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Green engineering labs for a multidisciplinary freshman engineering course

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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 Clinics are designed to be fully integrated and multi-discipline. The laboratories used in this course 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 pulley and weight system powered by a renewable energy. The energy source is the variable, and thus the crux of the labs. To operate the 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. All four engineering disciplines are covered, and all the labs (and hence energy sources) are directly inter-comparable.

INTRODUCTION

As the world's population and their needs expand every day, innovative engineers strive to minimise its effect on our quality of life and modernise 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 programmes 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 government administrations in the USA set such ambitious goals like doubling the production of renewable energy within the next four years, today's engineering graduates must be at 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].

This article will introduce a series of experiments that focus on renewable energy sources that are designed to be integrated into a multi-disciplinary engineering course. These experiments will provide the students with the vocabulary and design skills in sustainability and green engineering topics and encourage them to think about the future implications [3]. The following sections will discuss the classroom setting in which these experiments were designed, provide the basic objectives of the labs, and detail the individual experiments.

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 programme at Rowan University uses a multidisciplinary project-based team learning approach in the form of Engineering Clinics [4]. 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. The eight-semester Engineering Clinic sequence at Rowan covers basic engineering measurements and design through a senior capstone research project (Table 1).

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. Introducing the students to green engineering early will also stress its importance in design, rather than devaluing it by tacking it on at the end of many senior-level courses [5]. The lab experiments described herein were designed for the first semester of the Engineering Clinic sequence (Table 1).

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

LAB DEVELOPMENT

The series of labs described here focuses on renewable energy and sustainable engineering, but still achieve the fundamental objectives for any engineering lab, as well as conform to the basic twelve principles of green engineering [6][7]. Because the students that comprise the class come from four distinct engineering disciplines, the laboratories themes were approached from an interdisciplinary viewpoint. The labs had to be observably comparable, and therefore each had to have the same ultimate objective. The idea of comparing four different types of renewable energy drove the development of these labs. The four types of renewable energy examined in this course are: 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. The measurable power output can be calculated using the following sequence of equations derived from any basic physics curriculum:

$$F = mg \tag{1}$$

$$W = Fd \tag{2}$$

$$P = \frac{W}{t} \tag{3}$$

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.

Prior to each lab, the students are tasked to research individually the renewable energy source that will be examined and tested. As a result, 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 lab 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.

SOLAR POWER EXPERIMENT

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 behaviour of this current can be predicted by Ohm's Law (Equation 4), which states that the product of the resistance (R) and the electric current (amperage, I) is equal to the electric potential (voltage, V) of the flow:

$$\mathrm{V} = \mathrm{IR} \tag{4}$$

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).

For this experiment, the generated electric current is channelled through a DC motor, which is connected to a spinning axle. 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).

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. By repeating this for all possible combinations of the PV cells, the students now have an idea of which design will produce what power for their motor.

During the experiment, the students must choose an array design, set up the motor and pulley system, and record the voltage and amperage of their circuit as they power their motor with the PV cells. 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 can then vary the weights used, and the PV array design.

HYDROPOWER EXPERIMENT

An elevated tank of water serves as the power source for the hydropower lab. 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 *u* is a function of the elevation *H* of the stored water (Equation 5):

$$u = C\sqrt{(gH)} \tag{5}$$

This is not a perfect equation because of frictional losses within the flow-path (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):

$$P = w\rho Q(u - w)(1 - \cos\beta) \tag{6}$$

where *w* is the tangential velocity of the waterwheel created by the velocity *u* 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. The waterwheel will spin, thus wrapping up a string that is connected to the weight via a pulley. The tangential velocity can be measured with knowledge of the length of the string that was used, the time it took lift the weight (i.e. wrap the string around the axle), and the diameter of the axle. 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).

During the hydropower lab, the first task for the students is to understand how best to 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. 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. The students measure the weight, the distance it travelled, and the time in which it travelled that distance. The students also measure the volume of water consumed for their power generation, which can be incorporated into appropriate discussions of the positives and negatives of renewable energy.

WIND POWER EXPERIMENT

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. 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 distinguish this experiment from the hydropower experiment further, 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.

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 [8]. 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 [9]. 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 test the lifting power of their turbine against the number of attached blades and a varying gear ratio. 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.

CHEMICAL REACTION EXPERIMENT

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. 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).

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

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

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.

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. 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. Measurements include the weights, distances, and times. Students can experiment with multiple battery cells attached in series or parallel. These batteries do eventually lose power, which can segue into further discussions of the positives and negatives of such renewable energies.

CONCLUSIONS

All of these laboratories are simple to develop and implement, and they may be adapted and modified at the discretion of the individual faculty. As described in this article, each lab requires one to two lab periods to complete. Each lab centres 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 programme 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 author, 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 compare directly 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 as a utile introduction for first-year students. This suite of labs accomplishes the main goals of Freshman Clinic, or any introductory engineering course:

- provide students with engineering experiments in which they will learn to accurately record measurements and learn proper lab etiquette;
- provide a multi-disciplinary class with comparable multi-disciplinary experiments;
- provide experiments that have relevance to real-world engineering issues;
- incorporate sustainable engineering topics into the curriculum while instilling a sense of global responsibility in first-year engineers.

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