AC 2011-75: ENHANCING STUDENT LEARNING THROUGH HANDS-ON LABORATORY EXPERIMENTS ON RENEWABLE ENERGY SOURCES

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Enhancing Student Learning through Hands-on Laboratories on Renewable Energy Sources

Abstract

A theory based renewable energy sources course was complemented with seven hands-on laboratory experiments. The course was designed for engineering and non-engineering undergraduate students and did not require any advanced mathematics or physics background. Each laboratory experiment introduced a miniature version of an energy conversion device that mimicked the insights and workings of a real scale device. The seven hands-on laboratory experiments demonstrated the principles of the; flywheel, solar pathfinder, photovoltaic powered motor, hydroelectricity, wind turbine, thermoelectricity, and a fuel cell. In order to record the level of improvement of the class, each student was given a questionnaire before and after completing each experiment and at the end of the academic term. Each questionnaire consisted of five different types of questions relevant to an individual renewable energy source studied at that time. This paper presents results of our findings on performance improvements by laboratory type, class level, gender and student major. In more detail, our assessment showed that the students learned the most during the Flywheel laboratory experiment. When results were grouped by the class level, the most advanced class level, or forth year students, showed the most improvement. Overall, both genders showed significant improvement. Finally, when results were grouped by major discipline, our assessment showed that the students with social science majors showed the most improvement. A total of 140 students from the University of California, at Santa Cruz participated and as a whole, the class showed a significant increase in their knowledge at the end of the term.

Introduction

At the University of California, Santa Cruz, the Renewable Energy Sources course is offered to all undergraduate students without any prerequisites. In the spring of 2009, this particular course was completed by approximately 168 students. The student body represented more than 16 diverse majors which included sociology, psychology, literature, theater, community studies, economics, history, politics, mathematics, engineering, biology, chemistry and earth sciences. One of our goals was to introduce the basic physics and engineering concepts related to energy, power, temperature, and conservation laws in the context of renewable energy sources to a wide range of students. The goal was to familiarize non-engineering majors with quantitative analysis which is very important in the discussions related to a sustainable energy future and to familiarize engineering and science majors to social aspect of renewable energy sources. In addition, all students learned about the important social impact of our energy infrastructure and appreciated the social implementation issues associated with the new technologies.

Due to a wide range of students' backgrounds a large number of learning styles were expected. According to Richard Felder and Linda Silverman, there are 32 different learning styles and the usual methods of engineering education usually implement only five categories; intuitive, auditory, deductive, reflective and sequential[1]. A mismatch between preferred learning styles and corresponding teaching style could lead to student's discouragement and change to other curricula [1, 2]. Due to a large number of students with different majors, it was clear that more than one learning style needed to be implemented in this course in order to achieve successful learning experience for students of any major. Richard Felder and Linda Silverman suggest several teaching techniques to address all learning styles, one of which is to provide demonstrations for students with sensing and visual learning styles and hands-on experiments for students with active learning styles[1]. Edgar Dale's cone of learning shows that participating in discussions or other active experiences may increase retention of material by up to 90% [3]. Furthermore, the importance of experiential activities, such as laboratory sessions is highlighted by many [1-6]. In the past, in class performance has showed direct correlation to laboratory attendance and performance [7]. In renewable energy courses, active learning can be achieved through variety of activities, which could include lab experiences with testbeds [8, 9], hands-on projects[10], and hands-on laboratory experiments[11]. From the diverse background of the students enrolled in our course, we decided to complement our course with hands-on laboratory experiments to further enhance the student learning process.

In the past, the Renewable Energy Sources course was offered as a series of theory based lectures with a couple of short in-class demonstrations. In the spring of 2009, for the first time, a Renewable Energy Sources laboratory component was added to increase the level of acquired knowledge. The whole course consisted of 20 lecture, eight laboratory experiments and 10 discussion sections over a period of 10 weeks. In addition to the seven laboratory experiments below, the major assignments included an extensive home energy audit and a group project on the local implementation of renewable energy sources. The details of the energy audit and the group project will be described in a future publication.

Laboratory Experiments

A renewable energy sources course was complemented with seven hands-on laboratory experiments. The seven laboratory experiments illustrated principles of the flywheel, solar pathfinder, photovoltaic motor, hydroelectricity, wind turbine, thermoelectricity and a fuel cell laboratory. Each laboratory experiment introduced a miniature version of an energy conversion device. From completing each experiment, students were expected to gain knowledge about the principles and the operation of each device.

