Integration of Green Engineering Labs into Freshman Engineering Courses

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Abstract

The emergence of sustainability and green engineering projects is re-shaping the engineering classroom. One of the vehicles for these topics at Rowan University is within the Engineering Clinics- project based, required courses. The first freshman clinic focuses on engineering measurements, and is typically the first true engineering course the students experience. The clinics are designed to be fully integrated and multi-discipline. The labs used in this course, and described herein, are all related to "Green Engineering", and incorporate mechanistic elements from all four engineering disciplines offered at Rowan (electrical/computer, civil/environmental, mechanical, and chemical). The uniqueness of these labs is that all have the exact same objective – to create a renewable energy system with enough power to lift a given weight to a given height. The energy source is the variable, and thus the crux of the labs. To operate the pulley and weight system for each lab, the students were tasked to create a: (a) solar panel array connected to a motor, (b) hydro-powered turbine system, (c) wind-powered turbine system, and (d) chemical reaction battery connected to a motor. Thus, all four engineering disciplines are covered and all the labs (and hence energy sources) are directly comparable with each other. The comparatively high student evaluation scores for this course represent the participants' high level of engagement and enthusiasm/

Prior being conducted in the freshman course, the labs were designed and tested with the assistance of undergraduate engineering students. Because these labs were initially beyond their expertise, the students gained an extracurricular education through their research and involvement. Therefore, these labs are beneficial to a more diverse group of students.

Importance of Green Engineering

As the world's population and their needs expand every day, innovative engineers strive to minimize its effect on our quality of life and modernize our technology in a more sustainable manner. Sustainable engineering, commonly referred to as "green engineering", has quickly become a critical societal issue, an issue that the engineers of today and tomorrow will play a dramatic role in solving. Many universities are incorporating green engineering concepts into their core curriculum. In fact, the Board of Directors for the American Society of Engineering Education (ASEE) considers it a priority that all engineering programs prepare their graduates for a profession that uses sustainable engineering techniques and methods[1]. These techniques include alternative solutions to the consumption of non-renewable energy sources, such as oil. As the new presidential administration sets such ambitious goals like doubling the production of renewable energy within the president's first term, today's engineering graduates must be on the forefront of such technology. Education that focuses directly on alternative energy solutions is vital to the future of the engineering profession, and to the sustainable development of the world and its communities[2].

Engineering Clinics at Rowan University

All universities strive to develop graduates with strong analytical and critical thinking skills, who have an understanding of the role of engineers in developing a sustainable global community. The engineering program at Rowan University uses a multidisciplinary project-based team learning approach in the form of Engineering Clinics[3]. The Clinics are required project-based courses that students take every semester. The Clinics enable built in flexibility in the engineering curriculum to include important technical and societal topics. This approach has provided significant opportunities for students to acquaint themselves with real-world engineering issues, such as sustainability. Table 1 lists the general technical topics covered in the eight-semester Engineering Clinic sequence.

Table 1. Overview of the technical topics covered in the eight-semester engineering clinic course sequence.

Year	*Fall Engineering Clinic Themes*	*Spring Engineering Clinic Themes*
Freshman	Engineering measurements	Competitive assessment
Sophomore	Multi-disciplinary design modules	Multi-disciplinary design project
Junior	Product development	Process development
Senior	Capstone design/research	Capstone design/research

Freshman and Sophomore Clinics serve as an introduction to the rigors and opportunities of an engineering major. They typically incorporate topical engineering scenarios and use simple engineering projects to strengthen students' understanding of mathematics and science principles. Junior and Senior Clinics consist of projects, often sponsored by industry or government, which represent the culmination of the Rowan Clinic experience. Students apply engineering principles learned in the classroom to solve industrially and socially relevant problems. They also can learn new engineering technologies within the Clinic context. The excitement of working on such relevant and meaningful projects, especially at the Freshman Clinic stage, is a driving force for sustaining a student's interest through graduation and into his or her career. The lab experiments described herein were designed for the first semester of the engineering clinic sequence (Table 1).

