Executive Summary: Computational Physics at the Physics and Astronomy Department, Michigan State University

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Motivation

Modern scientists increasingly rely on computational modeling and data analysis to explore and to understand the natural world. Given its ubiquitous use in science and its critical importance to the future of engineering, computational modeling has been called the "third leg" of 21st century science, next to theory and experiment. This is particularly true in physics, where many important recent advances in our understanding of the physical world have been driven by large-scale computational modeling and data analysis - for example, the 2012 discovery of the Higgs boson, the 2013 Nobel Prize in chemistry for computational modeling of molecules (received by biophysicists), and the 2016 discovery of gravitational waves. It has become clear that a large fraction of theoretical and experimental physicists require a high level of computational sophistication to competently pursue many aspects of their work - a trend that is likely to grow with time as computers increase in power and experimental datasets grow exponentially. By 2020, it is also expected that one out of every two jobs in the STEM (Science, Technology, Engineering and Mathematics) fields will be in computing (Association for Computing Machinery, 2013).

Beyond its increasing centrality in research, the use of computational modeling in the classroom setting provides students with insights that are complementary to those resulting from pencil-and-paper manipulation of equations. In particular, the ability to closely examine the behavior of systems that are too complex to be easily analytically tractable, or that have no analytic solutions (i.e., many systems of practical interest), helps to develop intuition that is unavailable to many students from analytic calculation.

More broadly, computational modeling and data analysis is core to a variety of non-academic career paths that are often pursued by physics students following the receipt of their Bachelor's degree. A 2012 AIP survey of almost 5,000 recent physics bachelor's degree recipients indicated that roughly 50% chose to enter the workforce immediately after receiving their undergraduate degree. Of these, roughly 75% go into STEM-related fields including engineering, software development, or information technology. Depending on the specific sub-field, between 60% and 80% of these individuals regularly need to engage in computer programming or simulation/modeling tasks. Many respondents to the survey stressed the importance of computer skills, including programming, in increasing their marketability to potential employers.

Despite the ubiquity of computational modeling and data analysis by physicists in both academia and industry and its utility as a means of building physical intuition, the MSU undergraduate physics curriculum does not require its majors to learn these crucial skills (although there is optional coursework in computational methods in PHY 102 and PHY 480). In recent years, individual faculty have integrated computation into various upper-division courses targeted at physics majors, which is an important step forward - however, these efforts are highly dependent on the individual faculty teaching the course, and are largely uncoordinated.

For all of the reasons outlined above, it is critical to ensure that students graduating from MSU with a physics degree have mastery of a range of skills relating to computational modeling, data analysis, and visualization, as well as computer programming and software development. Furthermore, to ensure that students have a consistent and positive experience learning these subjects, it is important that computation is integrated into the undergraduate physics curriculum in a way that is consistent over time and between courses, and which facilitates a gradual progression in students' computational skill sets.

Proposal

By early in the Fall 2018 term or late Spring 2018 (in time to make any necessary curricular changes for the 2019-20 academic year), this committee will present a document to the faculty of the Department of Physics and Astronomy that: (1) outlines proposed learning outcomes relating to computational modeling and data analysis within the upper-division physics curriculum, (2) offers a concrete and realistic plan of action that will allow us to attain these learning outcomes, and (3) provides a plan to assess the progress of our efforts. Prior to Spring 2018/Fall 2018, the committee will pursue several goals. We will:

1. Engage the faculty in the department to understand current best practices, to identify areas of concern, and to solicit ideas for desired learning outcomes and curriculum modifications.
2. Survey current undergraduate students to understand their experiences thus far and identify the types of training that they would like to receive with regards to these subjects.
3. Survey students who recently received a bachelor's degree in physics or astrophysics to identify what aspects of their education have been useful to them thus far, and what they would have liked to have learned while here at MSU.
4. Identify possible areas of collaboration with the Department of Computational Mathematics, Science and Engineering, and explore the possibility of more in-depth educational options (i.e., a computational physics degree).
5. Contact faculty at other institutions that have pursued similar reform efforts to learn about potential opportunities and pitfalls.
6. Synthesize the results obtained from the previous points into a coherent document that will be presented to the faculty for discussion.

This proposal will provide a foundation upon which the Department could serve as a leader among large physics departments – ushering in an integrated 21st century physics curriculum, which is the first of its kind in the Big 10 and, arguably, the first among AAU institutions. Depending on the outcomes of the investigations described above, this proposal may include recommendations to integrate computational elements to some or all of the required 300- and 400-level courses (PHY 321, 410, 451, 471, and 481) over some reasonable period of time. This work can be supported by our unique connection with CMSE, which allow us to leverage the Department's recent decision to require physics students to take CMSE 201 ("Introduction to Computational Modeling") prior to PHY 321 ("Classical Mechanics I") in order to build on students' developing computational knowledge. Furthermore, the Department is home to the Physics Education Research Lab, which can help document the transition and support the evaluation of consensus-driven learning outcomes – further solidifying the Department as a 21st century leader in physics education among peer institutions. We strongly encourage faculty who are interested in sharing their views on this subject to contact any of the members of the committee in person or via email!

More material for reading and discussions. This committee has also drafted a longer document which addresses computational learning outcomes in more detail, lists examples of computational projects and topics that can be included in specific courses as well as other proposals meant to enhance computing in physics education. The longer document is meant as an input to the discussions. Please feel free to read more at this link or look up the Github repository. We will keep editing this document and welcome very much your inputs. You may also consult a longer article written by two of us (DMC and MHJ). In this reference the authors discuss how to develop a physics curriculum for undergraduate students that includes computing as a central element. The article contains several examples of numerical exercises/projects that can be incldued in Physics courses.