At the beginning of each laboratory experiment, all students were given minimal verbal background information introducing a particular type of renewable energy source. The same type of renewable energy source was also introduced in lecture in the previous week. Each laboratory session was limited to approximately 70 minutes.

The students were encouraged to work in groups of no more than two or individually. Each individual student was provided with a paper based laboratory write-up and each group was given a laboratory kit consisting of discrete components for the specific laboratory experiment. The students were asked to read the write-up, follow directions, conduct the laboratory experiment and fill in required information while showing their calculations. After completion of the course, all laboratory write-ups were posted on and can found at http://seed.soe.ucsc.edu. Details of each laboratory experiment are explained below which include short laboratory descriptions, a few steps from the laboratory instructions and a picture of main components. Some parts were commercially available and were purchased, structured and modified to meet the needs of the course.

A. Flywheel Laboratory Experiment

The flywheel laboratory experiment was designed for students to learn about gravitational potential energy, generated electrical energy and rotational kinetic energy. The system converts mechanical energy to electrical energy. The laboratory kit consisted of the following components; energy transfer generator, flywheel, flywheel nut, pulley, LED plug, resistor, thread, alligator clips, rod stand and plastic container[12]. Additionally, a custom built LabView program was used to display the acquired electrical potentials. During experiments, students dropped different masses connected by a string to a generator at a specific height. Next, students measured generated voltage and calculated generated power. Figure 1 contains a few steps from the laboratory write-up and a picture of the energy transfer generator.

Step 15: In LabView, click the start button. Let the mass fall and record the voltage levels.
Step 16: LabView, click the stop button and observe generated Voltage vs. Time plot. Plot it in the provided graph.
Step 17: Make a Power vs. Time plot using following relation;
Power = Voltage 2 / Resistance
Step 18: Record the value of the generated electrical energy. Be sure to include units.
Generated electrical energy=__________________ (_)
Step 19: Calculate the change in gravitational potential energy, where,
PE = m g h

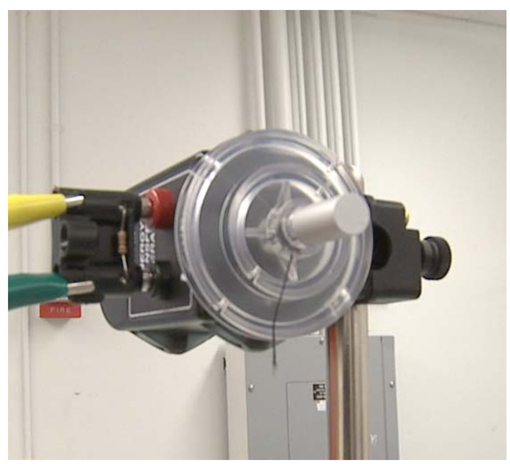

Figure 1 Left: Steps 15 through 19 from the laboratory write-up. Right: Image of the energy transfer generator.

B. Solar Pathfinder Laboratory Experiment

The solar pathfinder laboratory experiment was designed for students to obtain knowledge about determining criteria for true north, declination angle, sun path diagram and being able to determine the best location for maximum percentage of solar energy available at a specific location throughout the year. The laboratory kit consisted of the following components; tripod, angle estimator, sun path diagram, chalk, dome and plastic brief case[13]. Each group of students was assigned a specific location around the building for analysis of sun exposure throughout the year. After completing their assessments, each group shared their results and was asked to define objects that prevented obtaining higher percentages of solar energy. Figure 2 contains a few steps from the solar pathfinder laboratory write-up, as well as, the picture of the complete set-up that students assemble together and used to assess percent of solar energy available through out the year.

Step 6: Place the dome on top of the instrument section.
Step 7: View the pathfinder dome from 12-18" above.
Step 8: Use the opening on the side of the dome (opposite the compass) to outline the reflected image of shadowing structures.
Step 9: Using the solar pathfinder chart, estimate the percentage of solar energy that is available at this location at summer time.
Percentage=___________________________________
Step 10: Using the solar pathfinder chart, estimate the percentage of solar energy that is available at this location at winter time.
Percentage=____________________________________

Figure 2 Left: Steps 6 through 10 from the solar pathfinder laboratory write up. Right: image of the complete set-up.