Lab Development

The series of labs focuses on renewable energy and sustainable engineering. Because the student that comprise the class come from four distinct engineering disciplines, the lab themes were approached from an interdisciplinary viewpoint. The labs had to be observably comparable, and therefore they had to each have the same ultimate objective. The idea of comparing four types of renewable energy was hit upon fairly early in the brainstorming stage and drove the development of the labs presented herein. Four types of renewable energy are examined in this course: solar energy, hydropower, wind energy, and chemical reaction energy. The ultimate objective of the lab is to use each of these renewable energies to generate power output in a repeatable and measurable manner. Each energy source is used to raise a given mass to a given height

(Figure 1). The measurable power output can be calculated using the following sequence of equations (Eqs. 1, 2, and 3):

$$F = mg \qquad \text{(Eq. 1)}$$

$$W = Fd \qquad \text{(Eq. 2)}$$

$$P = \frac{W}{t} \qquad \text{(Eq. 3)}$$

where, F is the force created by the gravitational acceleration (g) applied to a given mass (m), W is the work done by applying the force (F) over a distance (d), and P is the power generated by the work in a given time (t). Thus the measured output power can be increased by lifting more weight for a given time, or decreasing the time it takes to lift a given weight.

Figure 1. Pulley system set up at a measurable distance above the testing station. The weights are tied to a string that is run through the pulley and attached to a spinning axle.

The power source for the solar energy lab is an array of photovoltaic (PV) cells. PV cells convert incoming solar light directly into utile electricity. PV cells consist of a specially treated semi-conductor material that absorbs protons of light and release electrons. The released electrons are then captured and converted to a flow, which creates an electric current. The behavior of this current can be predicted by Ohm's Law (Equation 4), which states that the ratio of the electric potential (voltage, V) to the electric current (amperage, I) is equal to the resistance (R) of the flow.

$$V = IR \qquad \text{(Eq. 4)}$$

The potential voltage available is additive for a PV array connected in series (i.e. one large continuous current loop), while the electric current is increased for PV cells connected in parallel (i.e. several current loops working together). The generated electric current is channeled through a DC motor, which is connected to a spinning axle (Figure 2). The expected effect of more voltage applied to the motor is faster spinning speed, while more amperage increases the applied torque. As the axle spins, a string that is connected to a weight wraps around it. This string is connected to the weight via a pulley that is located at the given measured height. Thus the weight, distance, and time can be measured, and the power output calculated using Equation 3.

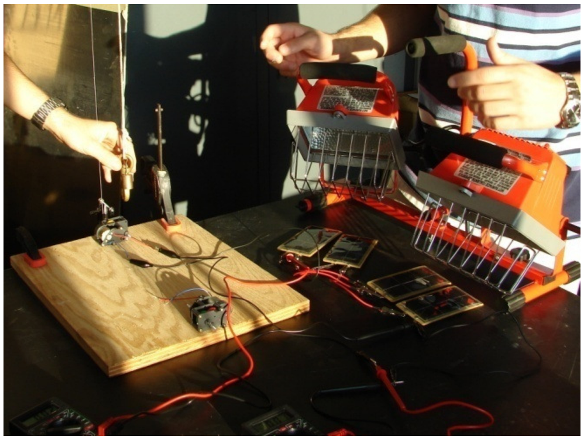

Figure 2. Photovoltaic cells are connected to a motor that spins an axle attached to a pulley system that lifts a given weight. The power supply for the cells are two flood lights.

An elevated tank of water serves as the power source for the hydropower lab (Figure 3). The elevated storage of water contains potential energy, which is converted to kinetic energy when it drains through a lower outlet. As the water flows down through the pipe, its velocity, and therefore its momentum, increases. At the exit of the pipe, the water impacts on a waterwheel, thus converting its momentum to the momentum of the wheel (i.e. converting kinetic energy to mechanical energy). The exit velocity (V) is a function of the elevation (H) of the stored water (Equation 5).

$$V = C\sqrt{(gH)} \qquad \text{(Eq. 5)}$$

This is not a perfect equation because of frictional losses within the flow (represented by a loss coefficient, C), but it provides easily measurable quantities for the first-year students. The power (P) derived from the momentum can be determined from Equation 6:

$$P = u\rho Q(V-u)(1-cos\beta) \qquad \text{(Eq. 6)}$$

where, u is the tangential velocity of the waterwheel created by the velocity (V) of the water, ρ is the density of the water, Q is the volumetric discharge of the water, and β is the relative angle of the turbine blades to the water flow. This waterwheel will spin, thus wrapping up a string that is connected to the weight via a pulley. Thus the weight, distance, and time can be measured, and the power output can be calculated using Equation 3 and compared with the turbine power calculated using Equation 6.

