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MAKER: Applications in Do-It-Together, Environmental Monitoring Technologies - Student Projects from an Interdisciplinary, Flipped, Service Learning, Makerspace Course

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MAKER: Applications in Do-It-Together Environmental Monitoring Technologies - Student Projects from an Interdisciplinary, Flipped, Service-Learning, "Maker" Course

Introduction

Higher education is under threat. First, costs for potential students keep rising and are substantial. Second, in recent years the emergence of zero- or low-cost competing Massive Open Online Courses or MOOCs offered by organizations like Coursera or EdX, with a goal of teaching large numbers of students through automated learning modules and testing. These phenomena lead to a critical question: What is the value-add of an on-campus experience that cannot be achieved through these emerging online, low-cost programs?

In our view, there are at least three responses to this question. First, the active, problem-based learning in teams, coupled with opportunities for community service learning available through an on-campus higher educational experience can significantly trump any online MOOC-type experience. Many higher educational institutions, including our own, recognize this and actively foster these experiences.

Second, the availability of open access educational material on the net – including video-based instruction – is an opportunity, not a threat. Their use not only helps to reduce textbook costs for on-campus students, but also provides content that students can be assigned to read or review outside of class rather than having to cover the material in a lecture-based format. Time in class can then be "flipped" and used for faculty and students to work on problems together in peer-to-peer learning contexts.

Third, the emergence of cloud-based platforms and the open access licensing of content[1] create exciting new opportunities for faculty to connect to and leverage significant commons-based peer-production[2] on the Internet. The relatively new maker movement (and emerging groups like the Public Laboratory of Science, described below) are prime examples of these new opportunities. This topic is perhaps the least well-known point in this paper, and holds significant promise.

In this paper, we describe our efforts to offer an interdisciplinary undergraduate class under a flipped-content model utilizing open access content, coupled with team-based learning and student-defined projects. In this class we introduce students to the idea of commons-based peer production, and give them the opportunity to define and implement their own "open source science" project. Projects in our first offering of this class (described more fully below) include: (1) Arduino-based air quality monitoring; (2) Arduino-based water quality monitoring; (3) Arduino-based GPS wildlife (dog) tracking;

(4) hydroelectric power generation; (5) helium balloon-based aerial photography, and an (6) open source research submarine.

This paper has two key sections. First, we describe the idea of Commons-based Peer Production. It is likely that many readers in Engineering or those with an interest in Making, Makerspaces or Maker-networks will not be familiar with this concept, except if we say that collaborative editing of Wikipedia is a well known example of this phenomenon. It is also the foundation that the "Maker" phenomenon is grounded upon. In this section we also describe PublicLab.org, a nonprofit organization that embraces Maker ideals and applies them in the context of science, particularly science to support environmental justice. Second, we describe our experience offering an interdisciplinary, flipped, service-learning, maker, open-science course and specially describe the projects that emerged in this course. We close with some reflections on the experience, and provide some recommendations for other instructors who might be interested in trying this idea out on their own campuses.

The Idea of Commons-based Peer Production

In his 2006 book *The Wealth of Networks*, intellectual property law scholar, Yochai Benkler coined the phrase "commons-based peer production" to describe the "most significant organizational innovation that has emerged from Internet-mediated social practice." [3 (page 1)] According to Benkler[3] commons-based peer production instances occur when three core characteristics are combined: (1) the decentralization of conception and execution of problems and their solutions; (2) the harnessing of diverse participant motivations; and (3) the separation of governance and management from property and contract.

The first peer production characteristic, "decentralization of conception and execution of problems and solutions," describes situations where conception, such as a new idea, and the actual implementation of that idea, are both decentralized and potentially executed separately, by different individuals or groups. Benkler uses the example of an idea for a new function in an existing open-source software, or, as we mentioned above, the idea of a new article that needs writing in Wikipedia as classic examples of the conception. The development of that new software feature or the actual writing of that new article might then be done by the person who proposed the idea; or it could be implemented by some other individual.

The second peer production characteristic, "the harnessing of diverse motivations," suggests that while some participants are motivated by pay, there are many others who participate for other non-monetary reasons, such as user-centered need,[4] enjoyment or "serious leisure",[5] the intrinsic desire to learn, and/or support for "freedom philosophies" that underlie many free/libre or open source software development efforts.[6]

The third peer production characteristic, "the separation of governance and management from property and contract," describes situations where inputs and outputs of the case are governed as either "open commons" or as "common property regimes" where some subset of participants have property rights to the products being worked on, but share them as a community. Open-source software peer production cases, for example, are the latter. Certain individuals have property rights in that they have control over what enhancements are included in the next release of the software product through their rights and control of the versioning system.[7] Further, instances of peer production will be characterized by governance or management systems that avoid the use of contract or property rights to steer or constrain new ideas, exploration, and experimentation by the peers.[3] In open source software peer production instances, new enhancements often flow from a participant's need or idea, rather than from the "boss" with authority telling them what or what not to implement.

