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Introduction of Renewable Energy to High School Students in a Summer Camp: Hands-on Experimental Approach

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INTRODUCTION OF RENEWABLE ENERGY TO HIGH SCHOOL STUDENTS IN A SUMMER CAMP: HANDS ON EXPERIMENTAL APPROACH

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Abstract

The hands on approach used to introduce the principles of renewable energy resources to high school students are presented in this paper. This approach was implemented for the eleven students who attended the STEM summer camp at West Virginia University Institute of Technology (WVU Tech) in summer 2015. The course was designed to include from the basic concepts of electricity to wind and solar energy as well as energy storage. First, the students were able to measure the grid power characteristics using an Electricity Usage Monitor. Then, they learned how to measure voltage and current using multi-meters. Next, they were introduced to the idea of renewable energy using the Alternative Energy Conversion Kit. After these preliminary steps, the students started to conduct experimentations of solar photovoltaic cells, solar thermal energy devices, wind turbines, and fuel cells. Through these experiments the students discovered (not lectured) the principles of operations of these units, the effects of various parameters on their performance, and their pros and cons. The students' performance on the pre-and post-quizzes showed a significant improvement in students understanding. Their feedback also indicated that while they learned a lot, they had a fun time and enjoyed the course.

Introduction

The introduction of renewable energy to the students while they are in the high school level or even earlier is becoming popular. The department of Energy and National Renewable Energy Laboratory (NREL) [1, 2], Illinois Valley Community College [3], the Union of Concerned Scientists [4], and others [5, 6] have published guidelines and booklets for this purpose.

This paper presents the hands on approach to educate the high school students who attended the STEM summer camp at West Virginia University Institute of Technology (WVU Tech) about the concepts of energy in general and renewable energy resources in particular. The idea of the program is to expose what engineers do and how they try to solve problems that the world is facing now. Compare to other programs with similar nature, this program is unique in its purely hands on approach. In this approach the level of lecturing is minimized and the students discover the principles behind each system themselves. Although the effectiveness of this approach has not been compared to other approaches, the growing interest in the program each year and the increase of enrolment indicate the relative success of the program (at least qualitatively if not quantitatively!).

There were eleven students from 9^{th} to 11^{th} grades in the class. The majority of them were female. As expected from students who decided to attend the STEM summer camp, their most favorite subjects were math and science.

Forming the teams

In order to motivate students, they were divided into two groups. The students were informed that there would be a competition between two teams. Each activity had a certain score. Table 1 was used to track the scores by the instructor and the students in each team.

Table 1: The score-sheet for the competition between two teams

Experiment	Max Score	Score - Team A	Score - Team B
Electricity Usage Monitor	5		
Voltage and current measurements	10		
Alternative Energy Conversion Kit	10		
Solar photovoltaic cell experiments	15		
Solar car race	10		
Solar flash light	10		
Solar thermal energy	10		
Wind turbines	20		
Fuel cells	10		
Total	100		

In the forming of the groups, the most important factor was diversity of team members. The students were not allowed to choose their teammates. At beginning of the class, each student was asked to write her/his high school name, grade level, and GPA on a piece of paper. To maintain confidentiality and avoid discomfort of students with low GPA, answering the question regarding the student GPAs was optional. This information was used to mix and match students to form the "almost equal" teams with maximum diversity in each team. Also, the gender balance in each team was taken into account. Beside the diversity of the teams, the objective of this practice was to help students to develop their ability to work in a team with team members that they were not already familiar with.

After the students wrote their information, the students took a pre-test related to the topic. While they were taking the test, the instructor formed the teams. Each team sat around a dedicated table. At this point they could start their experiments.

Each team was given an experiment to conduct and asked to prepare a brief report about it. For each experiment, all team members should discuss and one student should be in charge of writing the summary of the observation and the conclusion of the discussion. Then, the responsible student from each team should present the report of the experiment to the whole class as the representative of the team. For each experiment, a different student represented the team. In this practice, everyone in the team was engaged and developed the skill for technical writing and oral presentation of a scientific observation.