C. Photovoltaic Powered Motor Laboratory Experiment

The photovoltaic powered motor laboratory experiment was designed for students to learn about solar cells, electric power motors, the process of constructing Current vs. Voltage curves and being able to calculate maximum power and resistance. The system converted solar energy to electrical energy. The laboratory kit consisted of magnetic wire, solar panel, wire, alligator clips, thick unshielded wire, variable resistor and voltmeter. The students learned about the inner workings of a DC motor powered by solar cells. Figure 3 demonstrates a few steps from the photovoltaic powered motor laboratory write-up and a picture of laboratory set-up.

Step 9a: Cut the length of wire found in section 8 plus 2 cm.
Step 9b: Strip 2 cm off both ends of the magnet wire.
Step 9c: Coil wire into 3 cm loops.
Step 9d: Bend the unshielded wire into a stand to hold the coiled magnet wire. The stand must be taller than the thickness of a magnet and the radius of the coil.
Step 9e: Connect solar cell to the leads.
Step 9f: Place the coil into a stand.
Step 9g: Place the magnet under the coil.
Step 9h: Observe the movement of coil.

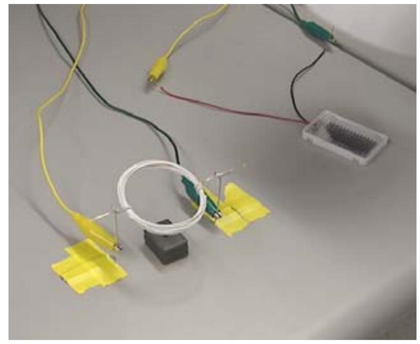

Figure 3 Left: Steps 9a through 9h of photovoltaic powered motor laboratory write-up. Right: picture of the photovoltaic powered motor.

D. Hydroelectricity Laboratory Experiment

The hydroelectricity laboratory experiment was designed for students to become familiar with the process of calculating gravitational potential energy and using a hydroelectric turbine. The system converts mechanical energy to electrical energy. The laboratory kit consisted of the following components; energy transfer generator, impeller housing, impeller, plastic tubing, plastic nozzle, tube clamp, screwdriver, water reservoir, water, resistor plug, alligator clamps, beaker, rod stand, finger clamp and a ruler[14]. Additionally, a custom built LabView program was used in displaying acquired electrical potentials that was similar to that in section A. During experiments, students varied the height from which water was dropped and the nozzle diameter. The students also measured generated voltage vs. time and estimated generated power vs. time plots. The students were also asked to calculate the efficiency of their systems and compare their values to values found in previous laboratory experiments. Figure 4 shows a few steps from the hydroelectricity laboratory write-up and laboratory kit set-up.

Step 15: In LabView, click start button
Step 16: Open the clamp and allow water to run through turbine Note: make sure the impeller is rotating
Step 17: Draw your Voltage vs. Time graph
Step 18: If Power = (Voltage)2 / Resistance, estimate Power vs. Time plot below.
Step 19: Record the value of electrical energy generated__________________(_)

Figure 4 Left: Steps 15 through 19 from the hydroelectricity write up. Right: image of the laboratory set-up.

E. Wind Turbine Laboratory Experiment

The wind turbine laboratory experiment was designed for students to learn about specific wind power, wind frequency, different types of turbines and their advantages and disadvantages. The system converts mechanical energy to electrical energy. The laboratory kit consisted of an energy transfer generator, five blade fan, thumb nut, spacer, rod stand, alligator clips, electric fan, plastic container and a ruler[15]. During the laboratory experiment students built a wind turbine system and calculated the period and the frequency of the rotating turbine at different speeds. Figure 5 contains a few steps from wind turbine laboratory write-up and image of experimental set-up.

Step 1: Turbine: place the spacer over the plastic shaft of the ET-generator. Place the 5 blade fan over the same plastic shaft of the ET-generator. Make sure that the 5 blade fan is facing the correct direction. Secure 5 blade fan with thumbnut.
Step 2: Attach the assembled wind turbine to the rod stand.
Step 3: Center the wind power source on the far left side of your table so that the wind's direction is across the center of your table.
Step 4: Create a wind frequency profile measuring frequency at each position.

Figure 5 Left: Steps 1 through 4 of the wind turbine laboratory write-up. Right: image of experimental set-up.

