A project-based mechanics and mathematics course utilizing MATLAB

This essay is based on a first-year graduate-level course that I recently started teaching on mathematical principles underlying concepts of solid mechanics, with an emphasis on computations achieved through MATLAB. In the following, I discuss the main components of the course and outline some key challenges.

Learning outcomes: The aim of the course is to uncover some unifying threads that connect all of mechanics. For example, linear operators take the form of matrices in discrete models of systems and of arrays of partial derivatives in continuum models, but a number of questions we ask of such operators like what their eigensystems are, remain the same. Similarly, a simple problem involving friction that arises in undergraduate Statics and the problem of determining factor of safety in structural engineering design, both can be formulated as identical inequality-constrained optimization problems. This aim of unification is broken down into five specific learning outcomes. Besides these technical learning outcomes, the course has certain attitudinal learning outcomes, "Demonstrate attributes of life-long learning including (a) confidence in understanding of fundamental principles, (b) willingness to make mistakes and learn from them, (c) perseverance in the face of frustration, (d) reason about mechanics/mathematics through interconnected principles and not isolated facts". The latter are the source of greater and more persistent challenges.

Course organization: The content and organization of the course are driven by the learning outcomes, by a process loosely based on the ideas in [1]. The course is centered around assignments, each of which is of two-week duration. The motivation for this is two-fold: (i) these assignments are closer in scope and scale to real-world scenarios than exams can be, and real-world context promotes intrinsic interest; (ii) they are lower stakes than exams, and therefore students are likely to be more willing to take risks, make mistakes and learn from them; furthermore, as described below, students can revise their work based on feedback. These assignments drive the topics covered (not the other way around); for example, relevant concepts of linear algebra and optimization theory are covered in the context of a particular assignment. Such topics are covered in online supplementary material associated with assignments. Class time is utilized for reflection and troubleshooting issues students encounter as they work through the assignments; in this sense, the course has a flipped format.

Online supplementary materials: These materials consist of (1) video lectures, (2) MATLAB LiveScripts that allow interactive exploration of concepts, and (3) MATLAB Grader practice problems. The Grader problems are meant for exercise and strength-building, and while tied to the theme of the assignment, are not directly part of the assignment.

Reflection: An additional component of the course is reflective essay at the end of the course, which is intended for the students to tie together concepts from the course and reflect on what learning outcomes were achieved from their perspective.

Assessment: The assessment strategy is inspired by [2]. Each assignment is assessed, based on a specific two-level rubric also provided to the students, as satisfactory/unsatisfactory. If unsatisfactory, feedback is provided, and the student can resubmit in a week after incorporating the feedback. If the student has invested in significantly incorporating the feedback the assignment is assessed as satisfactory. A final letter grade is determined based on how many learning outcomes are accomplished the assignments satisfactorily completed by the student.

Challenges and solutions: There are two primary challenges from my experience: (1) At the first-year graduate level, students are still not comfortable to open-ended problems and having to devise solutions themselves (particularly of a computational nature); (2) impressing upon students that developing and troubleshooting code, much like any other skill, requires practice and perseverance. Having lower-stakes assignments combined with access to constructive feedback on assignments as well as through discussion forums seems to have alleviated the first challenge. For a subset of students, the second challenge often remains, and possible measures for this are one of my learning goals at the workshop.

References:

1. Hansen, E.J. (2011). *Idea-Based Learning: A Course Design Process to Promote Conceptual Understanding*, Stylus Publishing.
2. Nilson, L. B. (2014). *Specifications Grading: Restoring Rigor, Motivating Students, and Saving Faculty Time*, Stylus Publishing.