Benkler[4] recognizes free/libre and open source software as the "quintessential instance" of commons-based peer production and the example with the longest history. Richard Stallman's[6] innovation in the use of copyright licensing and his development of his General Public License or GPL – sometimes referred to as "Copyleft" – to encourage the free (as in cost) sharing of the software and, in some instances, the permission in these licenses to encourage software developers to add new functionality (with the requirement that the new functions also fall under the same software license) is a foundational component of these instances of peer production. Another well-known and prominent peer production example is Wikipedia, which capitalizes on the later innovation by the organization CreativeCommons.org to develop copyright licenses for the sharing of text rather than software. Since these initial and important examples of online commons-based peer production systems, others have emerged, and this brings us to two peer production instances that are key elements of the class we will describe.

The Maker Movement and Public Lab as an Example of Commons-Based Peer Production

Readers of this paper will likely be familiar with the "maker movement", which is defined by Glinglin[9, page 21] as "[a] revived interest in building one's own technology with an emphasis on using affordable open-source tools and technology." For example, some of the projects we describe below are built upon the use of the open source Arduino microcontroller (http://www.arduino.cc/). And while there are different "flavors" of the maker movement (e.g., MakerEd, "Instructables," etc.), from this open source, open access perspective, the maker movement is grounded on commons-based peer production.

In parallel, specialized "maker" peer production organizations or networks of people are emerging with an eye toward open-source science. One non-profit organization called the Public Laboratory of Science (Publiclab.org) is a leading example:

> "The Public Laboratory for Open Technology and Science (Public Lab) is a community – supported by a 501(c)3 non-profit – which develops and applies open-source tools to environmental exploration and investigation. By democratizing inexpensive and accessible Do-It-Yourself techniques, Public Lab creates a

> collaborative network of practitioners who actively re-imagine the human relationship with the environment.
>
> The core Public Lab program is focused on "civic science" in which we research open source hardware and software tools and methods to generate knowledge and share data about community environmental health. Our goal is to increase the ability of underserved communities to identify, redress, remediate, and create awareness and accountability around environmental concerns. Public Lab achieves this by providing online and offline training, education and support, and by focusing on locally-relevant outcomes that emphasize human capacity and understanding." – http://publiclab.org/about

Many of Public Lab's environmental projects focus on the development and use of technologies to monitor water and land. Their foundational project was Do-It-Yourself remote sensing of the Deepwater Horizon oil spill in the Gulf of Mexico, using low-cost digital cameras hanging from kites and helium balloons (http://publiclab.org/wiki/balloon-mapping). Since then, they have expanded into other technologies, such as spectrometers and Arduino-based sensors for detecting pollution in water resources (see the list of tools under the "Research" menu at http:\\Publiclab.org for more information). Central to Public Lab as a form of commons-based peer production is their online web platform, which provides an online store for open source science equipment. Public Lab participants communicate with others through their web platform wiki or "Research Note" functions. The latter is the primary method for participants to document what they are working on, share what they have learned, ask questions to the community who are following the science topic, pose challenges to others to solve problems they have encountered, or critique one another's work. Research notes might include photos of project steps or components, documented steps they have or plan to undertake, or reports from some field excursion or Public Lab meetup. This particular function played a central role in the class we will now describe.

Course Overview

In the fall of 2014, we offered an experimental upper-level undergraduate course at the University of Massachusetts, Amherst.

The general goals of class align with the points we made in the Introduction. First, we wanted to offer an active, problem-based learning course with an opportunity to work in teams on some kind of environmental-monitoring-related project. Second, we wanted to embrace a "flipped" style of content learning, where students would find and utilize online open-access material related to the problem or relevant project technologies. For example, a central technology we thought would be relevant to potentially many projects is the open-source Arduino microcontroller, so we encouraged students to explore that as a potential platform for their project. Third, we wanted to give the students the opportunity to participate in a commons-based peer production setting. Consequently, we required all student teams to publicize their projects using the PublicLab.org's Research Notes system, and then throughout the semester publicly update their progress. Fourth, we gave students the option to build into their project some service-learning component to our local middle school, such as offering one or more after school exercises for 8th graders on something related to their projects. Our goal was not only to give our students some outreach experience, but also help to make a stronger "town-gown" connection between our university and the local schools.

