The University Senate of Michigan Technological University

Proposal 49-22

Establishment of a New Graduate Certificate in Scientific Computing

Submitted by: Department of Mathematical Sciences

1. **Proposal Date:**
   March 30, 2022

2. **Proposing Contacts and Departments:**
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3. **Sponsor Department Approvals**
   Approved by the Department: February 4, 2022

4. **General Description and Characteristics of Certificate**
   The Department of Mathematical Sciences proposes to create a nine-credit Graduate Certificate in Scientific Computing. This certificate will provide graduate students and certificate-seeking students with foundational knowledge to derive, analyze and apply numerical methods for scientific computing. This foundational knowledge is useful for many scientific and engineering disciplines where partial differential equations are used to model the system of interest. As part of the core requirements, students will be introduced to topics in numerical linear algebra and numerical methods for solving partial differential equations.

   4.1. **General Description of Certificate**
   This proposal offers students a path to obtain a Graduate Certificate in Scientific Computing as part of their MS or PhD degree program, or as certificate-seeking students. This certificate requires students to take two core courses, as well as a third elective course selected from a list of approved courses.

   4.2. **Catalog Description**
   The Graduate Certificate in Scientific Computing is designed to infuse foundational knowledge in deriving, analyzing and applying numerical methods for scientific computing in various scientific and engineering domains.

5. **Rationale for the Certificate**

   Computational simulations are a key part of scientific research for government, industry, and academia, complementing laboratory experimentation and theory. Currently enrolled students in the Mathematical Sciences, as well as others within the College of Engineering and College of Sciences and Arts, such as Mechanical Engineering, Electrical Engineering and Physics, could participate in this graduate certificate program to gain knowledge in numerical methods for scientific computing, enhancing their work in their respective disciplines.

Anecdotal evidence, including discussions with constituent employers, suggests that students and employers value graduate certificate programs as a way to achieve competency in specific areas. In fact, it may be that certificates are easier for prospective employers to understand as completion of a certificate represents a specific set of coursework and competency that may be hard to glean from a quick glance at a transcript. We propose to serve this market by offering this certificate.

6. **Related Programs**

Some similar graduate programs are offered at:

- (MI) University of Michigan - Graduate Computational Discover and Engineering Certificate
  A 12 credit graduate certificate offered by the Michigan Institute for Computational Discovery and Engineering. Two classes (6 credits) must focus on methodology (choice of 84 classes given) as well as one/two additional courses (choice of 122 classes given) depending on whether a student engages in an approved internship, practicum or profession project equivalent.
- (MI) Michigan State University – Graduate Certificate in Computational Modeling
  A 9 credit graduate certificate offered by the Department of Computational Mathematics, Science and Engineering. Consists of 2 core courses (chosen from a list of six graduate courses that span computational modeling, numerical methods, numerical linear algebra and parallel programming), and an elective course (that is approved by the graduate director)
- (WA) University of Washington – Scientific Computing Certificate
  An online 15 credit graduate certificate offered by the Department of Applied Mathematics that surveys numerical methods for solving ordinary and partial differential equations, statistical methods and their implementation, and an introduction to hardware, software and programming for large-scale scientific computing.
- (NJ) Princeton University – Graduate Certificate in Computational Science and Engineering
  Certificate requirements are two core courses (Software Engineering and Numerical Algorithms), one elective course (computational methods in various domains), delivery of a presentation at a research seminar, and completion of a dissertation with a significant computational component.
- (CA) Naval Postgraduate School – Academic Certificate in Scientific Computation
  Certificate requirements include two core courses (Matrix Analysis and Numerical Analysis), and two elective courses (options include advanced topics in numerical analysis, numerical ordinary differential equations, numerical partial differential equations, finite elements, computational linear algebra, distributed scientific computing, calculus of variation, perturbation methods or dynamical systems)
- (FL) University of Florida – Scientific Computing Graduate Certificate
  An online graduate certificate with one required course (uncertainty quantification) and two elective courses (selection of 16 courses that involve programming and modeling).
- (PA) University of Pennsylvania – Certificate of Advanced Scientific Computing
  Certificate requirements include two core courses: a) multiscale multiphysics modeling, with various flavors offered by different departments, and b) algorithms, with various flavors offered by different departments; two elective courses either focused on data science, advanced multiscale modeling or high-performance scientific computing.
- (TX) University of Texas at El Paso – Graduate Certificate in Applied & Computational Mathematics

A 15-credit certificate consisting of one required course (Numerical Analysis), 3 elective courses (from a prescribed list), and a 3-credit course that is approved by the graduate director.

- (TX) University of Houston – Certificate in Computational Mathematics
  A 15-credit certificate with two required courses (Numerical Analysis; Basic Scientific Computing) and three elective courses (from a list that includes numerical PDEs, ODEs, Finite Elements, Numerical Linear Algebra and Optimization)
- (AK) University of Alaska Fairbanks – Graduate Certificate in Applied And Computational Mathematics
  A 12-credit certificate with two core courses (chosen from a list of 5 options) and two elective courses (myriad of choices with some restrictions)

7. **Projected Enrollments**
Initially, the program will have most of the enrollment from currently enrolled Michigan Tech graduate students. If interest exceeds this project enrollment, additional resources may be required.

