A multi-campus, blended, connected course + MOOC

Practical Numerical Methods with Python

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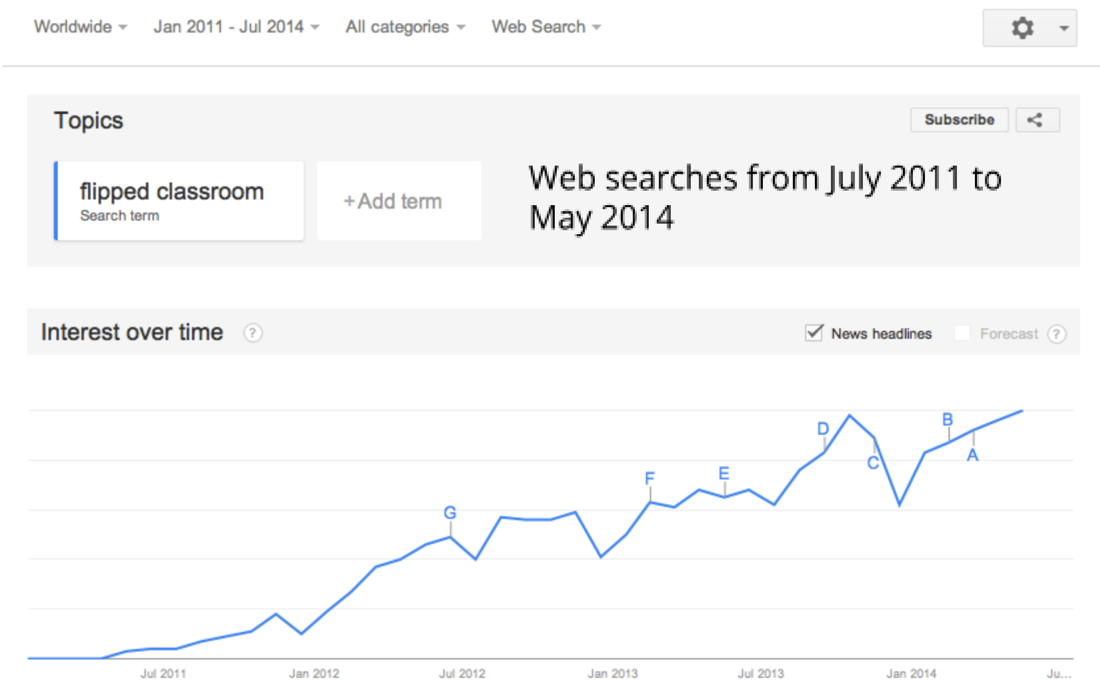
Summary

This educational project will combine several key innovations. We will collaborate internationally, across four institutions, to develop connected courses to teach the fundamentals of computational science and engineering. Each local cohort of students will experience a blended-learning environment, and the instructors will develop online educational materials collaboratively. This is a unique opportunity to show a shared venture in educational innovation functioning like research collaboration. At the same time, we will offer a MOOC (massive open online course), inviting self-learners and curious minds around the world to learn with us. The MOOC will be offered on an independent installation of the Open edX platform, without association with any major MOOC provider. The course content will be organized in granular learning units (modules), each motivated by a problem modelled with a differential equation. In the MOOC, online students who complete a module will be offered an Open Badge as recognition of their achievement. We incorporate badges and granular learning to better reflect the behavior of online participants. The local students (registered for credit) will participate in this wider community, across the four locations and with the MOOC participants. All materials will be developed openly and shared under a Creative Commons Attribution license.

Motivation for Blended & Connected Learning

Blended learning combines the advantages of online learning with the benefits of the traditional face-to-face classroom. One style of blended learning gaining popularity is the *"flipped classroom."* This term was almost unheard of in mid-2011, but a trend analysis via Google shows that it has been rising to the top of the vocabulary of modern education.