Key to this course were several design criteria: resources for project equipment, a makerspace for regular class meetings, and the willingness of Public Lab to allow us to use their Research Note system for student project documentation and reporting. The latter was easily achieved. Our Public Lab contacts embraced this idea, wholeheartedly.

Resources for the class projects – mainly funding for equipment that the students needed once they determined what they wanted to do – were purchased by leveraging a generous Public Service Endowment Grant we received from the University of Massachusetts, Amherst, or through faculty contributions from their individual research funds.

Several faculty co-authors have also been involved in the development of makerspace collaboration with a local nonprofit technology and community service organization. This organization provides public access, educational and local government television channels, hosts regular workshops (often technology-centered) and is an authorized Apple training center. It has a large studio space and two computer labs and is located in the center of the town between our university and other colleges. It is also relatively close to the local middle and high schools. Over the six months prior to the start of this class, we worked with this media organization to build regular maker hours in their facility, and we offered several weekend-long Arduino workshops and maker show-and-tell evenings. Our town-gown collaboration was highlighted in The White House Maker report.[8] In addition, our students enjoyed access to an existing makerspace facility in our Engineering program. This facility houses significant maker-related technologies and provides space for engineering students and faculty to work on projects. Several of our projects, described below, took advantage of this space and resources.

We targeted students in a variety of disciplines who would have some interest in environmental monitoring projects. Our course had no prerequisites, although we were hoping some students with technical background (e.g., programming or electronics skills) would enroll. We emailed a flyer describing the course to relevant student listservs on our campus but also to faculty contacts in other liberal arts colleges nearby. Nine undergraduate students ultimately enrolled from disciplines such as Engineering, Computer Science, Environmental Science, and Public Health. Two PhD students from Civil Engineering and Environmental Conservation also participated through independent studies.

In the first two introductory sessions of the course, the lead faculty member described the ideas of commons-based peer production, open access, and introduced the students to the organization Public Lab. In the second class, one of Public Lab's active participants, Don

Blair, gave a webinar presentation on Public Lab in general, but also on his specific Arduino-based work developing a Do-It-Yourself water pollution monitor he calls the "Riffle" (http://openwaterproject.io/), and provided an overview of the Public Lab collaborative platform including wiki and Research Note pages. We devoted some time to discussions by the students on what areas of environmental monitoring they were interested in (e.g., water, air, landcover change, etc.). The lead facilitating professor then presented some ideas for projects that he had in mind. Students were given the assignment to think about possible project ideas more in preparation for the next session. Finally, some of the class participated in an optional field trip to the international Makerfaire in New York City, which provided some inspiration to students who were not familiar with this phenomenon.

In the third and forth classes, one of this paper's co-authors gave a presentation on the basics of Arduino programming, and we provided Arduino starter kits to the students who wanted them. We took more time to have each student report back their project ideas and then, as a group, build on them or refine them, or see where student interests aligned, toward the natural formation of teams. We also revisited the use of the collaborative infrastructure on Public Lab (e.g., Research Notes), talked about general expectations on using it to document their project progress, and had a partial session providing an introduction to GitHub for possible code management. By Week 4, projects and project teams were fairly well identified and the lead faculty explained that the structure of the rest of the semester was to follow an iterative cycle, loosely based on the Agile Software Development Model,[10] as shown in Figure 1. About one-third of the projects (described in depth below) were something the lead instructor suggested, one-third were instructor and student defined collaboratively, and one-third were entirely student-defined ideas.

With projects and teams defined, we went through several weeks in and out of class trying to identify the needed equipment for their projects. Later in the semester we held one class session on the basics of 3D design and printing. Three teams utilized this knowledge to implement 3D printed components for their projects.

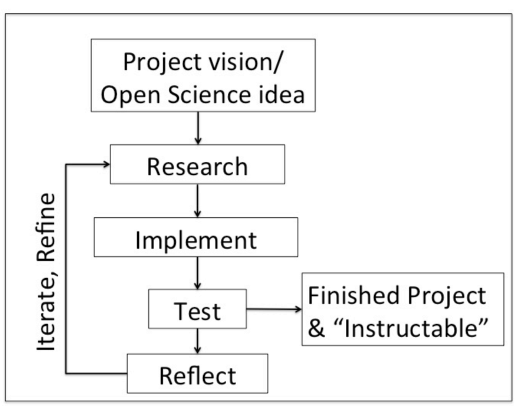

Figure 1.
General Approach Guiding the Class Projects

The following are the projects student teams identified and pursued:

- Air quality (ozone) sensor (student defined project)

  In this project, an undergraduate Environmental Science student began partnering with the Pioneer Valley Asthma Coalition on a project to develop a low-cost air sensor that could measure ozone levels. Her motivation was to build such a device that would enable her to then deploy it for sensing of ozone levels around several schools in a nearby city where high levels of asthma are reported to exist.

