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Upper Division Students Teaching Engineering Skills to Lower Division Students through Underwater Robotics

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Abstract
Many engineering students just starting out in their undergraduate career face problems with gaining hands on skills relevant to today's workforce. The plethora of math, physics, and general education courses students take in their first two years of college often precludes students from obtaining hands-on engineering experience until their junior year. This paper describes a 10 week, hands-on, extra-curricular workshop, taught by upper division students, that gives lower division students an exciting introduction to practical skills in the fields of Engineering, Robotics, and Marine Technology. The aim of this workshop is to guide students through a design, build and test cycle of an ultra-low cost underwater robotics platform- the BudgetROV. This workshop involves CAD design, machining, soldering, and programming at an introductory level appropriate to lower division students across all engineering disciplines. In this paper, we describe the curriculum for this workshop and discuss student feedback that suggests the workshop will help students find further project opportunities (such as summer internships) and will help with the retention of engineering students to their majors.

Introduction

Many engineering students just starting out in their undergraduate career face problems with gaining hands on skills relevant to today's workforce. The plethora of math, physics, and general education courses students take in their first two years of college often precludes students from obtaining hands-on engineering experience until their junior year. Although engineering freshman and sophomore students are encouraged to participate in extracurricular activities to obtain engineering project experience, many students (especially those who have never participated in high school robotics efforts such as FIRST robotics[1,2]) are afraid to join these activities because they feel they do not know enough yet to be a valuable contributor to a club or instructionally related project team.

Some schools have attempted to give lower division engineering students hands-on project instruction by introducing freshman design courses into the required curriculum[3-7]. These courses have proven very successful, but may not be possible to implement at many colleges and universities due to resource constraints - practical hands-on courses require a low faculty to student ratio and schools may just not have the funds to staff enough sections.

This paper describes an approach to give lower division engineering students a structured introduction to hands-on engineering skills in a resource constrained environment. The approach is a 10-week, hands-on, *extra-curricular* workshop, *taught by upper division students*, that guides students through a design, build and test cycle of an ultra-low cost underwater robotics platform - BudgetROV. This workshop involves

CAD design, machining, soldering, and programming at an introductory level appropriate to lower division engineering students across all engineering disciplines. Although the workshop is extra-curricular, it has the structure of a regular course (with a regular meeting time, weekly lesson plans, lectures and lab activities) to encourage those with little to no hands-on engineering experience to participate without the fear that they need prior knowledge to be a valued participant. Because the workshop is taught by upper-division students (who receive elective credit for their efforts), the offering of the workshop is solely constrained by the number of upper-division students wishing to teach it. Because the workshop is extracurricular, there is no set number of workshops that must be offered.

In this paper, we describe the curriculum for this workshop (its overview, weekly lecture topics, and weekly activities) and discuss student feedback that suggests the workshop will give students the motivation and confidence they need to find further project opportunities (such as summer internships, clubs and instructionally related project teams) and will help with the retention of engineering students to their majors. We conclude by discussing possible future additions/modifications to the workshop.

Workshop Overview

The BudgetROV workshop was designed as a 10-week, extracurricular, student-led workshop to give lower division students a chance to obtain hands-on engineering skills. The BudgetROV (a homegrown, student-built, underwater remotely operated vehicle) was selected as the workshop project. An underwater ROV had a high ‘coolness’ factor to attract a wide range of students, and the budget aspect of the BudgetROV design (it is about ⅓ the cost of the leading low-cost underwater robot design - the OpenROV[7]) made it affordable. The workshop was funded by a $500 grant from the Biology department and from a $30 workshop fee per student participant. The grant and fee covered all the materials costs for building three BudgetROVs (see Table 1). The enrollment was limited to 15 students to allow for a manageable student teacher to student participant ratio and to allow for team sizes of 5 students each building one of the three BudgetROVs.

