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Engineering Literacy for Undergraduates in Marine Science

A Case for Hands On

BY EMMANUEL BOSS AND JAMES LOFTIN

INTRODUCTION

Graduates in marine sciences most often lack basic engineering skills such as programming and robotics. Once they graduate, however, many of the available jobs require them to program (e.g., set a conductivity-temperature-depth sensor to sample at a specific time for a specific interval), collect data using sensors, and interface with robots (e.g., remotely operated vehicles, gliders, and floats). In general, whatever jobs they may land, the ability to teach *themselves* new skills will be required. We were inspired to develop the class described in this article by Randy Pausch's *The Last Lecture* (http://www.cmu.edu/randyslecture), in which he described the Carnegie Mellon University Master of Science in Entertainment Technology program, where all the classes are project based.

In our University of Maine semester-long class (14 weeks, 3 hours per week), juniors and seniors in marine sciences teach themselves to program, build and calibrate sensors, build robots, and use the robots as platforms to sample within a water column. Outside materials (e.g., papers, book chapters, movies, and TED talks) enrich the class. Students reflect on class activities and the outside material in a mandatory submission to a weekly blog. There are no prerequisites for taking the class. However, students are warned prior to registering that they will be responsible for their own learning.

Frontal "teaching" is limited to the first class meeting where the class philosophy and mechanics are introduced. Future class periods are devoted to working on projects and project presentations. For example, in the programming module, students present their working programs to the class followed by a Q/A session where the students and instructors pose clarifying questions. The instructors act primarily as advisors (through communications in class and via the blog), resource providers, and evaluators; we limit the class to 12 students to ensure sufficient contact. Evaluation is based on a project-specific rubric, which includes specific expectations for each project and the associated grade reduction if details are lacking or if the project is submitted late.

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MODULE 1: PROGRAMMING *(3.5 weeks)*

The first skill the students teach themselves is programming. This process begins with MIT's Scratch (http://info.scratch.mit.edu/About_Scratch), a programming language that makes it easy to create animations and share them on the Web. The students learn how to program from tutorials and from projects others have uploaded to the Web. The Scratch project has about 2.3 million (and growing) Scratch programs on its website that the students can consult (any program viewed can reveal its open-source code).

The students are required to complete two projects with Scratch and present them to their peers:

1. Program an infomercial for your favorite nonprofit or an inspiring class you took.
2. Create a prey-predator or a chemotactic simulation.

In each project, they are required to have specific programming elements (e.g., input/output, looping, use of random number generator, if-else statements). An example would be a loop governing the motion of a fish, which moves at a fixed speed in a random direction except when a predator is at a certain distance, in which case the

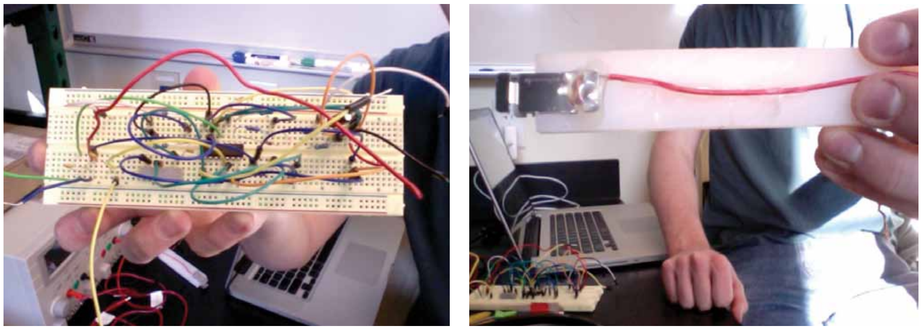

Figure 1. A conductivity sensor (board on the left and probe cell on the right) built by Molly and Peter, students in the 2012 class, based on a design they found in da Rocha et al. (1997).

speed increases and the direction is away from the predator.

After this module, the students learn two more programming languages—the one used to program Arduino boards[1] and the one used to program LEGO® robots. Because they are now familiar with the basic features of all programming languages, they have the necessary basics for learning a new language.

MODULE 2: SENSORS

(3.5 weeks)

The next skill the students teach themselves is that of building sensors using basic electronic components. The physical computing class for arts majors at NYU inspired this module (http://itp.nyu.edu/physcomp). Students completely new to the subject are encouraged to come to the lab and learn/play with the Elenco snap-it set.

Two sensor projects must be accomplished in this module:

1. Build a sensor with an LED that flashes at a variable rate depending on the quantity measured (e.g., flashes faster as the temperature increases).
2. Build a sensor that connects to a computer (via a chip or an Arduino board) that provides a variable numeric output (as seen on the computer screen), depending on the quantity measured. The chip must be programmed to obtain the desired output.