  Materials needed for this project included an Arduino starter kit, a Sainsmart Ozone Sensor module, and an Adafruit data-logging shield. By the end of the semester, Liz had her device measuring and recording ozone (Figure 2; see research note links below). She continues to work on this project as part of a longer-term Integrated Science program thesis, and is now testing her device in a controlled environment in an aerosol laboratory on our campus.

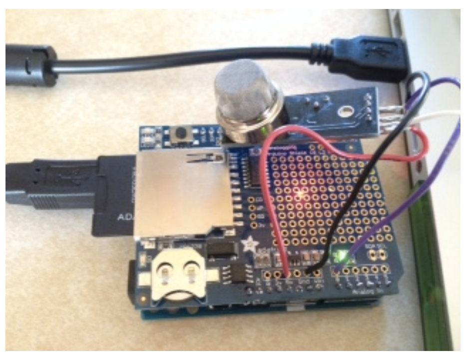

Figure 2. Arduino-based ozone data logger

  Associated Public Lab research notes through this semester are available at:

  http://publiclab/notes/epongrat/10-14-2014/research-note-1-10-14-14
  http://publiclab.org/notes/epongrat/11-19-2014/the-sensor-is-gathering-data
  http://publiclab.org/notes/epongrat/12-15-2014/calibrating-ozone-sensor

- Water pollution (temperature and conductivity) sensor (student and instructor defined project)

  In this project, a Civil Engineering PhD student and an undergraduate Public Health student teamed up to design and develop a durable water quality monitoring device using an Arduino data logger that could withstand inclement weather conditions over a set period of time. The team members were motivated to undertake this project because of their concern over the decline of surface water quality as a result of runoff from urban, agriculture, industry and other human activities. They wanted to contribute to the efforts in the Public Lab community to develop low-cost, DIY open source water quality monitoring devices.

They began the project by investigating the open source water temperature, conductivity measuring instruments already being developed and documented on the Public Lab website including the Riffle (http://openwaterproject.io) and Riffle-ito (https://github.com/p-v-o-s/riffle-ito). Over the course of the semester, the team implemented their own Riffle-ito device that measured temperature and conductivity and then tested their device by comparing its measurements to a temperature and conductivity probe available on our campus (Figures 3 and 4). They contemplated the nonlinear results (Figure 4) and also turned to the challenge of building a container that will protect the device from water damage while at the same time being durable and affordable. They built a prototype container using PVC pipe and PVC cement and submerged it in water (without the device inside) only to discover 2 ounces of water within it after 24 hours. The project design then forked, with a new design thread investigating the utility of a peanut butter jar coupled with a 3D-designed and printable cap with holes for the probe and a watertight seal using silicone caulk or epoxy. By the end of the semester, they had the functional measuring device, and these alternative containers built, but the leakage problem was still not completely solved.

Figure 3: Arduino-based "Riffle-ito" water conductivity meter

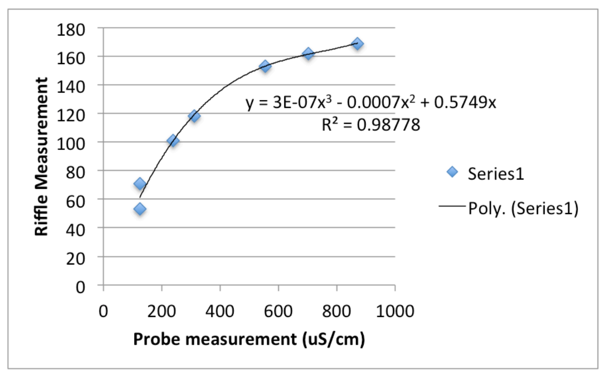

Figure 4: Calibration of Arduino Riffie-ito conductivity meter with a water conductivity probe available at our university

Associated Public Lab research notes (in temporal order) related to this project can be found at:

http://publiclab.org/wiki/riffle-esque-wq-monitoring
http://publiclab.org/notes/markwh/10-29-2014/calibrating-arduino-based-conductivity-meter
http://publiclab.org/notes/jenniferdsara/11-13-2014/waterproof-housing-for-the-arduino-conductivity-meter

http://publiclab.org/notes/markwh/11-19-2014/waterproof-housing-for-arduino-conductivity-meter-part-2-results-and-other-containers
http://publiclab.org/notes/markwh/12-16-2014/3-d-printed-jar-attachment-for-water-quality-monitoring

- GPS wildlife (dog) tracking device (instructor defined project)

  In this project, a computer science undergraduate student decided to develop an Arduino-based GPS data logger that could be used to track wildlife movements. For practical reasons, the goal was to develop a GPS device that could be harnessed to a dog collar.