Background for this project

Prof. Barba incorporated a plan to use the flipped classroom model in her computational engineering teaching as part of her NSF CAREER proposal submitted in July 2011, when (as seen in the Google trends plot) this form of blended learning was little known. She first taught a flipped "Computational Fluid Dynamics" (CFD) course in Spring 2012, using a set of previously recorded live lectures, with on-screen digital inking, for instructional content delivery. These videos were openly shared on **YouTube**, where they have accumulated nearly **250,000 collective views**. This was a single-instructor effort, with no additional support in funding or dissemination. Yet the videos achieved a large audience over the last two years, and continue to get views. More importantly, the experience with the flipped CFD course was productive in the classroom: students achieved more successful solutions to their course assignments and were engaged, collaborative, and satisfied.

What is blended learning?

The Clayton Christensen Institute publishes frequent reports and commentary on innovations in education. They define blended learning as:

> *"leveraging the Internet to afford each student a more personalized learning experience, meaning increased student control over the time, place, path, and/or pace of his or her learning."* [1]

Thus, the key to the effectiveness of blended learning is that it affords personalization. It is widely reported in the education literature that one-on-one tutoring is the most effective form of teaching, averaging *two standard deviations* of advantage (Bloom's two-sigma problem). *Personalization* is a way that mass education can inch toward the effectiveness of tutoring.

The various forms of validation for blended learning as an effective educational approach and the track record of Prof. Barba with flipped classroom and instructional technology are the *starting points* for this educational project.

Online-learning platform and content

We will use the OpenEdX platform to structure and deliver course content and learning objects online, while classroom activities can be designed in each course site and tailored to the local student cohort.

The partner instructors will collaborate on the creation of the course's educational objects, with the goal of improving quality through peer review and iterative improvement. And *during* the courses, the instructors in each site will exchange ideas about effective in-class activities that engage the learners. Each site will lead its own blended course, but the digital learning objects will be shared, and the students will benefit from an extended community for interactions via the discussion boards and social media.

To enable **sharing** of course materials, everything will be developed in the open model: content will acknowledge the copyright of the authors while being licensed under a Creative Commons Attribution CC-BY 4.0 license, while all code will be released under the MIT license.

What is connected learning?

Connected learning focuses on the experience of the learners through social connection and broadening access. The basis in learning theory for connected learning has to do with the idea of *intrinsic motivation* and making learning relevant through a social and value-based framework.

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[1] http://www.christenseninstitute.org/blended-learning/

In this proposal, the role of a **multi-campus, connected course experience** is to build a community of learners, while the simultaneous MOOC extends that community online at the same time as it broadens access.

We believe that being connected with other learners across the world will be exciting, motivating, interesting and enjoyable for the students. Connected learning aims to create the *desire to learn* and make the learning *relevant*, bringing people closer together through their common experience, all enabled by digital technologies.

Motivation for a MOOC

There may be a short window now to come up with something truly interesting, different, and eye-catching in the online-learning scene, in particular using MOOCs. While a lot of the fanfare of MOOCs has been dying down, the "big three" are consolidating their positions:

1. **Coursera**, with its Signature Track, is showing that MOOCs can indeed be monetized. They first made $1 million in one year on revenues from certification; they collected the next $1 million in 3 months; and hit a total of $4 million after another 2 months (Apr. 2014). They charge only $30–$100 per course and use simple yet effective technology for authentication (typing pattern fingerprinting). [See blog post by Donald Clark.]

2. **Udacity** announced its pivot to industry partnerships and employer-led curricula (Nov. 2013). They do not partner with universities, and take control of most of the production of videos and other learning objects. They are now squarely in the VOOC business (vocational MOOCs) and started phasing out free certificates and charging for tutoring (April 2014).

3. **EdX** is the only non-profit of the three, and has released its platform as open source (Open edX). This distinguishes them. Their university partners have to invest a large amount to be a part of the xConsortium (in one case we know of, the entry fee was on the order of $2 million), making it an expensive avenue into the MOOC world.