For experiments in which there existed two sets of instruments, the teams conducted experiments simultaneously. For others with a single instrument, two different experiments were conducted by teams simultaneously. After teams were done with each experiment, they switched the instrumentations.

These experiments are presented in the rest of this paper. Figure 1 illustrates the equipment used in these experiments. The program started with an experimentation using an Electricity Usage Monitor.

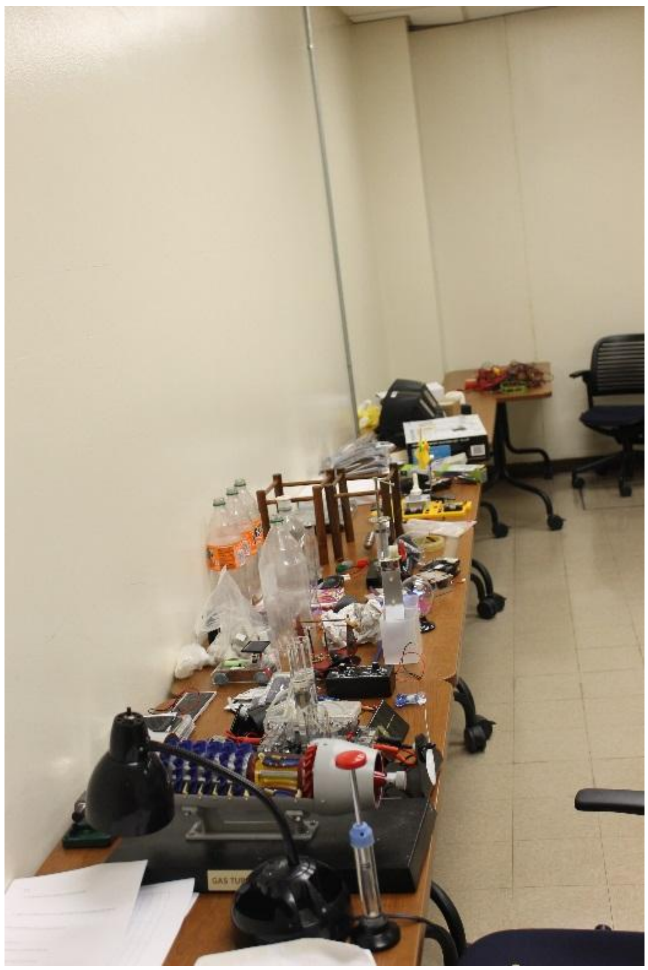

Figure 1: Equipment used in experiments

Experimentation using an Electricity Usage Monitor

In this experiment, the students used an Electricity Usage Monitor (Kill-A-Watt, about $30 each, Figure 2) to get familiar with the specifications of electricity in the US and the determination of power consumption and its cost. The students measured the voltage and frequency of the electricity from grid, current, the power consumption of the appliances connected to the unit, the power factor, the energy consumption, and the duration of the measurement. In order to conduct the experiments, two appliances (a fan and a heater) were connected to the meter and the values of the parameters recorded. Then, they were asked to disconnect one and then both consumers and observe that the voltage did not change and it is independent of the load. Later, when the students were conducting experiments with batteries, they reminded with the fact that unlike electricity from the grid, the voltage of electricity from batteries varies with the load. Finally, the appliances were reconnected and left to operate for a period of time and then the electrical energy consumption was recorded. During these measurements the students were reminded of the importance of recording units of measurement for each parameter. Also, the fluctuation of the parameters and the inaccuracy of instruments were discussed. Then, the concept of energy, power, voltage, current, frequency, AC and DC electricity, apparent power, real power, power factor, and electrical energy consumption along with appropriate equations were explained. The students used these equations to verify their readings from the meter. Finally, to conclude this part of the class, the students used an actual electricity bill to determine the cost of electricity per unit of energy (kW.hr). They used this value to estimate the cost of running two appliances for the measured period of time.

