ASEE's 123rd Annual • Conference & Exposition • New Orleans, LA • June 26-29, 2016

New Orleans JAZZED about Engineering Education

Paper ID #15083

WORK IN PROGRESS: Wave Energy Converter Design Project

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WIP: Wave Energy Converter Design Project

Introduction

At Rowan University, all sophomore-level engineering students are required to take Sophomore Engineering Clinic, a multi-disciplinary course that combines engineering design with communication (writing arts). The course invokes project-based learning (PBL) to teach students about the design process and how to write about design. In Fall 2015, the seventeen-section course was team-taught by twelve engineering faculty and seven writing arts faculty. The course has been described extensively in previous publications[1, 2, 3], but is briefly described here for clarity. This four-semester hour course has students spend 165 minutes with engineering faculty in lab each week and 150 minutes over two lecture sessions with writing arts faculty. During the writing arts time periods, students spend time learning about audience, rhetorical analysis, argumentation, and information literacy. In prior iterations of the course, some of the time with writing arts faculty was spent discussing technical genres such as the traditional lab or design reports. However, this component was de-emphasized in the Fall 2015 offering, and that material was picked up by engineering faculty during the laboratory sessions. In the lab sessions, students learn about design through open-ended design projects. There is some lecture time spent in the lab sessions to aid in project concept understanding, but most time is dedicated to hands-on design within student teams.

The course syllabus states that the learning goal for engineering students is to demonstrate effective design processes, which include generating multiple engineering design solutions, applying sound engineering principles to choose the best solution and see that solution through to completion, and using parametric design to optimize an artifact or process. Some of the learning goals for the writing arts portion of the course include: writing effectively in engineering genres; using conventions of academic writing in engineering; developing technical writing skills in description, data presentation, data usability, and ethics; and producing effective writing in a short time period. This paper describes a new design project implemented in Fall 2015 as an alternative to a project implemented in Fall 2005.

Course History Since 2004

In Fall 2004, students worked in teams on a semester-long design project, in which they designed a crane to lift the heaviest weight with the least amount of building material in the crane[4]. While the project had many successes, faculty observed that students did not quantitatively analyze design alternatives and chose a final design with only qualitative justification[5]. As a result, in Fall 2005, the sequence of design projects given to students was modified to include a simpler, four-week startup project that involved building and testing bottle rockets. Students were asked to use “parametric design” to systematically vary the amount of water in the bottle (propellant), clay on the nose of the bottle, and the size and shape of the fins[6]. The implementation of the simpler, parametric design project resulted in better technical performance in subsequent projects, including an improved design-process approach in the crane project[5].

This result has led to an attempt to maintain a similar project sequence with a simpler, more prescribed design project at the beginning of the semester followed by a more complex, open-ended project in later weeks of the course. In Fall 2014, all of the sections of the course were still using the bottle rocket project as the introductory project and the crane project had been replaced by a wind turbine design project[7].

In an attempt to provide alternatives to the ten-year-old bottle rocket project, a new project was implemented in three of the seventeen sections of the course in Fall 2015. The project required students to design a small-scale ocean wave energy converter (WEC) by using parametric design.

Project Description

The WEC Design Project was developed based on a device designed by members of the Oregon Sea Grant[8]. The project requires student teams to experimentally optimize the design of a small-scale ocean WEC for voltage output. The type of WEC studied in the project generates voltage by using the motion of waves to oscillate a magnet through a coil of wire. The drawing and image in Figure 1 provided students with a sample WEC to use as a guideline. Each team was provided with a set of materials to build the WEC – the primary materials used are called out in the drawing and listed in Table 1. The project is easy to implement with readily available materials. The estimated cost per student team for the project was less than $50.