F. Thermoelectricity Laboratory Experiment

The thermoelectricity laboratory experiment was designed for students to obtain knowledge about the Seebeck effect, the Peltier effect and thermal capacitors. The system converted thermal energy to electrical energy. The laboratory kit consisted of a thermoelectric converter, two Styrofoam cups, thermometer, DC power supply, hot and cold water[16]. The students learned about the insights of a thermoelectric device and the process of converting thermal energy to electric energy. Figure 6 demonstrates a few steps from thermoelectricity laboratory write up and the laboratory set-up.

Step 7: Place the two cups next to each other.
Step 8: Insert the thermoelectric converter so that each leg is in a different temperature cup.
Note: If the fan is facing you, the right-side leg should be in hot water and the left leg should be in cold water.
Step 9: Flip the switch on the thermoelectric converter to position "A" ($\Delta T \rightarrow E$)
Step 10: After flipping the switch, did your fan move?
Step 11: If the fan did not move, give the fan a push in the clockwise direction. Why does the fan require a "jump start" in order to spin?

Figure 6 Left: Steps 7 - 11 from the thermoelectricity laboratory write up. Right: image of the laboratory set-up.

G. Fuel Cell Laboratory Experiment

The fuel cell laboratory experiment was designed for student to learn about inner workings of a hydrogen fuel cell as a power source and its advantages and disadvantages. The system was designed to convert chemical energy to electrical energy to mechanical energy. The laboratory kit consisted of HyRunner car, power source, ruler, protective goggles, container and distilled water[17]. The students also learned about the HyRunner car kit Module and how its mechanical movement is powered by hydrogen. Figure 7 shows a few steps from the Fuel cell laboratory write up, as well as, the HyRunner being charged.

Step 8: Connect the hose of the water bottle to the inlet socket of the cell.
Step 9: Holding the bottle upside down and vertical, squeeze it to fill the gas tank up to the 'A' mark with water introduced via the fuel cell.
Step 10: Release the pressure on the bottle. When the water level has fallen to 'B' mark, pinch the hose between thumb and forefinger until the water stops dropping.
Step 11: Pull the water bottle hose off the fuel cell. Replace the black cap on the inlet socket.

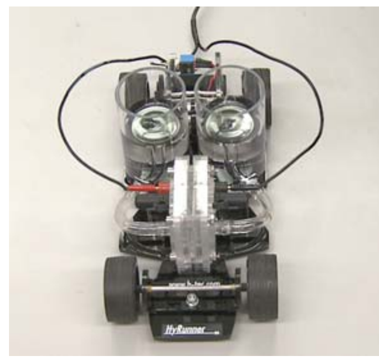

Figure 7 Left: Steps 8 through 11 from fuel cell laboratory write up. Right: a picture of the HyRunner.

Student Assessment

In order to test the acquired knowledge of the class, each student was required to complete a questionnaire before and after each experiment and at the end of the academic term. The questionnaires were called, pre, post and final questionnaires respectively. The pre and post questionnaires consisted of five identical questions with five multiple choice answers. The final questionnaire consisted of 35 questions, five from each questionnaire of 7 laboratory experiments. The final questionnaire did not contain questions from the Fuel Cell Laboratory because the students conducted the experiments the same week. At the end of the term, each questionnaire was graded on a scale of one to five, where each score represented a number of correct answers. Table 1 contains the number of the participating students for each laboratory experiment in the chronological order they were conducted. Due to the limited number of kits available, the solar pathfinder laboratory experiment was only conducted by a small group of students that were enrolled in the upper division of the course.

Table 1 Number of questionnaires analyzed by experiment type. The Solar Pathfinder lab was only completed by one out of the eight laboratory session due to the conflicting schedules.

	Flywheel Laboratory	Solar Pathfinder Laboratory	Photovoltaic Powered Motor Laboratory	Hydroelectricity Laboratory	Wind Turbine Laboratory	Thermoelectricity Laboratory	Fuel Cell Laboratory
Number of students who completed pre questionnaire	140	21	133	134	126	119	108
Number of students who completed post questionnaire	140	21	125	129	125	118	108
Number of students who completed final questionnaire	106	16	92	93	86	91	-