Figure 2: Electricity Usage Monitor (Kill-A-Watt)

In the next step, the students were trained in using multi-meters to measure voltage and current.

Voltage and current measurement using multi-meters

A quick discussion with the students revealed that they were not familiar with the utilization of multi-meters. So in this part, the students developed the skills to setup electrical circuits and to measure voltage and current. Each team was given a battery pack, a variable resistance, and two multi-meters. First, they connected the load (variable resistance) to the power supply (batteries). Then, they were instructed to connect one multi-meter to the load in parallel to measure voltage and connect the other in series to measure current (Figure 3). Finally, they connected both multi-meters to measure both voltage and current simultaneously. They varied the resistance and observed the effects on voltage and current. They realized that in this case, unlike electricity from the grid, voltage was affected by the load. This experiment was a challenging one and the students had a relatively difficult time to make sense of the arrangement.

In the next experiment, the students used a commercially available Alternative Energy Conversion Kit to conduct experiments on renewable energy sources.

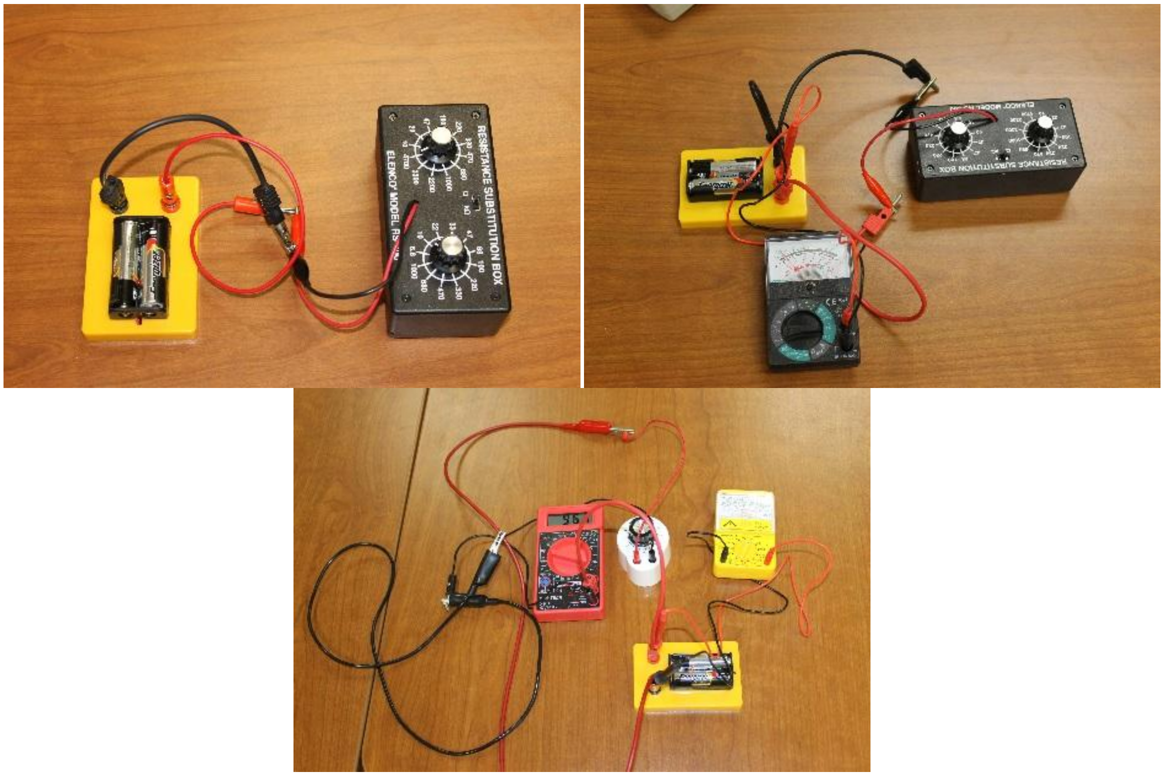

Figure 3: Voltage and current measurement using multi-meters

Alternative Energy Conversion Kit

This inexpensive kit (cost less than $70) is composed of various sources of electricity generation units. It also has several equipment as electricity consumers where electrical energy is converted to various forms of energy i.e. mechanical, chemical, light, and sound energy (Figure 4). The electrical energy suppliers were:

1. Batteries (conversion of chemical energy to electrical energy)
2. Solar cell (conversion of light energy to electrical energy)