  The project involved two stages: (1) the development of a GPS data logger using an Arduino Uno and an Adafruit Ultimate GPS shield, with data logging to a micro SD card; and (2) the design and print of a 3D container to hold the device and be strapped to a dog collar.

  The end result was a device that successfully data-logs GPS locations (Figure 5) and a test run was conducted using a large Golden Doodle and a smaller Morkie (black box near dog's neck, Figure 6). The most difficult challenge of the project was that the GPS required more power than could be delivered using the small lithium battery we utilized.

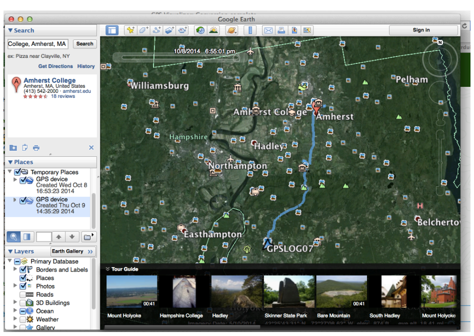

Figure 5: GPS data logging test results

Figure 6: Morkie with Arduino-based GPS unit on back

  PublicLab research notes for this project can be found at:
  http://publiclab.org/wiki/gps-tracking-device

- DIY Hydroelectric generator (student defined project)

  In this project, two undergraduate computer science students set out to build their own hydroelectric generator following online guidance they found on the Internet. Their overall goal was to develop something that could be, potentially, set into a brook or stream and would be capable of powering some Arduinio-based environmental sensor over longer periods of time.

We ordered or collected locally all the needed materials with the exception of one: the required magnet wire. The team wanted 100 meters of 24 gauge magnet wire, but the only kind available locally were 40 feet of 22 gauge, 75 feet of 26 gauge, and 200 feet of 30 gauge magnet wire. They connected these together by sanding off the enamel and twisting them together. But this technique, they believe, led to an inconsistent energy flow. Using a multi-meter they acquired at their institution, they found the most energy they could produce was 1 watt, not even enough to power one small LED light. With this result (and following the logic in Figure 1) they revised their device by ordering 100 meters of new twenty-four gauge magnet wire (Figure 7). This led to even less energy production than the first try and the students were not totally sure why. One theory they came up with is that they cut the wire and reattached them, which may have prevented easy electricity flow. Alternatively, adding several new magnets to the device might have caused the lower energy production, or possibly there was a mistake in wrapping the wire in the correct rotation. By the end of the semester, the team felt successful in that they created some energy flow, but were disappointed that they were not able to create a consistent energy flow at the level they wanted.

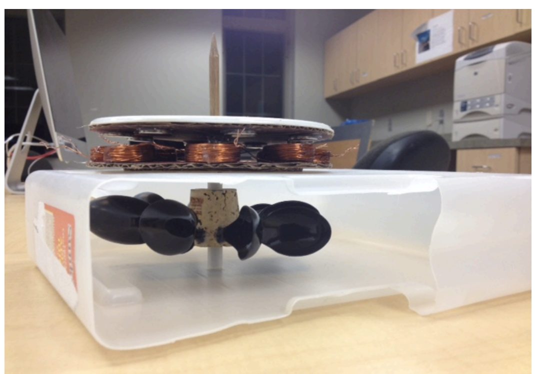

Figure 7. DIY Hydroelectric Generator

The Public Lab research note for this project can be found at:
http://publiclab.org/wiki/dyi-hydroelectric-generator

- Helium balloon remote sensing (instructor defined project)

This project utilized Public Lab's DIY helium balloon mapping kit. Two undergraduate students in our Natural Resource Conservation program wanted to see if we could detect the invasive water species Water Chestnut (*Trapa natans*) that are threatening to overtake the ecosystem in some recreational fishing ponds in a nearby city. We undertook this project at the request of contacts we have at the US Fish and Wildlife Service and a conservation officer working for the city.

Steps in this project included the purchasing Public Lab's Balloon Mapping Kit (http://store.publiclab.org/products/balloon-mapping-kit), and Chris Fastie's 3D printed Titan II camera "Oriole" rig with two cannon A590 cameras (one RGB, the other Near-infrared or NIR) with automatic shutter trigger mechanism (Figure 8). The project team built the rig and flew the balloon several times on campus and over the Westfield ponds. Unfortunately, a significant wind blew the balloon and rig into the water during the early stages of one flight, resulting in the dunking of the true color RGB camera. We did collect individual NIR imagery and were able to georeference these images using PublicLab's "MapKnitter" web application (http://mapknitter.org/). The dunking of the RGB camera in the pond ended up being catastrophic for the science component of the project for both the NIR and RGB images were needed to test to see if Water Chestnut canopy could be detected. But the team (and the professor) gained substantial practical experience in DIY balloon-based aerial photography.