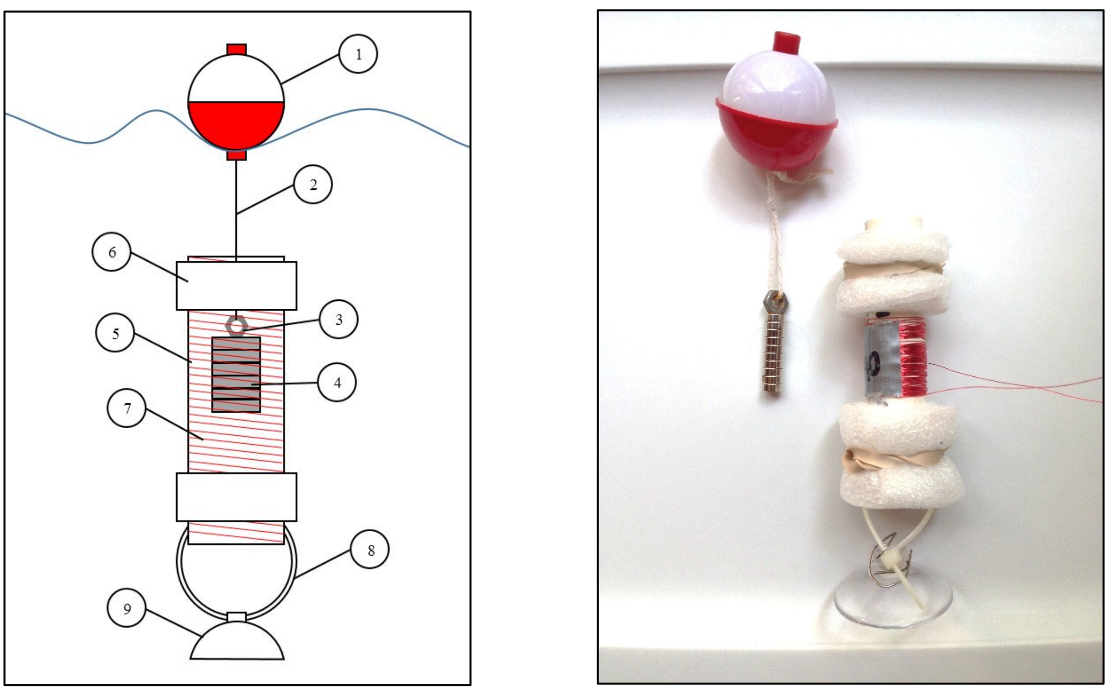

Figure 1. Sample drawing (left) and image (right) of a WEC provided to students to guide them through the brainstorming and designing phases. Callout numbers in the drawing correspond to parts listed in Table 1.

Table 1. List of parts called out in the sample drawing in Figure 1.

Part No.	Part
1	Fishing Bobber (1 ¼" size)
2	String
3	Hex Nut
4	Disc Magnets (N42, ¼" diameter by ⅛" height)
5	PVC Pipe (4" lengths of varying diameters)
6	Packaging Foam
7	Magnet Wire (30 AWG, 200' lengths)
8	Zip Tie
9	Suction Cup

In the sample WEC, the fishing bobber was tied to the magnets to keep them afloat. The PVC pipe served as both a shell around which to coil the magnet wire and a physical guide to steady the magnets' reciprocating motion. The packaging foam was wrapped around the PVC pipe to keep it upright and relatively still during testing. The zip tie and suction cup fixed the PVC pipe to the bottom of the testing tank, acting as the WEC's mooring. Before the project began, the 30-gauge magnet wire was spooled into 200-foot lengths, and the PVC pipes (½-inch, 1-inch, 1 ½-inch, and 2-inch diameters) were cut into 4-inch lengths, each with two holes drilled through at the bottom. The specifications and dimensions used for all materials were determined from extensive testing during the project's creation. The materials were prepared ahead of time so that teams could immediately start working on designing and assembling their WECs, and therefore have more time to run tests as the project progressed.

The project required student teams to first brainstorm design ideas, and then build a prototype to familiarize themselves with the design and construction of the WEC. They also practiced generating uniform waves in their "wave tanks," (29-quart Hefty storage totes) since all waves needed to be created manually. Students were given three design parameters to test: the number of magnets used, the diameter of the wire coil, and the number of turns in the wire coil. These parameters were offered because they are easy to test and have the most apparent effects on the produced voltage. The student teams then systematically varied each of the three parameters and measured the resulting AC voltage generated by the WEC in each test. To measure the AC voltage, each team attached the wire coil ends (after removing the insulation coating) to the analog inputs of a National Instruments (NI) myDAQ, and then connected the myDAQ to the Data Logger program within the NI ELVISmx software package. This NI software package is free for students to download and install on their personal laptops. The Data Logger program allows the user to select a sampling rate from 1-1000 samples per second, record the voltage at this sampling rate for any given period of time, and save the data as a LabVIEW Measurement File (.lvm). Students opened the .lvm files in Microsoft Excel and calculated the root mean square (RMS) of each data set, tabulating the results from all tests. From these results, teams selected the optimal values of the three parameters and combined them to create final optimized designs. Each team then tested its final design and recorded the results. The project culminated in a team-written laboratory report following the IMRAD (Introduction, Methods, Results, and Discussion) format.