3. Hand generator (conversion of mechanical energy to electrical energy)
4. Wind turbine (conversion of kinetic energy of air flow to electrical energy)

In each case, the students measured the open circuit voltage (OCV) of the generators by a multi-meter to get some idea about how much power each can produce (Figure 5). Since they were familiar with batteries, they started with them to have a bench mark to compare OCV of other electricity generators. For the solar cell, they observed the effect of distance to the source of light (a study-light) on the measured OCV. For the hand generator, they observe that the faster the cranking of the handle, the higher the OCV. Similarly, for the wind turbine, they observed that the higher wind speed turns the turbine faster which in turn produces the higher OCV. For the other end of the system, the power consumption side, they had a motor, fan, light, and buzzer as consumers. The students were encouraged to try as many combinations as they could and get more score for the competition. For each combination, they dedicated a row in Table 2 and recorded the information in the table (words in italic in the table). For some combinations, the students also measured current and calculated power consumption by the consumer.

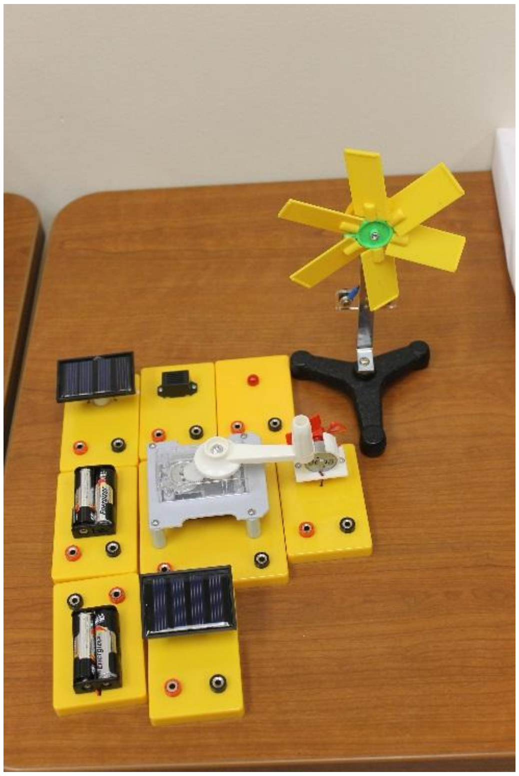

Figure 4: Alternative Energy Conversion Kit

Table 2: Table used in the Alternative Energy Conversion Kit with example of student recordings

Energy Source			Energy Carrier		Energy Consumer	
Device	**Type of energy**	**Renewable?**	**Type of energy**	**Max OCV (V)**	**Device**	**Type of energy**
Batteries	*Chemical*	*No*	*Electrical*	*3.2*	*Motor*	*Kinetic*
Solar cell	*Light*	*Yes*	*Electrical*	*2.1*	*Fan*	*Kinetic*
Hand generator	*Kinetic*	*Yes (?)*	*Electrical*	*5.5*	*Light*	*Light*
Wind	*Kinetic*	*Yes*	*Electrical*	*1.2*	*Buzzer*	*Sound*