The power source for the wind energy lab is a wind turbine. As wind impacts the turbine blades, they spin a system of gears that is connected to a string which is connected to the weight via a pulley system (Figure 4). The concepts of converting the wind's momentum to the wheel's momentum are similar to the hydropower experiment. However, the fluid that is used to provide the momentum, and the mechanism in which that fluid acquires its momentum are different. To further distinguish this experiment from the hydropower experiment, the wind turbine blades are attached to an interchangeable system of gears of varying diameters. Different gear ratios will provide different speeds and/or torque for the axle that is attached to the weight.

Figure 3. For the hydropower experiment, a storage tank of water is placed on the second story walkway and the water is fed to the turbines on the first floor via a plastic tube.

Figure 4. A mechanical fan creates wind that powers a turbine system connected to a spinning axle via a system of gear ratios. A string attached to the weight is connected to the axle by a pulley.

The power source for the chemical reaction lab is a student-created alkaline battery cell. A battery cell is comprised of two electrodes, a cathode and an anode (Figure 5). The electrodes are submerged in an electrolyte solution, which forms electrically charged ions. The positive ions (cations) will move towards the cathode, while the negative ions (anions) will move towards the anode. The battery cell described herein uses a zinc bar (Zn) as the anode that is submerged in a potassium hydroxide electrolyte solution. The cathode is a magnesium oxide powder (MgO_2). The chemical reactions of the battery cell used for this lab are shown as Equations 7 (anode) and 8 (cathode).

$$Zn\ (s) + 2OH^-\ (aq) \rightarrow ZnO\ (s) + H_2O\ (l) + 2e^- \qquad \text{(Eq. 7)}$$

$$2MgO_2\ (s) + H_2O\ (l) + 2e^- \rightarrow Mg_2O_3\ (s) + 2OH^-\ (aq) \qquad \text{(Eq. 8)}$$

As electrons (e^-) pass from the anode to the cathode, an electric current is produced. This current is collected via a copper wire set in the cathode powder. The current is completed by attaching the motor to the copper wire and the zinc bar. A flywheel is attached to the motor which spins and wraps up a string that is attached to the weight via a pulley.

The initial design and testing of these experiments was done with the assistance of an undergraduate engineering student. For this student, the experience provided her with extra-curricular learning of green engineering topics. Design skills she had first learned in the Rowan engineering clinics were utilized to test, calibrate, and perfect the lab procedures used during the experiments. She was a student in a Freshman Engineering Clinic that did not incorporate all of these experiments, and was excited to have this ‘hands-on’ opportunity to help better the course.

Figure 5. Students initiate the chemical reaction in the battery cell that will conduct a utile current that will power a motor attached to a spinning axle and weight system.

Lab Implementation

Prior to each lab, the students are tasked to individually research the renewable energy source that will be examined and tested. In turn, they enter the lab with some background knowledge of the subject. During the labs, each group is given a packet of material to be tested and used as their power source. They collect data from their own setup, draw conclusions about each energy source, and suggest recommendations for engineering applications. After each experiment, each group is expected to submit a written report on their findings. It should be noted that the goal of each experiment is not to produce the most power, but for the students to understand the relationship between the many variables and power output.

During the solar power lab, the first task for the students is to understand how PV panels operate in series and in parallel array systems. Each group is given several PV panels, a bundle of connector wires, a resistor board, and a multi-meter (for measuring voltage and amperage). To assess the potential voltage and amperage for a given array, the students measure and record the output volts and amperes for a given set of resistors (Figure 6). By repeating this for all possible combinations of the PV cells, the students now have an idea of which design will produce the most power for their motor. During the experiment, the students must choose an array design, setup the motor and pulley system, and record the voltage and amperage of their circuit as they power their motor with the PV cells (Figure 7). Students record the amount of weight they lift, the distance the weight was lifted, and the time in which the weight was lifted that distance. These measurements are used with Equation 3 to determine power output. Students then vary the weights used, and the PV array design.

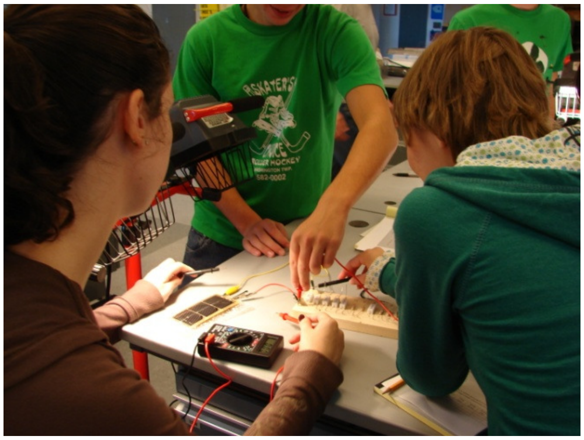

Figure 6. Students measure the voltage, amperage, and resistance for a given PV array.