A. Results by Laboratory Experiment

For each experiment, the mean of the scores and standard deviation was calculated. Next, the percentages of scores were plotted vs. laboratory experiment. This is represented in Figure 8. Our results demonstrate that the students that were tested right after the experiments showed an average of 11 percent improvement. When students were given the same test at the end of the academic quarter, they still showed an average 9 percent of improvement. A t-test was then used to determine whether the difference between the means is statistically significant. The test was performed by calculating the difference between two means and dividing the result by the standard error of the difference [18, 19]. The alpha level was chosen to be 0.05. The results from the t-tests confirmed overall significant improvement between pre and post questionnaire score averages and between pre and final questionnaire scores average. Due to significant improvement of average scores of students, it is evident that student learning was enhanced. It is also interesting to note that students showed the most improvement of 19 percent in understanding for the Flywheel lab. One possible explanation could be that the Flywheel laboratory experiment was the first to be completed and the flywheel fundamentals were not yet covered in class. The data from Flywheel and Solar Pathfinder laboratory experiments showed continuous improvement with greater final questionnaire averages. Again, this could be due to the fact that the material covered during laboratory experiments was not yet covered in theoretical part of the course. Once the material was covered in the course, it was then possible for students to receive higher scores on their final questionnaires using knowledge obtained from laboratory experiment and lectures. The score analysis from the Thermoelectricity Lab shows that students had a substantial amount of knowledge before conducting the laboratory experiments. The Photovoltaic Powered Motor, Hydroelectricity and Wind Turbine laboratory experiments showed similar pattern of scores for the pre questionnaires in the 60's %, post questionnaires in the 70's % and final questionnaires in the 60's %. This could be associated with the timing of exams in the theoretical part of the course for which students most likely preferred to concentrate their attention.

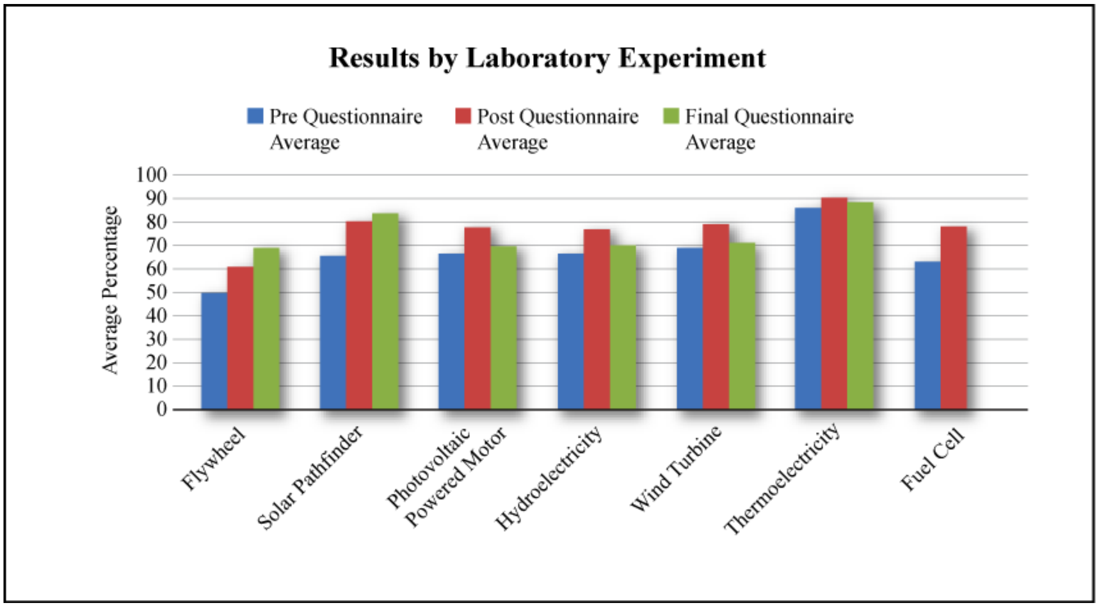

Figure 8. Average percentages vs. laboratory experiment. First column presents pre questionnaire average, second column presents post questionnaire average and third category presents final questionnaire average.

B. Results by Grade Level

Additionally, we grouped and analyzed the questionnaire scores by grade level or year. Figure 9 demonstrates the results of our findings. First, second and fourth year student showed over 10 percent improvement from the pre to post questionnaires scores. While the fourth year students showed 14.2 percent improvement of between the pre questionnaires and final questionnaires. It is also interesting to note that the average of the fourth or higher year student's scores of the final questionnaires are less than the post questionnaires, while the opposite occurs for the rest of class. It seemed that the fourth or higher year students may not have retained information as well as other students in the class.