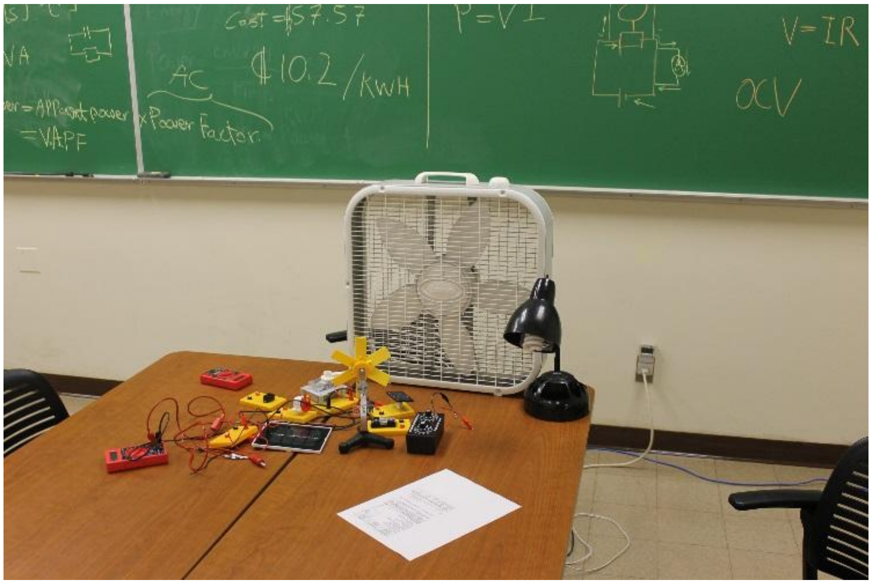

Figure 5: Experimentation using Alternative Energy Conversion Kit

Based on what the students did in this experiment, the concepts of power generation, transmission, and distribution were introduced. In this experiment the students also learned to identify various forms of energy and observe the conversation of one form to another. Furthermore, in some combinations, the power produced was not sufficient to run the consumer. For example the power produced by the wind turbine was able to light the lamp but not to run the motor. This observation was used to explain the idea of load and its effects on the power generation devices.

Solar photovoltaic cell experiments

At this stage, the students started to experiment with solar photovoltaic (PV) cells. They arranged the experimental setup to be able to measure voltage and current of the produced power (Figure 6). The cell was connected to a variable resistance. Using this setup, they manipulated the resistance and measured current and voltage. The recorded data were used to sketch the performance curve of the cell (voltage as a function of current). After they prepared their diagram, they were given an actual performance curve of a solar cell and asked to compare it with their own diagram. Then, it was explained that how the performance of PV cells depends not only on the specifications of the cell, the intensity of the sun light, and the orientation of the cell with respect to the sun but also on the load connected to the cell.

Figure 6: Solar photovoltaic cell experimental setup

As a next step, a solar garden light was demonstrated (Figure 7). Through discussion the students came up with the idea that the light is required during nighttime and there is no sun then so solar energy should be stored somehow. Then, they found the rechargeable battery in the light which led to the discussion on the internal components of the light especially battery. At this point the intermittent nature of renewable energy sources in general and solar energy in particular was introduced. Also, it was explained that how batteries are used to store electrical energy in the form of chemical energy. Finally, during the break, the teams had a racing with their little solar cars (Figure 8).

Figure 7: Solar garden light demonstration

Figure 8: Little solar cars for racing

Solar flash light kit

In this exercise, the students used a one-litter soda bottle to build a solar flash light using inexpensive commercially available kits (cost $35 per unit). In order to avoid any possibility of unsafe situation, the bottle was precut and drill by the instructor. The most important objective of this activity was to further develop teamwork skills through the involvement of all team members on the implementation of the project. After they finished the project, they were asked to take it with them and recharge it at home.