The workshop was advertised to students in the College of Engineering through flyers that included details about the workshop (including its fee) and a contact email. An astonishing 47 students responded, so we gave the 15 spots to the first 15 responders. As the flyers were first put up in the EE building (trafficked by all University students, but more heavily by Electrical (EE) and Computer Engineering (CPE) students), the composition of the workshop ended up being 3 CPE students, 11 EE students, and 1 Computer Science. Of those students, 7 were freshman, 7 were sophomores and the computer science student was a graduate student seeking hands-on skills outside the realm of a strict computer science degree. The 15 students completed a doodle poll to find a weekly 3-hour meeting time for the workshop. After the first week of the workshop, one of the CPE students dropped out because of a change in his course schedule disallowing him to attend the agreed upon meeting time.

Subsystem	Cost
Plastic Materials	$49.97
Wiring	$60.08

Motors	$76.00
Control	$83.38
Incidentals	$25.00
Total Materials Cost	$294.43

Table 1: Materials Cost per Budget ROV

During the first class meeting, students were organized into three teams. These teams of 4 or 5 were formed organically by the students and persisted throughout the quarter as teams with the goal to build the robot together. Project groups allowed individuals to divide labor and work together to build team dynamics alongside their robot. These teams each developed their own personality, and the team formations had their own benefits throughout the quarter.

Table 2 below outlines the weekly lecture topics and lab activities for the workshop. As the completion of designing, building, and testing a BudgetROV was the overall goal for the workshop, each week focused on a particular skillset required for success in robotics design and testing.

Week	Lecture	Activity
1	Underwater Technology Overview	N/A
2	Solidworks Design	Learning Solidworks
3	Critical Dimensions in design	Completing CAD models
4	Waterproof seals	Water testing Enclosures
5	Electronics Survey	Soldering and Electronics
6	Arduino Programming	Learning Arduino
7	Systems Testing	Complete assembly
8	N/A	Catch up week
9	Final Presentations	System demonstration in pool
10	Field Testing	Field trip to local pier

Table 2: The 10 week schedule for the robotics workshop

The following two sections of this paper discuss in more detail the lecture topics and the lab activities covered each week in the workshop.

Lecture topics

Each class period involved a short lecture, given by a senior level engineering student, introducing students to a relevant engineering breadth requirement for finishing their class project. These topics spanned various areas of underwater robotics design, building and testing, to adequately prepare them for that week's activity. The lecture was not intended to be comprehensive. Similar to the lectures given during lab classes at Cal Poly San Luis Obispo, it would give them enough background information and tips to properly execute the activity and troubleshoot any problems they may have in that same class period. The lectures varied in topic, covering a wide breadth of robotics and engineering knowledge.

Underwater Technology Overview

First, students were introduced to the current state-of-the art for underwater technology. This lecture covered relevant realms of underwater technology, such as ROVs, AUVs, ASVs, and static sensor arrays. ROVs (Remote Operated Vehicles) were of particular interest, showing students several ROVs similar to what they would construct in the coming weeks. The lecture ended with a Q&A, where students were encouraged to ask questions about the 10 week plan for the quarter and the underwater robot we planned on building.

Mechanical design and testing

For the design portion of the workshop, students were taught about design in Solidworks CAD software. An upper mechanical engineering student showed students how to use the sketch tools in CAD software to design laser-cut parts for later fabrication in the course. Once 2-d part designs were complete, students were shown how to extrude these sketches into parts, and in turn, put these parts into complete assemblies. These tools gave students everything they needed to complete the design of the ROV they would construct later in the class.

The next week, students moved from two part assemblies onto larger models. An explanation was given on the nuances of laser cutting compared to other fabrication methods. Students were taught how to design with their chosen machining methods in mind, and how to find and check the critical dimensions of a CAD assembly drawing. This skill was critical for success in the class, as these parts would be fabricated several days later for use in the course.