Figure 7. Students attach their chosen PV array to the motor and pulley system.

During the hydropower lab, the first task for the students is to understand how to best convert the flowing water's momentum into mechanical power. Each group is provided with a kit of pieces that can be snap-locked onto each other to form a flow conduit. The students can choose the length of the conduit, the number of conduit branches, the diameter of each exit nozzle, and the angle in which the flow impacts on the waterwheel (e.g. Figures 8 and 9). Each of these parameters has an effect on the potential momentum that can be transferred to the waterwheel. Before the experiment, the students must construct their waterwheel housing and flow conduit. During the testing phase, the students connect their conduit to the outlet pipe of the elevated tank and their waterwheel setup to the weight and pulley system (Figure 10). The students measure the weight, the distance it traveled, and the time in which it traveled that distance. The students also measure the volume of water consumed for their power generation.

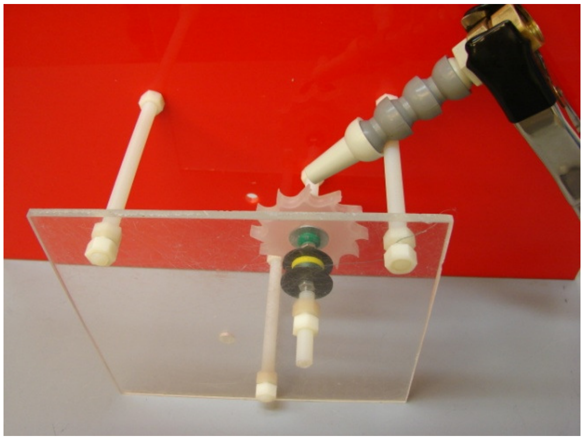

Figure 8. A turbine wheel with a small impact face and a flow conduit with a short length used in the hydropower lab.

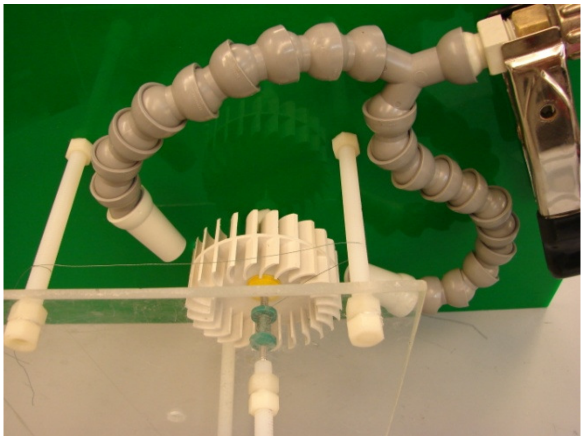

Figure 9. A large turbine wheel with multiple flow conduits used in the hydropower lab.

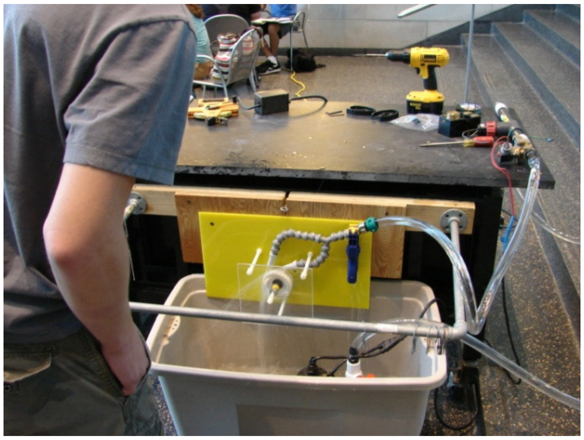

Figure 10. A turbine system is attached to the elevated tank by the outlet hose. Water flows through the conduit and impacts on the wheel, spinning it and pulling the weight up.