Even if the hype on MOOCs is dying down, there is absolutely a need to be a player in this movement and not stand on the sidelines. The question is *how* to come up with something that speaks of a commitment to innovation, to quality education, and to areas of study where we can recruit talent. And to do so without spending millions of dollars (and come in as edX member #50 with no impact).

We also recognize that the main goals that universities have for creating MOOCs are to innovate for improving classroom education, achieving improved access to educational content and satisfying outreach goals. The ways in which offering a MOOC can improve classroom education have not been clearly defined, but the careful course design that is invested is often already a boost to quality. We believe that creating an online community of learners is also an enhancement to the experience for on-campus students.

Our idea:

We propose an *independent* MOOC using the open-source Open edX platform, installed on a cloud service. “Independent” means that it’s not associated to a MOOC consortium (Coursera or edX). It is a grassroots initiative in open online learning, that uses the top technologies.

The MOOC that we propose will run simultaneously with on-campus courses at the George Washington University School of Engineering and Applied Sciences and partner institutions, making it a *connected, multi-campus* (even multi-continent) educational initiative.

Our partners are:

- the **King Abdullah University of Science and Technology** in Saudi Arabia,
- **Pontificia Universidad Católica de Chile** and
- **University of Southampton** in the UK.

Each site will run its own course with some variations in content, methodology and assessment, but the instructors will collaborate to design a joint program and course modules, and in writing some course content openly. Students at all sites will participate jointly in the social learning facilitated by the Open edX platform.

Why it’s a narrow window of opportunity

The source code of the Open edX platform was released on June 2013. As of now, there is no university in the US—except for Stanford—using an independent installation of Open edX to provide online learning. Stanford was the originator of major momentum in MOOCs (with two of the “big three,” Coursera and Udacity, being Stanford spin-offs), so we can hardly compete with them. **GW** could be one of the first US universities after Stanford to deploy Open edX, which makes a powerful statement of being ready to innovate.

This could be on the verge of happening elsewhere, too. Interest in the open platform is rising fast. As anecdotal evidence, a Professor of Innovation and Education Technology at the University of Queensland who leads the UQx effort recently tweeted from the edX Global Forum in Delft, June 2014: *“[The] Single most important thing about open edX for campus leaders - open source is insurance against the future.”*

The only obstacle, besides the willingness to “go it alone,” is the technical hurdle of customizing and deploying a large, bleeding-edge software platform on a scalable cloud service. To accomplish this, we have identified a contractor that is ideally suited to help us: IBL Studios in NYC. Their CEO, Michael Amigot, visited GW on April 2014 and presented a demo of Open edX, for which IBL prepared a full installation on their own servers. They have the expertise to customize the platform for us, embed standard learning objects (e.g., open badges), provide technical support and disaster recovery.

Course Description

Practical Numerical Methods with Python

Summary

The course centers on the implementation and analysis of numerical solutions for problems in engineering and applied mathematics that are expressed in terms of ordinary and partial differential equations (ODEs and PDEs). Topics will include numerical stability, accuracy, and convergence in the context of finite difference and finite volume methods for hyperbolic, parabolic, and elliptic PDEs. But the focus is on developing computational skills for writing code and exploring mathematical models through visualization, using modern tools and technologies of scientific computing. It is a MSc-level or first-year graduate course.

Structure

The "course" will be structured as a series of modules or units of learning. For the MOOC, we will issue digital badges for each unit (Mozilla Open Badges), rather than a single “certificate of completion” for the whole course. On-campus students at each participating site will be required to complete a set of modules for a credit-bearing grade, but MOOC followers can complete any number of modules to get a badge for each.

The idea is to break away from the "semester-long MOOC" to give online followers the flexibility of accomplishing shorter units of learning. Each module might be about 2 weeks long, and require about 12 hours of dedication online. So it will be possible for MOOC followers to achieve badges for units of work even if they decide to “binge” on the content unit over an intense weekend, for example (by making deadlines sufficiently flexible), which we hypothesize will help to reduce the “dropout” effect of MOOCs.