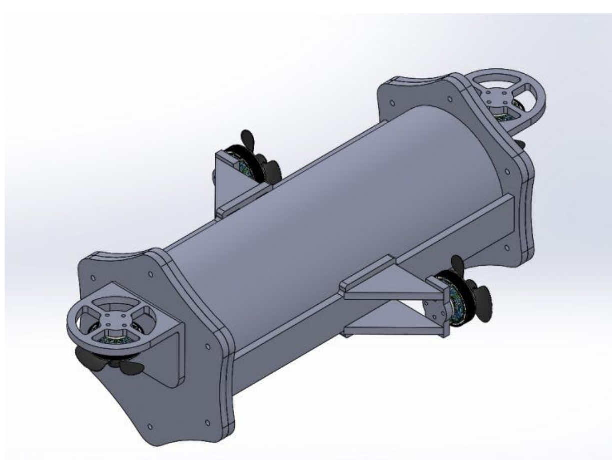

Figure 1: The BudgetROV template students used to design their ROV. Each team made variations on this robot design developed for the class.

Students were introduced to many different types of ways to keep systems watertight, including materials joining, adhesives, and o-ring seals. Particular stress was given to the seals to be used in the class- namely face seals and materials joining through acrylic solvent. A lecture on various types of waterproofing helped explain how each seal worked and how to properly use it in underwater systems construction. Advantages and disadvantages of each type were discussed, and some "last resort" methods of waterproofing were also shared in case students needed to make field repairs in the future.

Electrical and software construction and testing

For the electronics on the ROV, an Arduino was used as the central module for simplicity of teaching. Students were taught briefly about three phase power, PWM, NTSC, and UART signals, as well as lithium polymer batteries, which would all be used on their ROV. Every aspect of the electrical system design was explained so that students would know which electrical connections to verify and use in their programming the next week.

In the lecture for the programming side of the electronics, students were taught basic C++ syntax, as well as the Serial and Servo libraries for Arduino. Students were taught about ESC firmware configuration, Arduino to computer communications, and controlling motors from an Arduino.

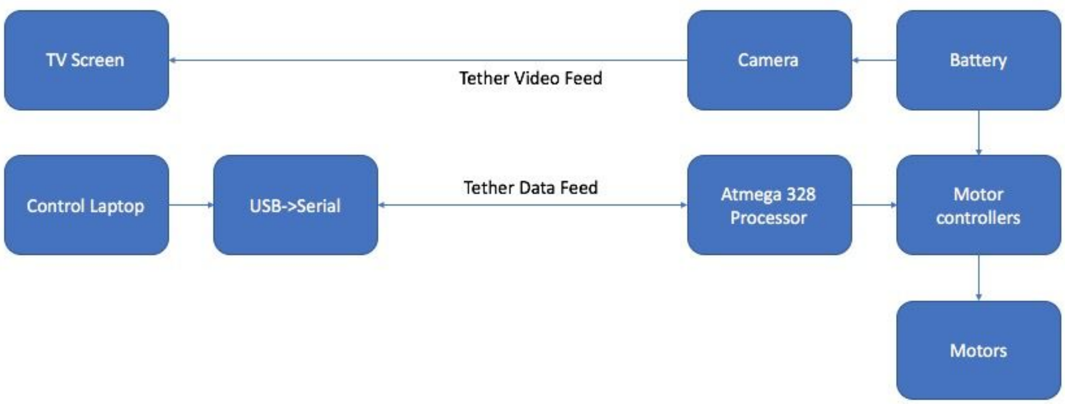

Figure 2: A basic block diagram of the robot's electrical systems.

Systems integration and testing

For the final lecture, students were advised on how to make sure all the parts of their robot were interacting as expected in the overall function of the ROV. Pre-test and post-test procedures were established to ensure safe testing of robotics systems. Students were given advice on how to troubleshoot their system until it worked fully, and maintain their system once done to ensure longevity.

<u>Activities</u>

Mechanical design and testing

For the solidworks sketching activity, students followed along with an upper division engineering student step by step in making a part, while volunteers walked around and answered any questions in the design activity. Students that followed along eventually made two parts of the twelve part assembly for their

ROV entirely from scratch. These two parts involved contours, radial patterns, bilateral symmetry, and other useful CAD design features. The quality of the drawings was assessed once the activity was done with feedback from senior engineering students.