Instructional Topics

In the engineering lab portion of the course, students were provided with instruction in several areas throughout the WEC project. During the first week of class, students were asked to brainstorm about sustainable energy sources and were then introduced to the concept of wave energy and the different types of existing WECs through a video[9] and web-animations[10]. The idea of parametric design was introduced, in which several variables that may affect a system's performance are examined individually by varying a single variable at a time while holding the other variables constant. During the second lab period, the physics of wave energy was discussed and equations to calculate the theoretical power available from waves were provided. Also during this lab period the genre of the IMRAD report was discussed. The final instructional period was used to highlight proper use of tables and figures in IMRAD reports, which has historically been a challenging component for students.

Typical Student Results

As was mentioned previously, each student team was required to document the results of its design process in an IMRAD report. As part of their reports, students were encouraged to include graphical representations of the effects of each tested parameter on the voltage produced by the device. Figures 2-4 show graphs of results from a sample student report[11].

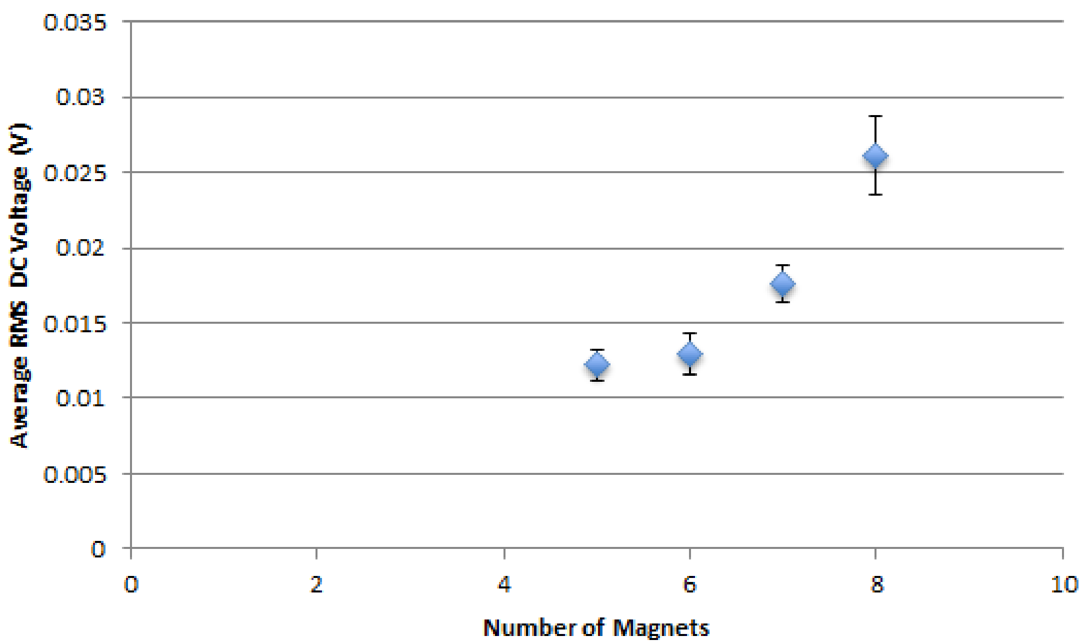

Figure 2. Effect of number of magnets on the average RMS voltage produced by the WEC device. The number of coils was 100 and the diameter of pipe was 1.27 inches. Error bars represent the standard deviation of triplicate measurements[11].