The students have to calibrate the sensors and provide the likely uncertainty based on their calibration (± 2°C). The instructors provide a "mystery" sample (or measurement environment) to test the calibration and uncertainties provided. Students are free to use a sensor of their choice (if there is time to obtain components), and basic designs are available as defaults (e.g., temperature and ambient light sensors). We have had students build fluorometers as well as conductivity and turbidity sensors (Figure 1).

MODULE 3: ROBOTICS

(~ 4 weeks)

LEGO® RCX or NXT robots introduce the students to robotics. These robots are programmable, they power mechanical motors, and they can receive input from a variety of standard LEGO® sensors (e.g., light, touch, sound, rotations, temperature). Students begin by following tutorials developed by Tufts University (http://www.legoengineering.com/teaching-resources.html) or Carnegie Mellon University (http://www.education.rec.ri.cmu.edu). They then have a series of three challenge missions (chosen out of 10) that they need to accomplish prior to being able to move to the final project. These missions involve programming the mechanical *and* sensor parts of the robots so that there is feedback between the sensors and the mechanical behavior of the robot (e.g., get the robot to converge within a few inches of a light source when facing a random initial direction).

THE FINAL PROJECT

(~ 3 Weeks)

The final project consists of building a remotely operated or autonomous underwater vehicle with LEGO® brains (Figure 2). Data need to be collected along the vehicle's trajectory with a student-built and calibrated sensor that transmits data to the LEGO® brains, where it is stored. As with all the modules in this class, the students are provided with known designs (e.g., Sea Perch, http://seaperch.org) but have the freedom to come up with novel ones.

THE WEEKLY BLOG

By midnight on Friday of every week, students complete a blog entry in which they answer the following questions:

- What have I learned this week?
- What excited me about the week's activities and why?
- What would I suggest to change if the class were offered in the future?
- What have I learned from the movie/lecture/readings I have seen this week?
- How do I feel about the movie/lecture/readings I have seen this week?

The blogs provide the instructors with feedback that is crucial to ensure that all

[1] An open-source electronics prototyping platform, the Arduino board is based on flexible, easy-to-use hardware and software. It is intended for artists, designers, hobbyists, and anyone interested in creating interactive objects or environments.

the students are on track and that each student understands the instructors' educational philosophy and expectations; this process allows for changes in the class as it unfolds. We have found that students feel very comfortable with this medium, often writing long and insightful entries that are both interesting and pleasurable to read.

The following are two examples of partial entries from blogs posted February 3, 2012:

1. *Electronics is one of those things I've always found intimidating. Maybe it's the unfamiliar lingo, the number-centric part names, or the hours I've spent watching my dad poring over and cursing at some sensor on our boat. For whatever reason, it's felt like a world in which I'll never be at home. As I started our reading in the Physical Computing book, however, everything seemed so straightforward. I liked it. I feel like, with no background, you just have to jump right in and not worry too much about not understanding everything instantaneously before even seeing it. … and I stayed after class and played around with the Radio Shack sensor kits, setting up the first two circuits diagrammed in the manual. It was tons of fun, very rewarding, and I can already sense that our learning curve is going to improve very rapidly. I guess the most important thing I learned is that it's doable. Obviously, what we were doing was very basic. Everything just builds off of the same ideas, though. Physics II prepared me very well for what we're doing now. I'm looking forward to doing more!*
2. *This video, like the others previously assigned, has done its job in inspiring me to continue exploring science. Most importantly, I am sensing a theme that supports crazy ideas. I mean that in the way of having new approaches to areas of study or theology (education) that are inspired by inspired people. They all love what they do. I can actually see the excitement on their faces and they explain crazy marine phenomen[a] to the crowd of viewers. I just hope that I find something I can be that passionate about. Also, I appreciate the interdisciplinary research…*

Figure 2. (left) Julia, Ashley, and Brittany (class of 2012) prepare their remotely operated vehicle, which includes two types of hydrophones and a light sensor, for the pool test. (right) Samantha (class of 2011) programs her autonomous underwater vehicle prior to the final pool test.

FINAL NOTE

This class is by far the most fun-filled and fulfilling class that I (first author Boss) have ever taught. Although it is well known that humans learn well by play, we seldom use this approach in university-level classes. Students respond well to it, often spending whole weekends on class projects. In addition, students in the class learn skills on their own and while interacting with peers without being supplied the knowledge by the instructors. This teaching technique empowers them by providing the needed self-confidence to seek knowledge on their own. This knowledge is now abundantly available, for free, on the Web.

Those who complete this class are not expert programmers, electronic gurus, or roboticists. However, they all have a new appreciation for the role technology plays in oceanography as well as basic literacy in this subject. Indeed, at least three graduates of the class have landed marine tech positions and have commented to the instructor that the class was instrumental in their choice. A recent graduate of this class has built a cheap (< $150) submersible chlorophyll fluorometer as a capstone project, which he presented at the Ocean Sciences 2012 conference.

Additional materials about this class can be found at: http://misclab.umeoce.maine.edu/education.php.

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