The next week, students used their new solidworks skills to practice design modification from the instructor's robot template. Every critical dimension was checked in the design to fit the unique kit parts given to each team. Each student team was given a template design to follow for their ROV, but with a set of parameters to check for and change on their particular design. Each team was given differing plastic stock to start with, and as such had to make modifications to make their design fully functional.

Each team reserved a set time at the engineering department's laser cutter to manufacture their parts. This activity was optional, but over half of the enrolled students showed up out of interest in learning how to laser cut parts. In the machine shop, all of the parts were cut from ¼" acrylic. Students then cut a step into some of the plastic parts on a routing table, completing their plastic water enclosure kits themselves in the machine shop.

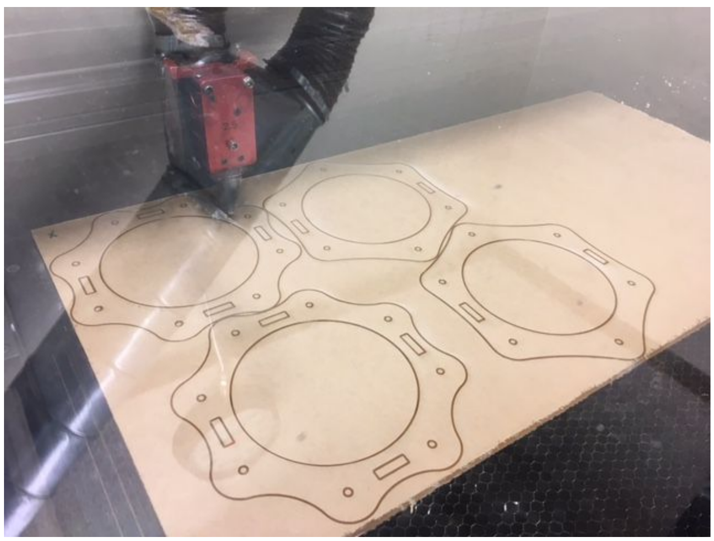

Figure 3: Student designed pieces of plastic being fabricated on the laser cutter.

Next, students put the plastic pieces together and water tested them. Acrylic solvent and heat inserts were integrated with the laser cut parts. Laser cut gaskets were sandwiched between acrylic parts, and the complete enclosures were left in a tub for a half hour. In practice, only one of the four enclosures were truly watertight on their first test. This lead to a learning experience of taking good notes on where the leaks were, and making small changes such as adding solvent or cleaning the gasket. After several tests, all of the enclosures proved to be successful.

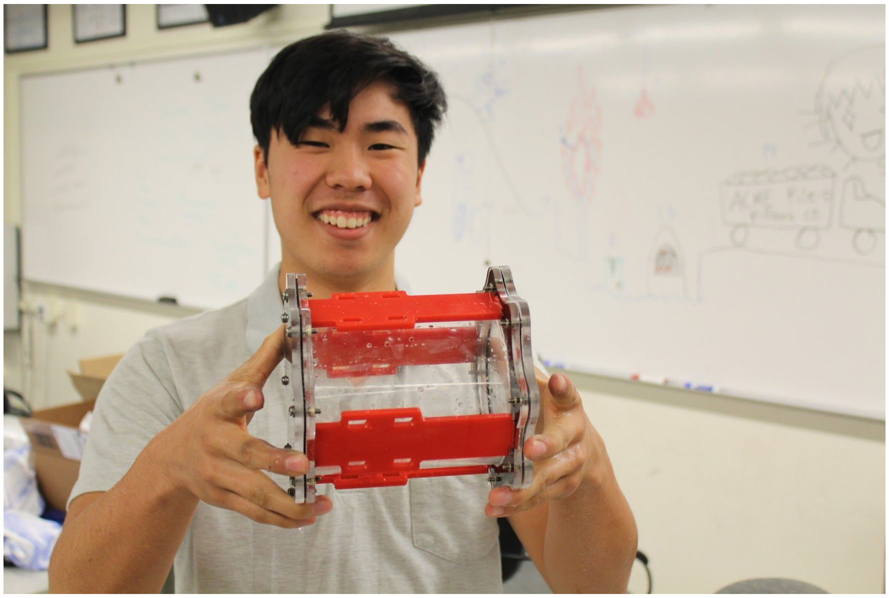

Figure 4: A student showing off his enclosure after a water test.