During the wind energy lab, the first task for the students is to understand how different gear ratios can provide different power outputs from the same power input. Each group is provided with a commercially-available wind turbine kit[4] (Figure 11). With this kit, many variations of wind turbines can be created. The variations include the number of blades to be attached to the turbine and the number and ratio of gears that connect the blades to the rotating axle. The shapes of the blades are fixed, but the students will have the opportunity to manipulate these shapes during their sophomore clinic project[5]. Before the testing phase, the students are tasked to manipulate various gear ratios in order to determine potential turning speed and torque for the axle. The students have some freedom in deciding the design of the turbine frame and gears. During the experiment, the students testing the lifting power of their turbine against the number of attached blades and a varying gear ratio (Figure 12). The students must again record the weight, the distance, and time, and compare these values to the number of blades and gear ratios used. The wind speed is also measured and used as a comparable variable in their reports.

Figure 11. Commercial kit for designing a wind turbine, with all parts shown[4].

Figure 12. A student-built turbine showing the turbine blades attached to a small–to-large gear ratio that is attached to the spinning axle.

During the chemical reaction lab, the first task for the students is to understand how chemical reactions can produce a flow of electrons (and thus electricity). The students first create a 'voltaic pile', which consists of stacking alternating plates of copper and zinc separated by thin layer of saline solution (Figure 13). The resulting reactions between the copper and zinc produce a small current that is measurable with an ammeter. The students then set up their zinc-magnesium battery cell. Once the battery is charged, it is connected to the small motor that is connected to the weight and pulley system (Figure 14). Measurements include the weights, distances, and times. Students can experiment with multiple battery cells attached in series or parallel.

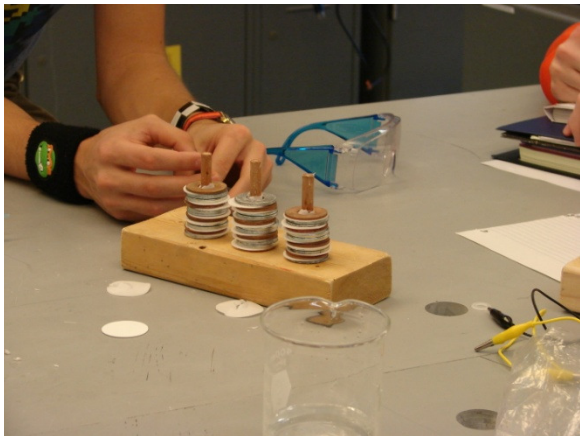

Figure 13. A voltaic pile consists of alternating copper and zinc plates separated with paper soaked in a saline solution.

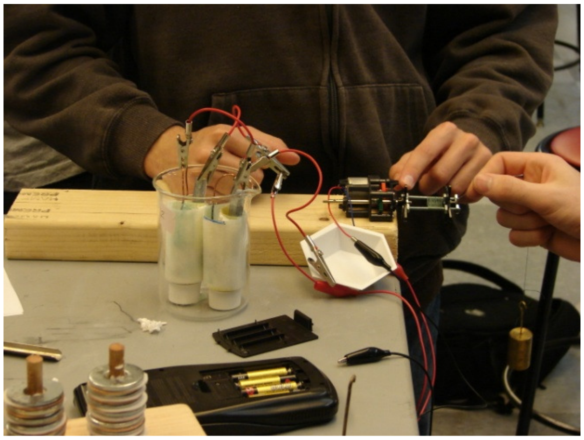

Figure 14. Two battery cells connected in parallel power the small motor that spins the axle attached to the string and weight.

Conclusions

All of these labs are simple to develop and implement. Each lab centers on a particular renewable energy source, and caters to a specific engineering sub-discipline. A common complaint among first and second year students about the Rowan Engineering Clinic program is that even though the classes are all multi-disciplinary, the assigned lab experiments are usually not multi-disciplinary. This stems from the fact that the instructors typically assign projects that are within their realm of expertise. Several of the experiments described are outside the expertise of the writers, yet each lab was prepared and conducted with little difficulty. Because each lab has a focus in each of the available engineering disciplines, each student will have the opportunity to run an experiment that directly pertains to his/her major. At the same time, each student will be able to directly compare their chosen major to the other disciplines.

Each of the experiments described herein may be a little rudimentary compared to how in-depth a lab on that subject could be; however, they serve a utile introduction for first-year students. This suite of labs accomplishes the main goals of Freshman Clinic: (1) provide students with engineering experiments in which they will learn to accurately record measurements and learn proper lab etiquette, (2) provide a multi-disciplinary class with comparable multi-disciplinary experiments, (3) provide experiments that have relevance to real-world engineering issues, and (4) incorporate sustainable engineering topics into the curriculum while instilling a sense of global responsibility in first-year engineers.

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