Figure 8: Balloon and Titan 2 camera rig

Figure 9: Collecting data over the Westfield ponds

The PublicLab research notes for this project can be found at:

http://publiclab.org/notes/aferland/10-21-2014/aerial-balloon-mapping and http://publiclab.org/wiki/balloon-mapping-of-local-invasive-species-and-town-mapping

- OpenROV underwater research submarine (student and instructor defined project)

The initial project idea proposed by this team of students was to build a robotic boat that would use a localized decision-making algorithm (similar to a Roomba) to traverse a pond or lake while sampling oxygen and nitrogen levels in the water with sensors. The data collected would help to predict possible invasive cyanobacteria "algae" blooms that are choking native ecosystems. However, this idea seemed too bold for a single-semester project, and when we went to the New York City Makerfaire excursion we discovered the "Open ROV" project – an open-source, relatively low-cost underwater robot for exploration and education. We decided if we could get the funds for this device, the team could build, and possibly deploy the device to complement fisheries ecology research being done by scientists at our institution.

The class' lead faculty was able to solicit the help of several fish ecology professors to fund the roughly $1000 needed to purchase the device. These researchers were interested in both the ability of the OpenROV tethered submarine to collect video, and its potential to do data logging and collect other important data, such as dissolved oxygen measurements.

Once the OpenROV parts were received, it took the team the semester to build it, given the complexity of the machine. As of this writing the build is nearly complete, and we are now extending this project into a new semester team independent study to add the oxygen sensor and data logger and then to deploy it in local field research areas, working with the fish ecologists.

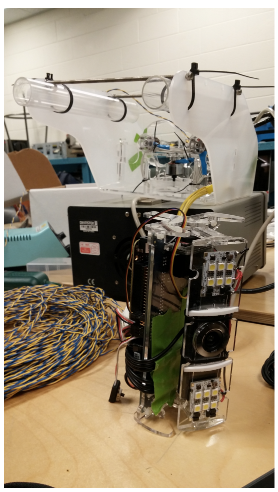

Figure 10: OpenROV submarine build

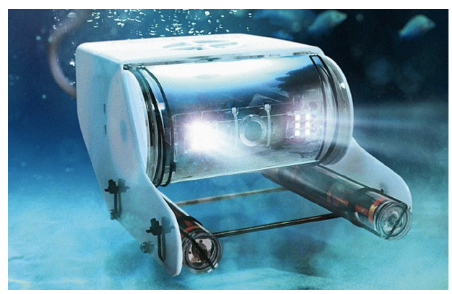

Figure 11: OpenROV product image

The PublicLab research note for this project can be found at: http://publiclab.org/wiki/s-a-l-o-r-submersible-autonomous-liquid-oxygen-reporter.

Three of the undergraduate students decided to take advantage of the optional opportunity to assist in the outreach component of the class by teaching or demonstrating their projects to local middle school students in a weekly maker after school program at our partnering community media organization. We demonstrated the balloon-based aerial photography, the GPS dog collar project, and the ozone air-quality project. In addition, one of the students taught a session on 3D design using Google Sketch-up using what she learned through this class.

The conclusion of this class was an open "show and tell" evening at the nonprofit television studio, where middle students and each class project team presented their technologies and discussed issues to a public audience. This evening was recorded by the media center's technicians.[11]

Results: Student Feedback and Assessment

Given its experimental nature this class was intentionally kept small. Our grading rubric for this first try was kept intentionally general and open for instructor interpretation, for at the start we really were not sure what the students would achieve by the end of the semester. Primary grading components were regular class attendance and participation (25%) and a grade for their semester term project deliverable (based on an assessment of their research notes, their clear efforts in and out of class, and what they were ultimately able to achieve). Students who chose to participate in after school service learning were given additional participation credit for that effort.

