Development of an Interactive Textbook Backed by Cloud Infrastructure to Pilot Active Computational Learning in an Upper Level Mechanical Vibrations Engineering Course

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Overview

Many undergraduate engineering curricula today are unable to keep pace with the rapidly growing industry demand for individuals who can solve engineering problems by writing computational programs using modern software engineering practices and tools[1]. The engineers with only spreadsheet and minimal scripting skills that emerge from these university programs are unlikely to be competitive in the future job market. In contrast, there is recent evidence that teaching students to "think computationally"[2] complements their "analytical thinking" to more effectively learn engineering concepts. To address this deficiency in computational teaching in current curricula, the UCD MAE department is in the early stages of developing a new entry level course that teaches students to solve engineering problems by thinking computationally while simultaneously learning effective modern computational engineering tools and practices. This will further tie into future plans to address integration of these methods into many of our upper level courses.

As a pilot exploration of these teaching methods, we have been utilizing "computational notebooks" using the open source Jupyter software in two upper division courses: Applied Aircraft Dynamics (EAE 127, Robinson) and Introduction to Mechanical Vibrations (ENG 122, Moore). This proposal focuses on enhancements to ENG 122, a technical elective course in which students learn how to predict mechanical vibrations and interpret simulated and measured vibrations using both analytical and computational means[3]. In the Fall of 2016, a set of 10 computational Jupyter notebooks[4] was developed for in-class, hour-long learning activities where students learned vibration concepts through exploratory computational work, as opposed to traditional chalkboard lecture. The assessments in the exams indicated improvements in

[1] For example, "The State of Mechanical Engineering: Today and Beyond" (ASME, 2011) found that the second most desirable skill for the next 10 to 20 years is "computer programming/software".
[2] "Computational Thinking: I do not think it means what you think it means" (Barba, 2016)
[3] ENG 122 Syllabus: https://moorepants.github.io/eng122
[4] Repository of existing ENG 122 computational notebooks: https://nbviewer.jupyter.org/github/moorepants/eng122/blob/master/content/materials/notebooks/index.ipynb

computation skills and similar performance in conceptual understanding as compared to those learned through traditional lecture.

Our plans for the Summer and Fall 2017 are to develop at least 10 more notebooks so that we can flip 10 additional hours of class time to active learning (making this 20 of the total 40), package the notebooks into an online interactive textbook, setup the cloud based JupyterHub[5] infrastructure for the College of Engineering, and finally pilot the activities in ENG 122 using this new content and software. We will assess the learning objectives in this class using the nbgrader[6] JupyterHub extension for automatic grading of weekly computational exercises and by designing exam questions which assess conceptual understanding of topics learned by both traditional and computational methods. After the course is over we will introduce both computational thinking teaching methods and the software tools to UC Davis. The following describes our plan to disseminate this work to our department, the College of Engineering, the University, and internationally.

Three courses in the MAE department will take advantage of this proposed work in the Fall of 2017: ENG 122 Mechanical Vibrations (Moore), EAE 127 Applied Aircraft Dynamics (Robinson), and MAE 233 Multibody Dynamics (Moore). Once demonstrations are available we will introduce these methods and results to the department faculty. In particular we will target the most likely courses/instructors for adoption, e.g. EME 151 Statistical Methods in Design and Manufacturing (Davis), MAE 207 Engineering Experimentation and Uncertainty Analysis (Davis), MAE 219 Introduction to Scientific Computing in Solid and Fluid Dynamics (Delplanque). In the long term, we will develop the aforementioned introductory engineering computation course that will take advantage of the results of this proposal.

At the college level we intended to share the teaching methods and results through the Engineering Education Community which is primarily made up of the College's LPSOEs and to engage instructors which we may be interested in this approach, such as Jonathan Herman in Civil Engineering. In addition, the JupyterHub server that we maintain will be available for other college instructors to use.[7]

To share the efforts of this work with the entire university we plan to invite Olin College Prof. Allen Downey, author of ThinkPython, ThinkDSP, and other similar titles, to give both a seminar and a workshop on these methods. Prof. Downey is an international leader in educating undergraduates with computational thinking.[8] He is supported by Olin's Collaboratory[9] which is "dedicated to co-designing transformational educational experiences with and for other

[5] JupyterHub, a cloud-based infrastructure, allows individuals to interact with and use Jupyter notebooks without needing to install specific programming languages and the required libraries on their own computer. This feature mitigates a huge hurdle for beginners and allows for classroom management of assignment submissions.

[6] http://nbgrader.readthedocs.io

[7] As resources are available.