Semester	On-campus Enrollment
Fall 2022	5
Fall 2023	5
Fall 2024	8
Fall 2025	10

8. **Scheduling Plans**
The proposed certificate can be completed on the existing course schedule. The proposed coursework will be offered during regular instructional time periods and will not require changes to scheduling of classes.

9. **Curriculum Design**
This 9-credit certificate consists of two 3-credit required courses and one 3-credit elective. The required and elective course list is given below. It is expected that students will work with the program advisor to select courses that fit their interests and prerequisite skills.

Required courses - 6 credits
MA 5629 - Numerical Partial Differential Equations (3 credits)
MA 4610 or MA 5627 - Numerical Linear Algebra (3 credits)

Elective Course - 3 credits (select one)
MA 4620 - Numerical Methods for Partial Differential Equations (3 credits) (cannot be taken for this certificate if MA 4610 was used for the required courses)
MA 5630 - Numerical Optimization (3 credits)
MA 5631 - Advanced Numerical Linear Algebra (3 credits)
MA 5390 / BE 5390 / PH 5390 / UN 5390 - Scientific Computing (3 credits)

10. **Course Descriptions**

MA 4610 - Numerical Linear Algebra (3 Credits)
Derivation and analysis of algorithms for problems in linear algebra. Covers floating point arithmetic, condition numbers, error analysis; solution of linear systems (direct and iterative methods), eigenvalue problems, least squares, singular value decomposition. Includes a review of elementary linear algebra and the use of appropriate software. Offered each Spring semester.

MA 4620 - Numerical Methods for Partial Differential Equations (3 Credits)
Derivation, analysis, and implementation of numerical methods for partial differential equations; applications to fluid mechanics, elasticity, heat conduction, acoustics, or electromagnetism. Offered each Fall semester.

MA 5390 / BE 5390 / PH 5390 / UN 5390 - Scientific Computing (3 Credits)
Set in a Linux environment, the course offers exposure to FOSS tools for developing computational and visualization workflows. Students will learn to translate problems into programs, understand sources of errors, and debug, improve the performance of and parallelize the code. Offered each Spring/Fall semester on demand.

MA 5627 - Numerical Linear Algebra (3 Credits)
Design and analysis of algorithms for the numerical solution of systems of linear algebraic equations, least-square problems, and eigenvalue problems. Direct and iterative methods will be covered. Offered each Spring semester.

MA 5629 - Numerical Partial Differential Equations (3 Credits)
Analysis and design of algorithms for the numerical solution of partial differential equations. Offered each Fall semester.

MA 5630 - Numerical Optimization (3 Credits)
Numerical solution of unconstrained and constrained optimization problems and nonlinear equations. Topics include optimality conditions, local convergence of Newton and Quasi-Newton methods, line search and trust region globalization techniques, quadratic penalty and augmented Lagrangian methods for equality constrained problems, logarithmic barrier method for inequality-constrained problems, and Sequential Quadratic Programming. Offered Spring semester, even years only.

MA 5631 - Advanced Numerical Linear Algebra (3 Credits)
Design and analysis of numerical algorithms for linear algebra. Covers sparse iterative algorithms (including preconditioners) for linear solve, eigenvalue, and singular value problems. Includes the use of appropriate high performance computational libraries and applications of linear algebra. Offered each Fall semester.

11. **Model Schedule Demonstrating Completion Time**
The Certificate can be completed in a two-semester sequence. Students may enter in the Fall or Spring. One possible model schedule would be:
Fall Semester 1: MA 5629 - Numerical Partial Differential Equations
Fall Semester 1: MA 5390 - Scientific Computing

Spring Semester 1: MA 5627 - Numerical Linear Algebra

12. **Library and other Learning Resources**
    No library or other learning resources are required at this time.

13. **Faculty Resumes**
    The curriculum vitae of the faculty members are given at: https://tinyurl.com/5x4xatet and https://tinyurl.com/v3kkdpnn. Graduate Faculty serving this program will be the same as in the existing MS and Ph.D. degrees in the Department of Mathematical Sciences.

14. **Equipment**
    No new equipment will be required.

15. **Program Costs**
    While no costs are anticipated for offering this certificate initially, additional instructional resources may be needed if enrollment grows beyond projections.

16. **Space**
    No new space is required for this certificate

17. **Policies, Regulations, and Rules**
    Please refer to Senate policy on Graduate Certificates.

18. **Accreditation Requirements**
    This certificate does not require professional or specialized accreditation.

19. **Planned Implementation Date**
    Fall 2022.

20. **Learning Outcomes**
    Upon successful completion of this certificate, students will be able to:
    1. Transform scientific problems into computational models and understand how various error sources influence the accuracy and reliability of the models and computed results;
    2. Design and implement computational algorithms to tackle scientific problems.