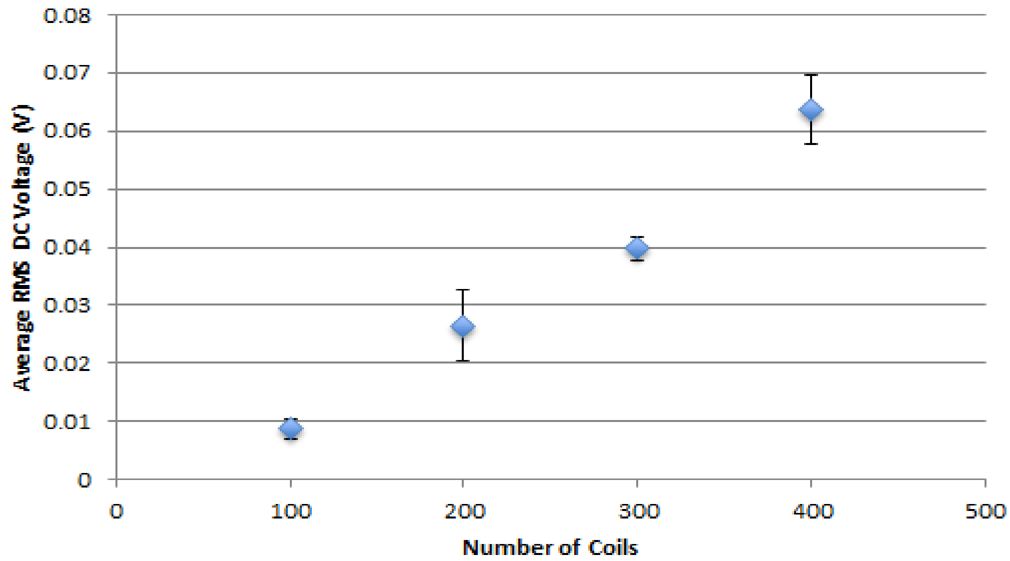

Figure 3. Effect of number of coils on the average RMS voltage produced by the WEC device. The number of magnets was 8 and the diameter of pipe was 0.5 inches. Error bars represent the standard deviation of triplicate measurements[11].

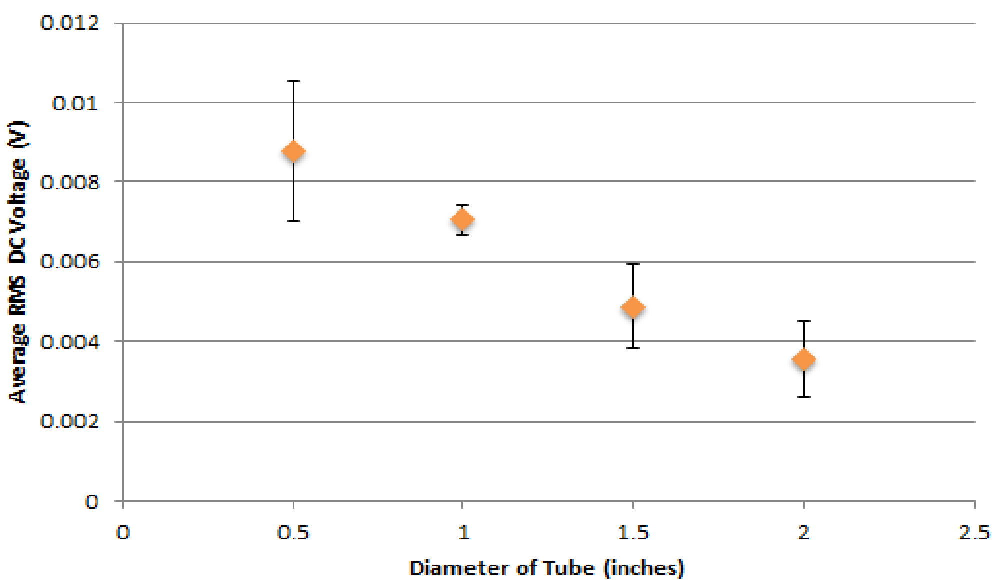

Figure 4. Effect of tubing diameter on the average RMS voltage produced by the WEC device. The number of coils was 90 and the number of magnets was 8. Error bars represent the standard deviation of triplicate measurements[11].

From these student results, there is an obvious trend for how each parameter affects the WEC's voltage production. These trends follow what is expected based on the physics of the process.

Not all student teams observed such straightforward results, though, as students found it challenging to produce the waves consistently, and did not always execute the trials with care. However, most student groups settled on a final design that involved the smallest diameter tube that was tested, and the highest number of coils and magnets that were tested. These final designs produced RMS voltages between 0.02 and 0.1 volts.

Writing Assignment

The report discussed above was team-written, with guidance provided by both engineering and writing arts instructors. A draft report worth 50% of the final grade was submitted to the engineering instructor for feedbackin the form of both written comments and a meeting with each team. A final report was submitted approximately two weeks after the draft report was submitted. The rubric for the report is shown in Table 2.

Table 2. Report Rubric for the IMRAD report describing the WEC Design Project.

