables. Offered every two years.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**MATH 9061. Lie Groups. 3 Credit Hours.**

This course develops Lie theory from the ground up. Starting with basic definitions of Lie group-manifolds and Lie algebras, the course develops structure theory, analytic and algebraic aspects, and representation theory. Interactions with other fields, e.g., differential equations and geometry are also discussed.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**MATH 9062. Lie Groups. 3 Credit Hours.**

This course develops Lie theory from the ground up. Starting with basic definitions of Lie group-manifolds and Lie algebras, the course develops structure theory, analytic and algebraic aspects, and representation theory. Interactions with other fields, e.g., differential equations and geometry are also discussed.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**MATH 9063. Riemann Surfaces. 3 Credit Hours.**

Introduction to differential geometry, Riemannian manifolds and Hodge theory; classification of complex structures of oriented two-manifolds as conformal classes of Riemannian metrics; covering spaces and the uniformization theorem; the moduli space of the torus; the Riemann-Roch theorem for compact Riemann surfaces; interpretation of the Riemann-Roch theorem as the index of an elliptic operator.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**MATH 9064. Riemann Surfaces. 3 Credit Hours.**

Moduli and Teichmueller spaces for compact Riemann surfaces; introduction to modular forms; embedding of compact Riemann surfaces in complex projective spaces. Branched coverings and maps onto the Riemann sphere.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**MATH 9071. Differential Topology. 3 Credit Hours.**

Moduli and Teichmueller spaces for compact Riemann surfaces; introduction to modular forms; embedding of compact Riemann surfaces in complex projective spaces. Branched coverings and maps onto the Riemann sphere.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**MATH 9072. Differential Topology. 3 Credit Hours.**

Topics and emphasis may vary depending on instructor and may include surgery, handlebodies, cobordism; topological manifolds with smooth structure, manifolds with more than one smooth structures; topology of vector bundles, characteristic classes, index theorem.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**MATH 9073. Geometric Group Theory. 3 Credit Hours.**

This semester-long course will survey the rapidly expanding field of geometric group theory, focusing on the role played by negative curvature. We will begin with classical combinatorial techniques used to construct and study infinite discrete groups. After introducing basic concepts in coarse geometry, we will turn our attention to Gromov's notion of hyperbolic groups. In addition to studying geometric, algebraic, and algorithmic properties of these groups, we will keep an eye towards several generalizations of hyperbolicity that have recently played a large role in understanding many geometrically significant groups. As examples, we will also touch on the study of mapping class groups, outer automorphism groups of free groups, and cubical groups.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may not be repeated for additional credits.

**Pre-requisites:**

(MATH 8061|Minimum Grade of B-|May not be taken concurrently)  
AND (MATH 8062|Minimum Grade of B-|May not be taken concurrently)

**MATH 9082. Independent Study. 1 to 3 Credit Hour.**

Independent research supervised by a Mathematics faculty member.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may be repeated for additional credit.

**MATH 9083. Independent Study. 1 to 3 Credit Hour.**

Independent research supervised by a Mathematics faculty member.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may be repeated for additional credit.

**MATH 9100. Topics in Algebra. 3 Credit Hours.**

Variable topics in theory of commutative and non-commutative rings, groups, algebraic number theory, algebraic geometry.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may be repeated for additional credit.

**MATH 9110. Topics in Algebra. 3 Credit Hours.**

Variable topics in theory of commutative and non-commutative rings, groups, algebraic number theory, algebraic geometry.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may be repeated for additional credit.

**MATH 9120. Seminar in Algebra. 3 Credit Hours.**

The seminar aims to lead participating students up to the frontier of current research in algebra. The typical formats are single lectures or short series of lectures by students or the instructor on various topics in algebra, including noncommutative algebra, representation theory, group theory, operads and connections to mathematical physics. Occasionally, slightly longer mini-courses are presented in the framework of the seminar or an entire semester is devoted to a single topic of particular interest.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may be repeated for additional credit.

**MATH 9200. Topics in Numerical Analysis. 3 Credit Hours.**

These courses cover some basic, as well as advanced topics in numerical analysis. The topics can be changed from time to time. The usual topics include: scientific computing, numerical methods for differential equations, computational fluid dynamics, Monte Carlo simulation, Optimization, Sparse matrices, Fast Fourier transform and applications, etc.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may be repeated for additional credit.