Hands on electronics experience was valuable to the students as well. During the electronics activity, students soldered together the motor wiring and power distribution cables, while also tying down each part on a piece of foam board to keep things organized. Students also made their own modifications to standard drone three phase motors, so that they could operate in the water without shorting. Students followed a wiring diagram given by the instructor, and by the end of the class students had a system exactly like Figure 2. This activity took only one class period, because most of the students had done some level of soldering before.

Once all other parts of the ROV were constructed, the only task left was to program their ROV. This was done in the Arduino Sketch development environment. In the activity, the instructor laid out a software flowchart to guide more advanced students in writing their program, but left implementation up to the students. However, for students new to programming, a step by step walkthrough was given to guide them in writing the program to control their ROV.

Finally, a catch up and systems integration day was given to the students to apply all the finishing details on their ROV and catch up on any activities they did not finish throughout the quarter.

Student Feedback

In order to obtain feedback for the workshop, students completed an anonymous Survey Monkey survey that included responding to questions in a text box or on a Likert scale. Thirteen out of the 14 students in the workshop completed the survey.

Figure 5 illustrates a measure of the knowledge gained in the workshop. The figure shows the average data collected from asking the students about their relative experience before and after the workshop with the topics covered in the workshop. Students responded on a 3-point Likert scale with 1=no experience, 2=some experience, and 3=lots of experience. Notice that before the workshop, students reported none to some experience for most topics whereas after the course, students reported some to lots of experience illustrating growth of knowledge in these topic areas. The areas of the most growth involved SolidWorks, laser cutting, and water proofing which were the more mechanical engineering aspects of the workshop. As the composition of the course ended up being only electrical and computer engineering and computer science students, this result makes sense as these students were likely never exposed to these topics in their standard curriculum. Also note that the laser cutting topic did not achieve an average of at least a 2.0 (some experience) because not every student participated in the laser cutting part of the workshop. These students were unable to take the University's required machine shop safety class (necessary for entering the machine shop) prior to the allocated time to use the laser cutter.