	Exceptional	Strong	Competent	Unsatisfactory	Unacceptable
Purpose and Audience (20)	(18-20) Each section of the report completely fulfills multiple readers' expectations and needs; description of design and process is thorough and detailed enough to allow for replication; presentation of data (charts, graphs, and tables) enables immediate understanding.	(15-17) Each section fulfills multiple readers' expectations and needs; description of design and process allow for replication with minimal confusion; presentation of data (charts, graphs, and tables) enables understanding.	(12-14) Sections mostly fulfill multiple readers' expectations, though some information may be missing or unclear; description of design and process allow for replication; presentation of data (charts, graphs, and tables) is adequate though may require interpretation from readers.	(9-11) Sections do not fulfill readers' expectations or are missing; description of design and process does not enable replication; Presentation of data (charts, graphs, and tables) is very unclear or missing.	(under 9) Sections do not fulfill reader's expectations; design, process and data are presented insufficiently or not at all.
Content (50)	(45-50) Explanation of design problem is fully developed; demonstrates full understanding of parametric	(40-44) Explanation of design problem is well developed; demonstrates strong understanding of parametric design process;	(35-39) Explanation of design problem is complete; demonstrates partial understanding of parametric design process;	(30-34) Explanation of design problem is incomplete; demonstrates partial or little understanding of parametric design process;	(under 30) Explanation of design problem is incomplete or missing; demonstrates little understanding of parametric design process;

	design process; each design decision is fully supported by research and data; provides insightful analysis of how design might be better optimized; all figures and tables are included and are effective independent of text; text and visuals are well-integrated.	supports each design decision with research and data; provides readers with reasonable analysis of how design might be better optimized; figures and tables are included and largely effective independent of text; text and visuals are well-integrated.	most decisions are supported by research and data; analysis of future optimization is underdeveloped; figures and tables are present though may be partially ineffective; text and visuals are integrated.	decisions have no clear support; analysis of future design optimization is underdeveloped or unsound figures and tables are present but largely ineffective; text and visuals minimally integrated.	decisions have no clear support; analysis of future design optimization is unsound or missing; figures and tables are ineffective or missing; text and visuals are minimally integrated.
Format, Organization, and Style (30)	(27-30) Follows IMRAD organization; writing is clear, concise, and precise; sources are correctly cited; fully conforms to *Style Guide*(especially with respect to figures and tables); cover letter is thorough and professional.	(24-26) Follows IMRAD organization; writing is largely clear, concise, and precise; sources are correctly cited; fully conforms to *Style Guide* (especially with respect to figures and tables); cover letter is thorough and professional.	(21-23) Follows IMRAD organization; writing is at times unclear, wordy, or imprecise; sources are included but may not be well-integrated or correctly cited; mostly conforms to *Style Guide* (especially with respect to figures and tables); cover letter is complete and professional.	(18-20) Follows IMRAD organization, though some information may be misplaced; writing is frequently unclear, wordy, or imprecise; sources are missing or incorrectly cited; frequently does not conform to *Style Guide* (especially with respect to figures and tables); cover letter is incomplete or unprofessional.	(under 18) Follows IMRAD organization, though some information is misplaced; writing is frequently unclear, wordy, or imprecise; sources are missing or incorrectly cited; does not conform to *Style Guide* (especially with respect to figures and tables); cover letter is incomplete or unprofessional.

Students were required to document their individual contributions to the report as part of a cover letter, and they were also given the opportunity to submit reviews of their teammates' participation and citizenship.

Student Perceptions of Project

While quantitative data is not available regarding the project outcomes at this time, students were surveyed regarding the project upon its completion. Most students had positive comments about the project. A typical comment included sentiments similar to this one: "[The Wave Energy Converter Project] worked very well to illustrate parametric design. [It] was interesting/fun to be able to build something and test it." Other students, however, were frustrated by the lack of freedom in the design process: "I would have liked to have more creativity for the project (like creating our own version of the converter). Additionally, several students noted that the manual creation of the waves was challenging and frustrating. Several teams also had trouble with the data acquisition using the myDAQs.

Plans for the Future

Fall 2015 was the first time this project was implemented. For the Fall 2016 implementation, we plan to make several changes. One such change is developing an automatic wave generator to create uniform waves, which will minimize the nuisance of manual wave generation and its influence on the results. We plan to give students more freedom with the project by offering a greater number of testing parameters so that they can choose which three they are interested in testing. Some of these additional parameters include the length (or height, depending on how one views it) of the wire coil, as well as the position of the WEC relative to the waves and the type of floatation device used. We are also looking at other ways to quantify the results, in addition to RMS voltage calculations, which include ideas such as recording the time required to charge a capacitor or measuring the capability to power certain devices.