[8] http://allendowney.blogspot.com/2017/04/python-as-way-of-thinking.html

[9] http://www.olin.edu/collaborate/collaboratory

institutions”. We will partner with the Data Science Institute, the Library, and the Center for Educational Effectiveness for the location and advertisement to broadly reach interested parties at UC Davis. The one hour seminar will accommodate up to 75 participants and the half day workshop will accommodate up to 40 participants. An outline of the each of his proposed activities is presented below:

Seminar: Programming as a Way of Thinking

> Programming is not just a way to translate well-known solutions into code; it is a way to explore, discover solutions, and then create the language to express them. Programming is a meta-skill that helps people learn other skills and understand new ideas by expressing them in code. When programmers debug code that represents their understanding, they are debugging their brains at the same time. Modern programming languages like Python allow programmers to think in code, and think differently as a result.
>
> In this talk I present examples where Python is used as a thinking tool, a way to understand abstract ideas by expressing them in code. I start with basic examples that demonstrate the expressive power of Python, and move on to recent projects that prompted me to reflect on Python as a way of thinking. I draw examples from statistics, mechanics, and digital signal processing.

Workshop: Computational Thinking in the Engineering Curriculum

> This workshop invites faculty to think about computation in the context of engineering education, and to design classroom experiences that develop programming skills and apply them to engineering topics. Starting from examples in signal processing and mechanics, participants will identify topics that might benefit from a computational approach and design course materials to deploy in their classes.
>
> Although our examples come from engineering, this workshop might also be of interest to faculty the natural and social sciences as well as mathematics.

Finally, for international exposure we will initiate development and community building by leading a “Birds of a Feather” session at SciPy 2017 in collaboration with Prof. Allen Downey on computational thinking course development, we will share Prof. Downey’s seminar and workshop via Youtube for public consumption, and we will write a blog post for the EELC blog.

Student Learning Outcomes

- Students will derive and interpret analytical vibrational theory.
- Students will create mathematical models of mechanical systems capable of explaining vibrational phenomena.

- Students will write computer programs that simulate and explore vibrating mechanical systems.
- Students will analyze and interpret simulations and measurements of vibrating mechanical systems.

Assessment

1. After the student is familiar with the computational thinking procedure, we will provide the student with a dynamic system. The student will use the given procedure to understand the system and make a design choice with that knowledge. The student will be graded on how well they are able to explain how the system works. *Example: Explain how aerodynamic damping is different than Coulomb damping.*
2. We will have the student submit programs to solve a problem and will grade them on the quality of the solution and the results. *Example: Develop a program that discovers the frequencies at which a bicycle vibrates at different speeds.*
3. The students will develop a notebook to communicate their proposed solution to a vibration design problem. This solution will be presented in the form of a Jupyter notebook and graded on presentation, formatting, and content. *Example: Design a vibration absorber to dampen the Causeway road vibration issues.*

Project Timeline

- Summer 2017
  - Write 10 new notebooks.
  - Update the existing 10 notebooks.
  - Package the notebooks in an online “textbook” format.
  - Develop the class assignments and assessments.
  - Setup the JupyterHub cloud infrastructure.
  - Facilitate “Birds of a Feather” session at SciPy.
- Fall 2017
  - Deliver the materials in ENG 122.
  - Assess the students’ learning.
- Winter 2018
  - Publish EELC blog post.
  - Present to EELC and the MAE faculty.
  - Seminar and workshop by Allen Downey.

Budget

Summer TA Stipend (3 months @ 25%)	*$3392*

Server for JupyterHub Installation	*$3000*
Faculty Summer Salary (3 months @ 30%)	*$9096*
Travel for two to SciPy 2017 Conference	*$2200*
Collaboratory seminar, workshop preparation	*$1500*
Collaboratory seminar, workshop delivery	*$1500*
Travel, room, board for Allen Downey	*$1500*
Total Requested	***$22188***
MAE Contribution: Fall TA (25%)	*~$10000*

One faculty member, Jason Moore, and one graduate student, Kenneth Lyons, will be funded to develop the teaching materials and setup the computer infrastructure during the summer of 2017. The MAE department will cover the teaching assistantship in the Fall. Jason and Kenneth will travel to SciPy 2017 in July 2017 to run the “Birds of a Feather” session. We are asking for $3000 to purchase a computer (server) to host the free and open source JupyterHub installation. This dedicated computer will provide sufficient computing power for simultaneous classroom use of up to 100 students and will be maintained by the grantees over the course of its 7+ year effective life span. Olin College’s standard cost for a 1 day collaboration is $1500 for preparation and $1500 for delivery in addition to travel costs for Allen Downey.