**MATH 9210. Topics in Numerical Analysis. 3 Credit Hours.**

These courses cover some basic, as well as advanced topics in numerical analysis. The topics can be changed from time to time. The usual topics include: scientific computing, numerical methods for differential equations, computational fluid dynamics, Monte Carlo simulation, Optimization, Sparse matrices, Fast Fourier transform and applications, etc.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may be repeated for additional credit.

**MATH 9300. Seminar in Probability. 3 Credit Hours.**

Research topics related to probability theory are presented in the seminar. Topics vary depending on the interests of the students and the instructor. Current topics include stochastic calculus with applications in mathematical finance, statistical mechanics, interacting particle systems, percolation, and probability models in mathematical physics.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may be repeated for additional credit.

**MATH 9310. Seminar in Probability. 3 Credit Hours.**

Research topics related to probability theory are presented in the seminar. Topics vary depending on the interests of the students and the instructor. Current topics include stochastic calculus with applications in mathematical finance, statistical mechanics, interacting particle systems, percolation, and probability models in mathematical physics.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may be repeated for additional credit.

**MATH 9400. Topics in Analysis. 3 Credit Hours.**

Variable content course.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may be repeated for additional credit.

**MATH 9410. Topics in Functional Analysis. 3 Credit Hours.**

This is a year-long sequence. The content varies from time to time depending on the interests of the students. Typical topics include some of the following: pseudodifferential operators, Fourier integral operators, singular integral operators, applications to partial differential equations.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may be repeated for additional credit.

**MATH 9420. Topics in Differential Equations II. 3 Credit Hours.**

This is a year-long sequence. Topics covered may include the theory of elliptic partial differential equations in divergence form and non-divergence form, and nonlinear PDEs. These courses may also focus on pseudodifferential operators and Fourier integral operators.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may be repeated for additional credit.

**MATH 9991. Master's Research Projects. 1 to 6 Credit Hour.**

Short-term, limited research project or laboratory project in the field. This course is not the capstone project course, nor can it be used for thesis based research. The course is for master's students only, including PSM, MA or MS. This class will not confer full-time program status unless nine credits are taken.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Degree Restrictions:** Must be enrolled in one of the following Degrees: Master of Arts, Master of Science, Prof Science Masters.

**Repeatability:** This course may be repeated for additional credit.

**MATH 9994. Preliminary Examination Preparation. 1 to 6 Credit Hour.**

This course is required for students who are preparing for the preliminary or candidacy examination. Students should enroll after coursework is completed or when preparing for the candidacy exam until the time that the preliminary or candidacy examination is completed. This course will confer full-time status at the minimum credit hour registration limit of one credit. All students must complete a minimum of one credit of this course. Students must complete a total of 6 credit hours of 9994, 9998 and 9999.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may be repeated for additional credit.

**MATH 9995. Capstone Project. 1 to 6 Credit Hour.**

Capstone project for master's students including students in PSM, MA or MS. This class will provide full-time status. Students in PSM programs need to register for at least one credit of this course to fulfill program requirements. Additional credits may be required for specific programs. This course will confer full-time status at the minimum credit hour registration limit of one credit.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Degree Restrictions:** Must be enrolled in one of the following Degrees: Master of Arts, Master of Science, Prof Science Masters.

**Repeatability:** This course may be repeated for additional credit.

**MATH 9996. Master's Thesis Research. 1 to 6 Credit Hour.**

Course for master's thesis research. Only intended for students in thesis bearing master's programs. A minimum of one credit is required. This course will confer full-time status at the minimum credit hour registration limit of one credit.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may be repeated for additional credit.

**MATH 9998. Pre-Dissertation Research / Elevation to Candidacy. 1 to 6 Credit Hour.**

This course is intended for students who are performing research prior to candidacy. Students can register for this course after required courses are completed. This course will confer full-time status at the minimum credit hour registration limit of one credit. Students must be registered for this course during the semester that they are to be elevated to candidacy examination. Students must complete a total of 6 credit hours of 9994, 9998 and 9999.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Repeatability:** This course may be repeated for additional credit.



**MATH 9999. Dissertation Research. 1 to 6 Credit Hour.**

The course is for Ph.D. students who have been elevated to candidacy. During the course of their candidacy students must complete a minimum of two credits of dissertation research. This course will confer full-time status at the minimum credit hour registration limit of one credit. Students must complete a total of 6 credit hours of 9994, 9998 and 9999.

**Level Registration Restrictions:** Must be enrolled in one of the following Levels: Graduate.

**Student Attribute Restrictions:** Must be enrolled in one of the following Student Attributes: Dissertation Writing Student.

**Repeatability:** This course may be repeated for additional credit.