As we stated earlier, eleven students (nine undergraduates, and two PhD students) participated from a variety of disciplines. Near the completion of the course, we administered a new student course-evaluation questionnaire designed specifically for team-based-learning courses to the nine undergraduates. Given the small class size, statistical measures are of questionable utility and therefore not reported, but the general tone of their responses was overwhelmingly positive. Six of the nine students provided comments at the end of the survey. We are including all concluding comments so as not to demonstrate any kind of reporting bias:

1. "I think I could have gotten more out of this class if I had more direction and individual reviews."
2. "Awesome course, more should be offered in this "uncourse" style, best experience in team work I've had in any class."
3. "Great class! Perfect to introduce students to technology. Learned teamwork and do effective research..."
4. "This was an interesting and new course. I think that it should continue so students are able to experience it. It's a unique way of learning/teaching while integrating students."
5. "This course is different than other team courses. Team based learning in team based learning classrooms aren't effective."
6. "I am amazed at how well this course succeeded. Small class size with various disciplines was key."

In our final class meeting, we also had discussions on whether this class should be offered again, and ideas for improvement (discussed next). Students were overwhelmingly in favor of us offering the class again.

Finally, one last observation that should be reported under "results." What was amazing and rather unexpected to both students and the course facilitator was the role of the broader Public Lab community of "lurkers" or online interested parties. Most of the individual project research notes (listed above) posted by students have been viewed at least 100 and sometimes more than 200 times. In several instances, readers posted encouraging comments, or provided ideas to solve problems the students were encountering. One research note related to the use of Public Lab's balloon-based aerial photography technology received more than one hundred views in less than twenty-four hours. Essentially, the students' active participation in Public Lab's commons-based peer-production platform and the response from the community was quite striking and added an important element to the class.

Next steps – Class Version 2.0

The overall experience of this course was extremely positive both for the faculty participants and, based on course survey and final class discussions, the students. Our plan is to offer this class again in Fall 2016 with the following improvements:

First, the course will continue to be facilitated by the lead author (Schweik) but will formally include other UMass Amherst faculty as co-instructors. This helps to give these other colleagues credit for their participation, and brings in more problem-solving expertise into various open work class sessions. We will have faculty expertise in Arduino and computer programing in biology, engineering as it relates to water resources as well as engineering student recruitment, public health and air quality, a faculty with expertise in 3D design and printing, and a new faculty on campus specializing in business and entrepreneurship.

Second, we hope to partner with our research library in their efforts to create a makerspace in their building that builds on their Digital Media Lab. In that space, students can already sign out high-definition video equipment, and can use video-editing software. They are now adding 3D printers to this laboratory for student use and offering 3D design and printing workshops.

Third, we will continue to recruit students from different disciplines. However, in this first version, all students focused explicitly on the technology in their projects. While we will continue to encourage this, we also intend to open the course up to some students who have no strong interest in the actual creation of technology for environmental applications – but do have interest in their use. For example, next year we hope to include an unmanned aerial vehicle landcover mapping project, using some low-cost and quad-copter device. We hope to have a technical team who will build or explore its use for environmental monitoring applications, but at the same time have one or two students who, in parallel, will work on studying the state of the art public policy issues involved and the pro and con debates over these technologies. A second example of a non-technical project would be the opportunity for one or more students from the business school's entrepreneurship program to take a project idea and consider how a social or business enterprise might be developed around it.

Fourth, we will continue to work on how best to align this course with the various cross-campus and community makerspaces such as the one in our Engineering program, our off-campus media center's makerspace, our library's Digital Media Lab, and emerging interest in this area in our School of Management's entrepreneurship program. These are all valuable organizations; what we will continue to work on is how to best utilize these as a network of makerspaces with their individual areas of expertise and contributions.

Fifth, we will continue to work on better ways to integrate the course with commons-based peer production communities like PublicLab, and leverage those connections.

The most significant challenge in offering this course is how to finance the equipment needs of the student projects. Each of the projects listed cost at minimum fifty dollars, with a few (helium balloon remote sensing, ozone sensor) being in the hundreds of dollars, and one – the OpenROV – close to $1000. We were lucky in this session in that we had a UMass Amherst public service endowment grant to draw on for some of the project technology, and we had several UMass faculty willing to invest in the OpenROV project.

In our end-of-semester discussions, students suggesting adding a lab fee of $50, in lieu of the fact that we required no textbook costs. In addition, course facilitator Schweik taught, at the same time, a 1-cr honors seminar where he was provided $2000 from the honors program for those services. He intends to offer the same course next fall and utilize those funds to support technology purchases. An open issue remains how to most efficiently order the equipment and minimize the demands on UMass staff in assisting with our purchasing. This was a sizable time-sink, and establishing a system for inventory and management of all of the equipment is a significant logistical challenge.

