Computational Mathematics, Science and Engineering (CMSE): Establishing an Academic Department Dedicated to Scientific Computation as a Discipline

Dirk Colbry, Michael Murillo, Adam Alessio and Andrew Christlieb
Department of Computational Mathematics, Science and Engineering
Michigan State University
East Lansing, USA
{colbrydi; murillom; aalessio; christli}@msu.edu

ABSTRACT

The Computational Mathematics Science and Engineering (CMSE) department is one of the newest units at Michigan State University (MSU). Founded in 2015, CMSE recognizes computation as the "triple junction" of algorithm development and analysis, high performance computing, and applications to scientific and engineering modeling and data science (as illustrated in Figure 1). This approach is designed to engage with computation as a new integrated discipline, rather than a series of decentralized, isolated sub-specialties. In the four years since its inception, the department has grown and flourished; however, the pathway was sometimes arduous. This paper shares lessons learned during the department's development and the initiatives it has taken on to support computational research and education across the university. By sharing these lessons, we hope to encourage and support the foundation of similar departments at other universities and grow this integrated style discipline as a new profession.

1. Support

Establishing a new department is no trivial task. For example, the traditional university funding model would require existing departments to give up a portion of their current budget in order to free up funds to create a new unit. While many faculty and administrators could envision the potential positive impact of creating CMSE, no one wanted to lose their existing funding. Fortunately, MSU announced its Global Impact Initiative (GII) [2], which offered new resources to bring more than 100 additional faculty to the university to pursue solutions to "Grand Challenges." One of these grand challenges was the continued advancement of computation in science, and the proposal to create a new CMSE department was an obvious fit for the MSU GII. Almost all faculty in the new department have joint appointments with other units, which created opportunities to leverage the GII funding to simultaneously create CMSE and grow the faculty of programs across campus.

2. Collaborative and Cross-Disciplinary

The idea of "jointness" has been ingrained into the culture of CMSE from the beginning. The department is shared between the College of Natural Science and the College of Engineering. Faculty wear multiple "hats," typically in CMSE and in another STEM (science, technology, engineering, math) unit on campus. The department was designed from the start to encourage faculty to speak from two

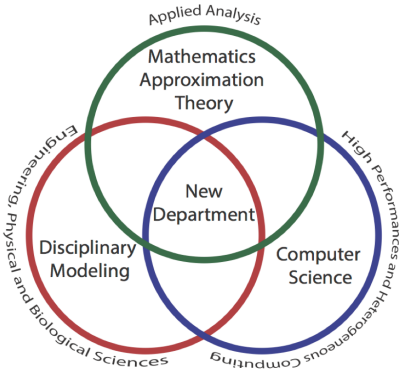

Figure 1: Triple Junction of algorithm development and analysis, high performance computing, and applications to scientific and engineering modeling and data science

valued perspectives: the common language we are developing in CMSE, and the traditional language used in their STEM departments. The CMSE department is home to computational thinkers from many fields and actively fosters discussion and collaboration across disciplines. Ten existing MSU faculty transferred (part of) their appointments into CMSE and the department conducted numerous searches to bring in 25 new, external hires. These faculty members have expertise in a range of science and engineering areas, as illustrated in Figure 2, as well as a variety of experience. Of the 35 current faculty in Summer 2019, 22 are Assistant Professors, 3 are Associate Professors, 7 are Full Professors, and 3 are Academic Specialists (faculty not on a tenure track). In Fall 2019, 3 new hires will join the faculty and the plan is to grow CMSE to 50 faculty members over the next few years.

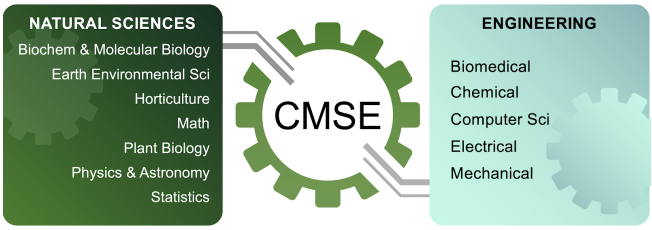

Figure 2: The new department is shared between two colleges and almost all faculty have joint appointments between CMSE and another department.