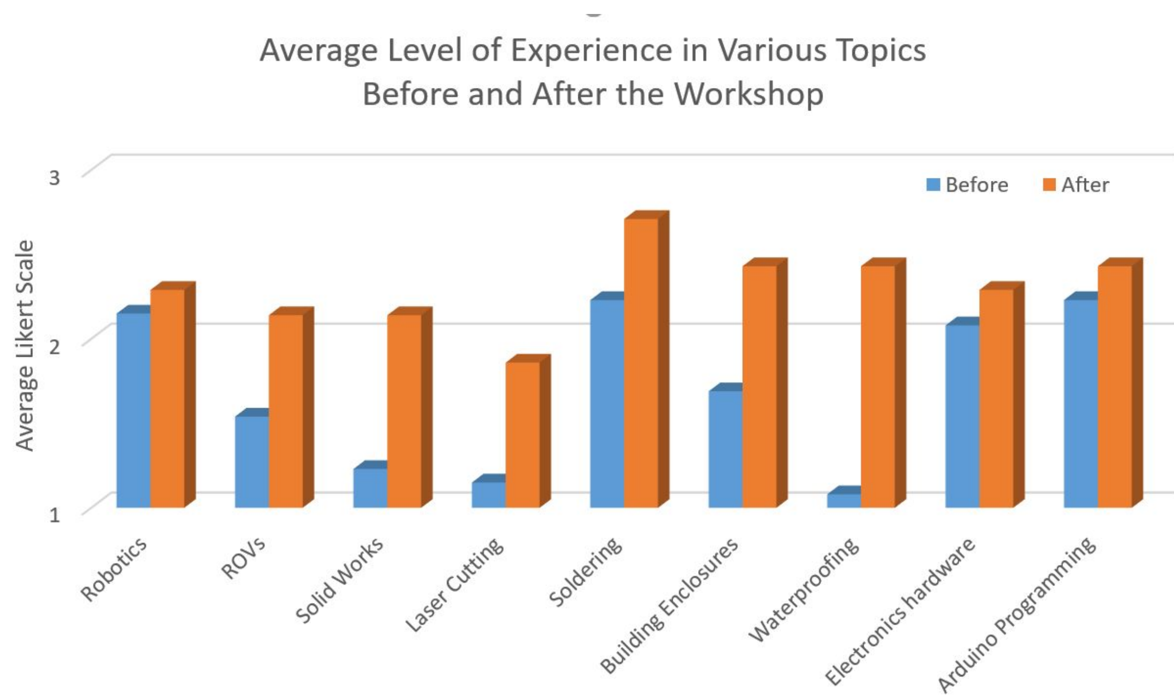

Figure 5: Average Level of Experience in Various Topics Before and After the Workshop

Figure 6 illustrates the average level of agreement with statements concerning the students' perceptions of the workshop on a 5-point Likert scale (with 1-strongly disagree, 2-disagree, 3-neutral, 4-agree, 5-strongly agree). Overall, the students found the workshop highly worthwhile. They indicated it gave them increased hands-on engineering skills and a project they'd feel proud to list on their resume. They also indicated the workshop gave them increased confidence to talk to potential employers, and increased confidence in their decision to be an engineering major. Notice that the average response for all statements is over 4.5 illustrating that most students marked fives for all categories. The authors have never seen this high level of agreement/enthusiasm for any of their related engineering education work. When students were asked why they liked the workshop so much and stuck with it for the full 10 weeks (even though they did not receive any credit for their efforts), they indicated because it was "fun" and they were "learning a lot." They also indicated it was nice "being able to ask questions without feeling stupid."

Figure 6: Average Workshop Feedback on a 5 point Likert scale
(1 indicated strong disagreement and 5 indicating strong agreement)

The data suggest that the workshop enabled students to obtain the hands-on skills and project experience they needed to give them the motivation and confidence to stick with their majors and seek out more opportunities (such as summer internships) to gain real-world engineering experience.

Finally, the workshop teaching experience was valuable to the upper division students as well. This class was taught by a fourth year engineering student considering a masters degree, and teaching lectures in the workshop was good practice for teaching positions common to many graduate programs. Teaching experience in undergraduates makes for a stronger application to master's programs. This program also lets the teaching student get an idea of what teaching lab based classes is like, as well as making a curriculum and writing publications. Overall, the workshop was a great opportunity for both the teacher and the students to get experience in engineering, teaching, and prototyping.

Future Additions

For the first iteration of this course, the BudgetROV platform was still in development for the first few weeks. This took some trust on the part of the students, hoping that this new robotics platform would function as expected once complete. Excitement and hope were the spirit of the first few weeks of the course, while upperclassmen finished the prototype model. It was a great risk to base the class on a platform that didn’t pass final testing until week 4 of the course, but the students also found it encouraging that if the instructor finished their bot during the class, so could they. However, this practice would probably not be sustainable for future labs of this curriculum, as students prefer to have a live demonstration of their goal at week 1 of the course. A complete demo at week one would have proved that the concept is achievable and not far off.

Since this workshop was created by upper division students for freshmen and sophomores, it would also be good to pick some students at the beginning of the quarter to be teacher's assistants, who might become course instructors in the future. We hope that since this course was mostly taught by a Senior Electrical Engineering student, another student could continue this course in the future.
For future iterations of this course, a more complete system diagram and a full lab manual would have to be completed and edited for clarity. Students were sometimes confused as to how parts of the system would go together, and would have to ask the instructor for the purpose of design decisions often. Having a full lab manual for future versions of the course would answer many student questions, while also giving them a "big picture" view of the project as a whole.

<u>Acknowledgements</u>
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