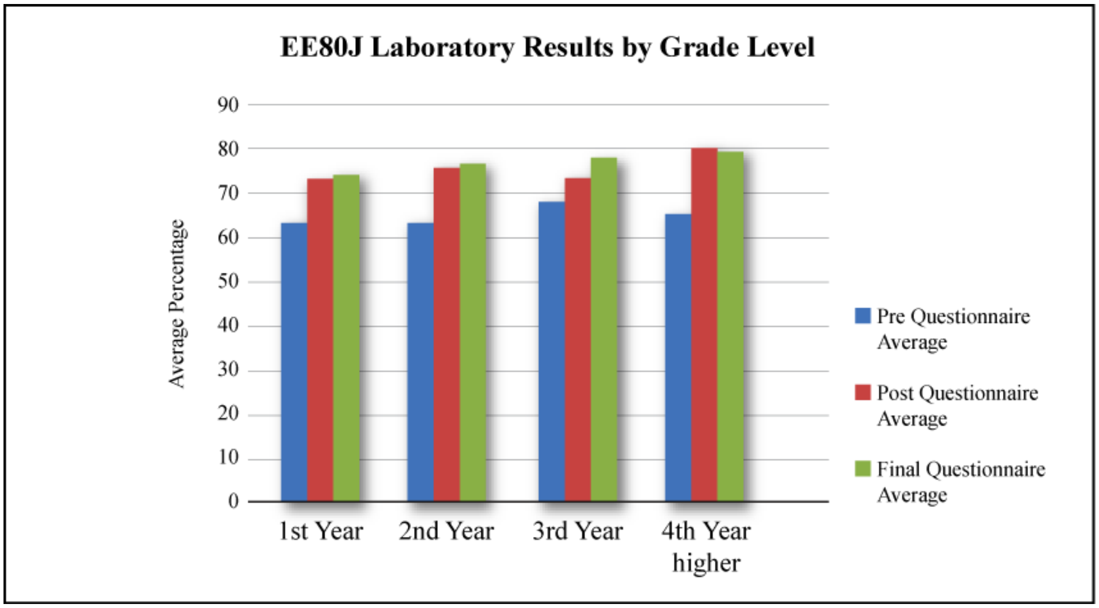

Figure 9. Results by grade level or year level. First column shows pre questionnaire average, second column is post questionnaire average and third column is final questionnaire average. Overall, the class population consisted of 60 1st year students, 45 2nd year students, 38 3rd year students and 25 forth and higher year students.

C. Results by Gender

We also analyzed our results in groups by gender. Figure 10 demonstrates results of our findings. The male population of our class showed 10.8 and 12.7 percent improvement between the pre and post questionnaire scores and the pre and final questionnaire scores respectively. The female population showed 12 and 12.5 percent improvement between the pre and post questionnaire scores and the pre and final questionnaire scores respectively. Both groups showed continuous improvement through time varying assessments.