A second challenge in this kind of course is how to find the "sweet spot" between the encouragement of a student team idea and the reality of the time and effort it might take to actually design and implement the project. Some of the projects in this class were reasonably realistic while others were overly optimistic in what could be achieved during a one-semester class. For the latter, we intend to try and keep projects going that have substantial promise, and/or had substantial equipment investment. For example, the helium-balloon remote sensing technology is in hand, so all we need for next year are funds for the helium. In the case of the $1000 OpenROV project, two of the students have decided to keep working on the project under independent studies and while working in conjunction with the faculty sponsors. Our hope is that they will continue to document the project so that next fall, new students can learn through their documentation and continue to implement new field studies or new technological features on the OpenROV platform.

Advice for Other Faculty

For readers who might be inspired and want to try to implement such a course at their own institution, here are some of our insights, gained from this experience:

1) Consider how you can make it easier for students to fit this course into their programs.

If your undergraduate engineering program is anything like ours at UMass Amherst, it is probably jam-packed with requirements. To make this course more available to students, we are working to get it classified as a "general-education" course to make it easier for students to fit it into their program. This insight is making us reflect as we write on what the learning objectives are specifically for our proposal to make this a general education offering.

2) Plan for equipment funding and bulk equipment purchases.

As described above, we are trying to be creative by taking advantage of small teaching incentive grants at UMass to build up a purchasing account for student project equipment. In addition, given students are using open access materials on the Web (no required texts), consider requiring students to be prepared to contribute some funding (up to say, $50) for equipment needed for their project. Related to equipment ordering, plan for this ahead of time. Give your students a deadline to decide on a project and identify needed equipment so that all of these purchases can be handled in one or several purchase transactions.

3) Consider offering some "introduction to technology" classes in the beginning.

We ran several sessions where we gave some introductions to some of the technologies: Arduino programming, 3D Design with Sketchup and 3D printing fundamentals, and an introduction to GitHub. If there are certain technologies you want to emphasize for student projects, consider offering such modules.

4) A 3-hour class project work session each week worked well, along with a second, optional "open meeting" time at a Makerspace.

In these sessions, we would take 1 hour at the beginning where each student team would report on their project progress for that week, and then discuss any problems they were dealing with. These informal report backs nearly always led to interesting dialogs between students where they gave each other ideas on how to solve the problem they were up against.

We recommend designing into the course a second optional meeting time at a makerspace where student teams can meet and work with potentially other teams or instructors around.

5) For relevant citizen science-type projects, consider the PublicLab Research Note idea.

This idea of entering project notes and progress via a public open science commons-based peer production system was a unique component of this course and, in our view, extremely valuable. In our next version of this course, we will require more consistent entries of Public Lab Research Notes on projects.

Students appreciated the fact that others were reading their notes and periodically commenting on them. Readers considering offering a similar course should carefully consider whether they want to add this component or not, and if they do, put some thought into how you want to structure that component so that students do a very good job on writing and maintaining those notes.

6) Consider ending the course with a project product demonstration at your Makerspace.

   For the "final" student teams were expected to present their projects in a public event at our AmherstMedia.org Makerspace. We got their permission to film these presentations [see 11]. Making this a public event gave this a more "important" feel, which, we think, led students to take it more seriously.

Conclusions

We opened this paper by first describing some common trends and "threats" to higher education and the trends that have been occurring related to "flipped" classes, and team-based and service learning as opportunities for higher educational institutions in the 21st century. We then described the age-old – but newly revised (thanks to the Internet) – phenomenon of "making" and DIY or do-it-together, learning. We also discussed how maker-type collaborative efforts are one form of "commons-based peer production." These ideas provide the foundations of our new "environmental monitoring" maker course that we first offered at the University of Massachusetts, Amherst in the Fall 2014 semester. We described the general structure of the class, and the specific projects that emerged. We closed the paper with some reflections on this first try at such a course, ideas we have for next year's version, and advice for other faculty who might want to try this in their own institution.

Overall, by standard course evaluation metrics and upon reflection by the faculty involved, this first edition of the course was a success. Students appear to have enjoyed it and learned through it, and the faculty involved continued to be enthusiastic in what the teams were able to achieve. The outreach component to local middle schools also was a success with the school asking to continue the relationship.

In our view, the course we described does two things: First, it addresses the points made in the introduction for it embraces the phenomenon of open access education material and "flips" the class so that the in-class meeting time focuses on project problems and roll-up-your sleeves work in a makerspace atmosphere. It brings in team-based learning and service learning. It is an example of where some of higher education must go. Second, the course introduces students to the important phenomenon of commons-based peer production that is, these days, widespread but not clearly understood. The course allows students to focus in on that and participate in one focused on open source science (PublicLab.org).

And in that spirit of commons-based peer production, we hope what we have described will encourage other faculty in other institutions to devise their own new derivatives of this maker-relevant open science course we have described.

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