We also plan to do a comparative study between students who are exposed to the WEC project and those who, instead, are exposed to the Bottle Rocket project that has been in use since 2005. We will explore whether the WEC project improves students' achievements of the course goals, including their ability to demonstrate an effective design process and ability to use parametric design to optimize a process. We will also assess students' perceptions of the two projects to better understand what qualities students prefer in a project.

Conclusion

A small-scale wave energy converter design project was developed and implemented in a multidisciplinary, sophomore-level, engineering design and communication course. The project was based on work from Oregon State University[8] and allowed teams of students to use parametric design to optimize a small-scale wave energy converter incorporating PVC pipe, magnet wire, and magnets. The student teams then wrote about their optimization process and results in an IMRAD lab report. By completing the project, students fulfilled several of the course goals, such as demonstrating an effective design process, generating multiple solutions, analyzing possible solutions, and seeing the design through to completion. They also gained exposure to the IMRAD genre and were able to practice writing a technical description of their optimized WEC design and creating effective visuals for data presentation.

References

[1] Dusseau, R. A., & Chandrupatla, T. R., & Slater, C. S., & Schmalzel, J. L. (1996, June), *Development Of Multifunctional Laboratories In A New Engineering School* Paper presented at 1996 Annual Conference, Washington, District of Columbia. https://peer.asee.org/5990

[2] Mariappan, J., & Newell, J. A., & Schmalzel, J. L., & Ramachandran, R., & Sukumaran, B., & Marchese, A. J. (1999, June), *The Sophomore Engineering Clinic: An Introduction To The Design Process Through A Series Of Open Ended Projects* Paper presented at 1999 Annual Conference, Charlotte, North Carolina. https://peer.asee.org/7946

[3] Simone, M., & Jansson, P. M., & Riddell, W., & Farrell, S. (2008, June), *Communication In A Project Based Learning Design Course* Paper presented at 2008 Annual Conference & Exposition, Pittsburgh, Pennsylvania. https://peer.asee.org/3318

[4] E. Constans, J. Courtney, K. Dahm, J. Everett, C. Gabler, R. Harvey, L. Head, D. Hutto, H. Zhang *Setting The Multidisciplinary Scene: Engineering Design And Communication In The "Hoistinator" Project* Paper presented at 2005 Annual Conference, Portland, Oregon. https://peer.asee.org/14899

[5] von Lockette, P., & Dahm, K., & Constans, E., & Courtney, J., & Riddell, W., & Harvey, R. (2007, June), *The Converging Diverging Approach To Design In The Sophomore Engineering Clinic* Paper presented at 2007 Annual Conference & Exposition, Honolulu, Hawaii. https://peer.asee.org/2012

[6] Riddell, W., & Acciani, D., & Diao, C., & Courtney, J., & Dahm, K., & von Lockette, P., & Harvey, R. (2006, June), *Bottle Rockets And Parametric Design In A Converging Diverging Design Strategy* Paper presented at 2006 Annual Conference & Exposition, Chicago, Illinois. https://peer.asee.org/276

[7] Riddell, W., & Bhatia, K., & Dahm, K., & Weiss, L., & Bakrania, S. (2009, June), *Wind Turbines To Teach Parametric Design* Paper presented at 2009 Annual Conference & Exposition, Austin, Texas. https://peer.asee.org/5278

[8] Hanshumaker, W., Moon, R., Perrill, A. Wave Energy Engineer. Retrieved from: http://nnmrec.oregonstate.edu/sites/nnmrec.oregonstate.edu/files/we_curriculum.pdf. Accessed Sep 2015.

[9] The National. August 8, 2015. *Wave Energy Industry Growing.* Retrieved from https://www.youtube.com/watch?v=qICMqYR2nd8&feature=youtu.be

[10] The European Marine Energy Center Ltd. *Wave Devices*. Retrieved from: http://www.emec.org.uk/marine-energy/wave-devices/. Accessed September 2015.

[11] Nathan J. Sulzer, Mike T.D. Luu, Samuel Josephs, Kurt F. Wagner. Optimization of Voltage in a Wave Energy Converter Using a Small Scale Model. *ENGR01201 Section 6 Class Report*. 2015.