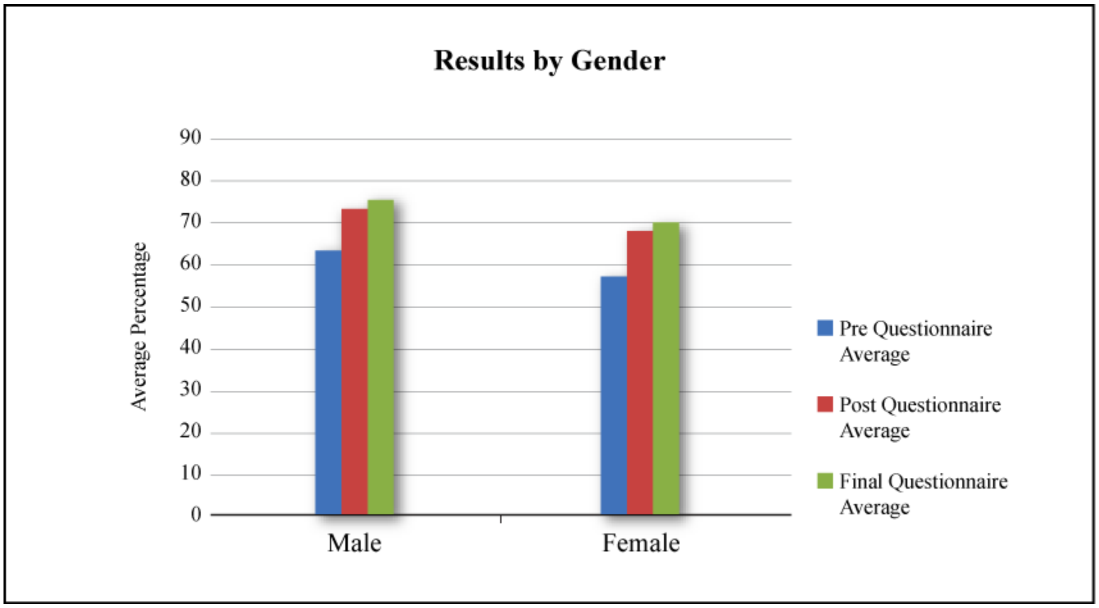

Figure 10. Results by gender. First column shows pre questionnaire average, second column shows post questionnaire average and the third column shows final questionnaire average. Overall, the class population consisted of 128 males and 40 females.

D. Results by Major

Additionally, we grouped and analyzed questionnaire scores by the declared major. Figure 11 demonstrates results of our findings. Undeclared students showed 9.5 and 9.6 percent improvement between the pre and post questionnaire scores and the pre and final questionnaire scores respectively. Engineering majors showed 9.2 and 9.5 percent improvement between the pre and post questionnaire scores and the pre and final questionnaire scores respectively. Natural Sciences majors showed 10.2 and 13.4 percent improvement between the pre and post questionnaire scores and the pre and final questionnaire scores respectively. Finally, Social Sciences majors showed 14.12 and 14.13 percent improvement between the pre and post questionnaire scores and the pre and final questionnaire scores respectively. Even though, all groups showed improvement, students with social sciences majors showed the most improvement. This is likely to be due to the fact that social science students may have less prior knowledge in the area when they started and therefore had a lower baseline.

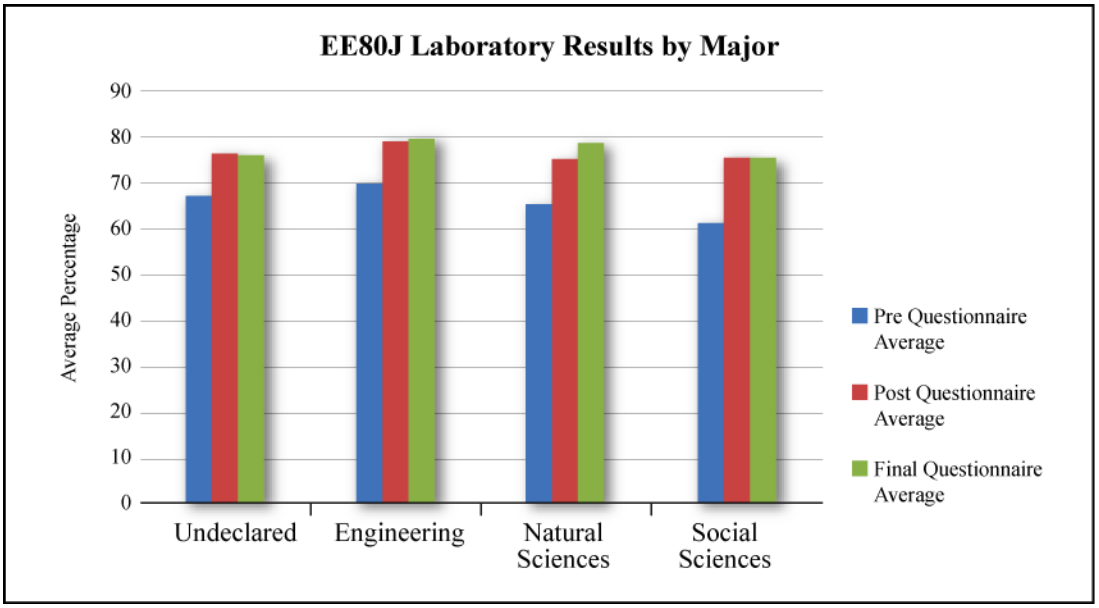

Figure 11. Results by major. First column shows pre questionnaire average, second column shows post questionnaire average and third column shows final questionnaire average. Moreover, the class consisted of 30 students with undeclared majors, 37 students with engineering majors, 53 students with natural sciences majors, and 48 majors with social sciences majors.

Conclusion and Future Work

Overall, all students in the class showed improvement in learning and understanding concepts about renewable energy sources by complementing a theory based lecture with hands on laboratory experiments. Our future plans include transferring paper based laboratory sheets and assessment to computer based interactive applets. We are hoping to increase the number of available laboratory experiments and cover additional renewable sources that complement even more of what is covered in lectures.

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