3. Undergraduate Education

At MSU, all STEM undergraduates are expected to take some combination of common "gateway" courses (e.g., calculus, chemistry, physics, biology). CMSE has developed two scientific modeling courses: Introduction to Scientific Modeling (CMSE 201) and Tools for Scientific Modeling (CMSE 202). These courses focus on learning to program in the context of solving scientific and engineering problems and contribute to a parallel effort across MSU to add "computational competency" to the "gateway" learning goals for all STEM majors. Ideally, all STEM students will learn basic programming concepts within their first two years at MSU, which will enable instructors in higher level courses to use programming as a tool to more effectively teach other STEM concepts. For example, computational competency is now a requirement for all Physics majors and is a prerequisite in courses such as Linear Algebra (MTH/CMSE314), which uses real world examples and computational methods to teach Linear Algebra

The CMSE 201/202 course use a Flipped Classroom style of teaching that focuses on hands on learning inside of the classroom, with accompanying lectures provided in videos watched outside of class. This course pedagogy is grounded in learning sciences [1] and is growing rapidly (see Figure 3).

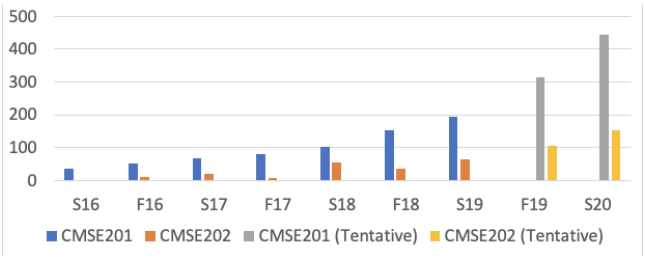

Figure 3: Growth of 201/202 enrollment by year as the CMSE department grows to serve the MSU STEM community

Students who are excited by what they learn in CMSE 201/202 now have the option of earning an undergraduate minor in Computational Modeling and Data Science. This minor is targeted primarily at STEM students but is open to undergraduates from across the university. This minor gives students a solid background in programming and computational science through a 2-3 semester introductory course sequence; additional exposure to a breadth of methods in computational and data science, including a disciplinary-specific computational course; and options for a research experience or project-focused "capstone" course.

Starting in Fall of 2019, MSU is offering a new undergraduate major in data science. This program is a collaboration between multiple departments (CMSE, Statistics, Computer Science), and MSU is working with other institutions to develop a common set of competencies for data science programs [3], We are very cognizant of the current hype surrounding data science and machine learning, and the explosion of "data science" programs across higher education. Unfortunately, the term data science is not well defined and there is not yet a standard understanding of the content of a "data science" degree. As part of its overarching mission to help establish data science as a discipline, CMSE is working across disciplines within MSU – and across institutions more broadly – to help define the standards for data science programs as its own discipline.

4. Graduate Programs

In 2016, CMSE launched three program options for graduate students: a Master's of Science, a Doctor of Philosophy, and a dual-major PhD program that allows students to combine CMSE with another doctoral major at MSU. These graduate programs are designed to help students develop broad skills for solving problems through computational modeling, data exploration, and high-performance computing techniques. Our graduate alumni will have acquired a broad range of computational skills, as well as substantial expertise in solving mathematical and statistical problems using scientific methods.

In Fall 2019, CMSE expects to include 43 PhD students; two dual enrollment BS+MS students; approximately 25 dual-major PhD students; and 15 postdoctoral researchers. The CMSE graduate curriculum features a core set of courses in mathematical, numerical and computational methods: numerical linear algebra, numerical differential equations, parallel computing, and the mathematical foundations of data science. With this foundation, students may choose additional coursework that is tailored to their research interests; common examples include graduate courses in physics, applied mathematics, engineering and/or computer science. In addition to completing coursework, PhD students must pass qualifying exams in the four areas covered by the core curriculum and must write and defend a dissertation research plan for their comprehensive exam. The PhD is awarded upon completion and successful defense of their research dissertation.

The dual-major PhD option allows students to pursue a substantial, novel, computationally-focused research program in consultation with at least one advisor (committee member) in CMSE; other advisors (committee members) may be drawn from any appropriate unit on campus. CMSE already has the most dual-major PhD students of any department in the College of Engineering (the department's administrative home), and we anticipate that this interdisciplinary PhD option will be an advantage in recruiting new graduate students with novel research paths. For example, a typical dual-major PhD student in CMSE might be developing algorithms that are more computationally in-depth than is typical in their home discipline. By creating a dual-major PhD program, these students can craft a set of course and research requirements specific to their area of interest and gain access to the faculty and university resources to support their success.

REFERENCES

[1] Brian Danielak, Brian O'Shea, and Dirk Colbry. 2016. Using Principles from the Learning Sciences to Design a Data-Driven Introduction to Computational Modeling. In *Workshop on Teaching Computational Science (WTCS)*.

[2] Global Impact Initiative | Research at Michigan State University. https://research.msu.edu/global-impact/

[3] 2019 Data Science Leadership Summit, Nov 7-9, Santa Fe, https://sites.google.com/msdse.org/datascienceleadership2019/home