On campus, the courses may include some additional work, especially through projects and in-class formative assessment. Active learning in the classroom cannot be replicated in the online version, and thus the on-campus experience is augmented to a full three-credit course via the face-to-face component. Each site can customize its course by the order and mix of selected modules that are required. Students are, of course, free to complete non-required modules online, as MOOC participants. Providing this “menu” of learning units, beyond the required, lets more advanced students trace a personalized path through the course. Assessment in each site will be independent and up to the local instructor, but formative assessment (quizzes and short assignments) will be designed collaboratively and embedded in the Open edX platform.

Technology

The programming language used in the courses for the computational work will be Python. Each learning unit will consist of several lessons, for which content will include videos and media-rich computational documents in the form of IPython Notebooks. In addition, advanced lessons will explore high-performance computing via IPython parallel and GPU-accelerated computing via CUDA Python.

Videos will present theory via on-screen annotations (digital inking) and screencasting, while written content presented on IPython Notebooks will support all the lessons, while at the same time providing instructional scaffolding.

To record the videos, we count with the support of **GW's Academic Technologies** unit, whose experience and professional toolset will ensure a high production value. (Examples can be seen in the GW AcadTech YouTube channel.) The videos will be recorded by Prof. Barba during August 2014, with collaboration from the partner instructors according to their preference.

The partner instructors will collaborate in the writing of course lessons as IPython Notebooks, via a version-control repository on GitHub. To enable this collaboration, all materials will be developed under a Creative Commons Attribution CC-BY 4.0 license, acknowledging the authors of each document in the copyright notice. All content will be open, shareable and remixable.

The instructors already share a vision and previous experience with this type of content. See:

- Barba's AeroPython and CFD Python collections
- Ketcheson's HydroPython collection
- Hawke's Numerical Methods collection

The platform for online delivery of course content, formative assessment and social learning (discussion board) will be **OpenEdX**—the open-source software platform released by the edX consortium in June 2013. The MOOC followers and the students in each of the partner sites will all access the same platform, but local course sites may have an additional learning management system (like Blackboard) to manage gradebook.

To customize and deploy OpenEdX on cloud hosting servers, GW will contract the services of **IBL Studios**, a NYC consulting company that specializes in educational technology and open-source solutions. They presented a demo in April 2014 for the GW Strategic Committee in Online Learning, for which they prepared a quick-and-dirty demo site, currently still live at http://gwu.iblstudios.com

The OpenEdX platform of course allows many courses, but we are proposing to develop just one course at this time, as part of this pilot.

Local courses

The simultaneous, connected courses in campuses across four continents are:

- **GW** — MAE 6286: Numerical Solution Techniques in Mechanical & Aerospace Eng.
- **KAUST** — AMCS 252: Numerical Analysis of Differential Equations
- **Soton** — MATH6141: Numerical Methods (for 4th-year Engineers and MSc students) and FEEG6001: Numerical Methods (1st-year doctoral program of the newly funded Next Generation Computational Modelling centre)
- **PUC —** *"Métodos Numéricos para Ingenieros"*

Not all the contents of the local courses mesh exactly, but the partner instructors are discussing how much the contents overlap and what the presentation strategy should be for the connected courses.

MOOC

The simultaneous MOOC in *"Practical Numerical Methods with Python"* will be run from GW, but the course page will feature the partner instructors and their course numbers at the partner sites (with their photo, biography and university logo). The course page will also acknowledge and feature the logo of any sponsors.

Course topics

The partner instructors are currently discussing the details and will continue refining the common topics during the summer, but a preliminary list of topics follows.

1. The phugoid model of glider flight.

Described by a set of two nonlinear ordinary differential equations, the phugoid model motivates numerical time integration methods, and we will build it starting from an even simpler model (e.g., the pendulum), so that the unit can include 4 or 5 lessons on initial-value problems. Roughly, this module would include: a) Forward/backward differencing and Euler's method for the pendulum; b) extension to the phugoid model; c) the midpoint method, convergence testing, local vs. global error; d) Runge-Kutta methods.

Computational techniques: array operations with NumPy; symbolic computing with SymPy; ODE integrators and libraries; writing and using functions.

2. Space and Time—Introduction to finite-difference solutions of PDEs

Starting with the simplest model represented by a partial differential equation (PDE)—the linear convection equation in one dimension—, this module builds the foundation of using finite differencing in PDEs. (The module is based on the *"CFD Python"* collection, steps 1 through 4.) It also motivates CFL condition, numerical diffusion, accuracy of finite-difference approximations via Taylor series, consistency and stability, and the physical idea of conservation laws.

Computational techniques: more array operations with NumPy and symbolic computing with SymPy; getting high performance with Numba.

3. Riding the wave: convection problems.

Starting with the inviscid Burgers' equation in conservation form and a 1D shock wave, cover a sampling of finite-difference convection schemes of various types: upwind, Lax-Friedrichs, Lax-Wendroff, MacCormack, then MUSCL (discussing limiters). Traffic-flow equation with MUSCL (from HyperPython). Reinforce concepts of numerical diffusion and stability, in the context of solutions with shocks. It will motivate spectral analysis of schemes, dispersion errors, Gibbs phenomenon, conservative schemes.

4. Spreading out: Parabolic PDEs

Start with heat equation in 2D (first introduction of two-dimensional FD discretization). Introduce implicit methods: backward Euler, trapezoidal rule (Crank-Nicolson), backward-differentiation formula (BDF). Pattern formation models (reaction-diffusion). Theory content: A-stability (unconditional stability), L-stability (?). Fourier spectral methods and splitting.

5. Relax and hold steady: elliptic problems.

Laplace and Poisson equations (steps 9 and 10 of "CFD Python"), explained as systems relaxing under the influence of the boundary conditions and the Laplace operator; introducing the idea of pseudo-time and iterative methods. Linear solvers for PDEs : Jacobi's method, slow convergence of low-frequency modes (matrix analysis of Jacobi), Jacobi as a smoother, Multigrid.

6. [Optional] Tsunami: Shallow-water equation with finite volume method

1D first, then 2D problem with HPC solution (Python parallel or CUDA Python)

[Other modules pending, for a total of 7 or 8.]

Resources needed

At George Washington University

1. Consulting services from IBL Studios to customize and deploy OpenEdX for GW, troubleshoot, deal with all tech issues during course creation and delivery, install digital badges (and design an icon for each)— approximately $10k
2. Cloud computing / hosting … we don't have an estimate yet, and we are looking for sponsored hosting.
3. TA support for course creation: Summer'14 — $7000 (Cooper) $4000 (Forsyth)
4. TA support for course delivery during Fall'14 — $11k x2 (TAs will answer questions on the discussion boards on a daily basis, will field technical issues, manage MOOC assessments and content deployment)
5. GW Academic Technologies support for recording videos
6. Optional tech development work: integration of a Python environment in Open edX or a separate Wakari server.

Sub-total budget at GW: $43k + cloud hosting

Summer salary for Barba (one month in August) will be supported by her NSF CAREER award, to develop course materials, record video lectures and populate content on the Open edX platform, with the help of the TAs at GW.

Internal GW Funding & Sponsorship

GW's Vice-Provost for Online Learning and Academic Innovation will contribute $20,000 to this pilot. The SEAS Dean's office will contribute $11,000 to cover the salary of one TA during Fall 2014.

We are also requesting industrial sponsorship for the course from partners that can help us deliver this pilot in the interest of better training young STEM professionals in the computational sciences (and PR benefits). Sponsorship in the amount of $12 would help pay for the external development team at IBL and the cloud hosting.