Figure 9: Solar flash light kit

Solar thermal energy

After they had enough knowledge of PV cells, the students were introduced to solar thermal energy. They first used a solar spark lighter (Figure 10) to melt marshmallows and light a match. Next, they used a solar Stirling engine (Figure 11) to realize that solar thermal energy can produce mechanical work. They dropped a few water droplets on the center of the dish and observed that the water was immediately boiled. Also, they explored the concept of the Stirling engine through several other working models (Figure 12).


Figure 10: Solar spark lighter


Figure 11: Solar Stirling engine

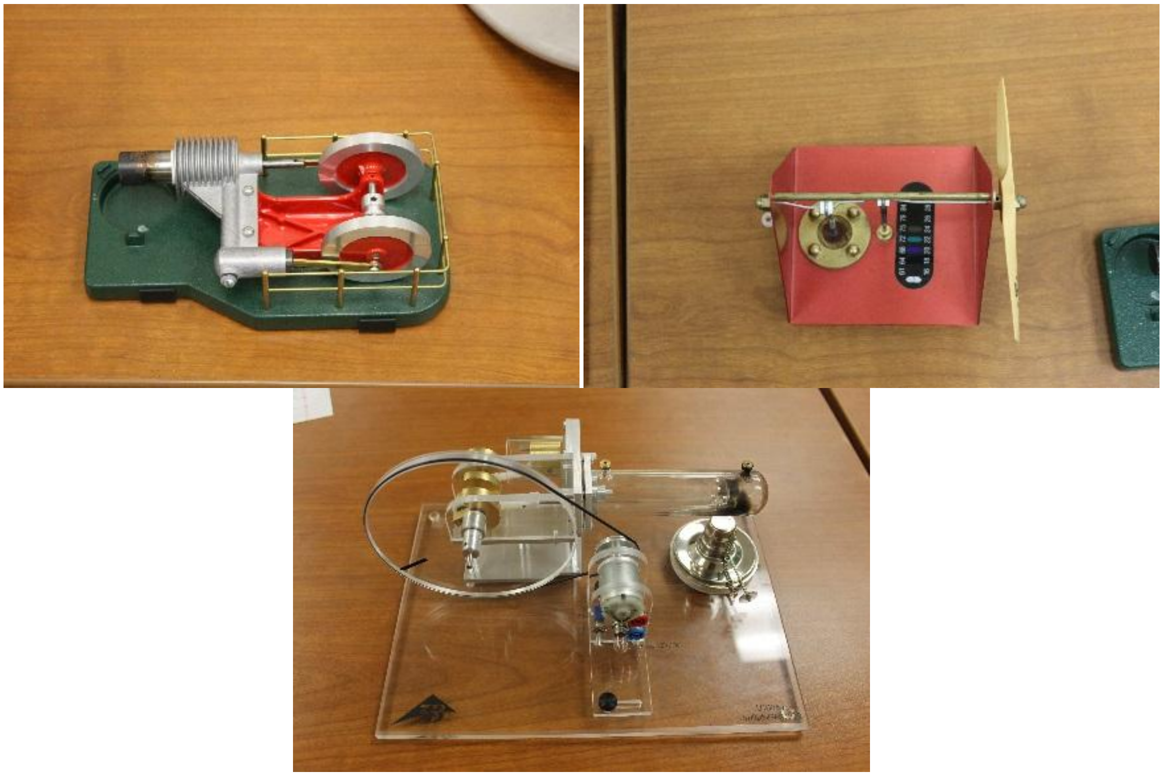

Figure 12: Stirling engine models

Wind turbine

For this experiment, first the students built a pinwheel (Figure 13). When they built and tested their pinwheels, they were congratulated for building their first wind turbines. Then, they compared the performance of their pinwheels with that of the commercially built ones (Figure 13) and observed how their pinwheel's rotational speed was less than that of the commercial ones. At this point, it was explained that building a wind turbine is not a big deal and the fact that the first windmills were built probably 2000 years ago is a proof for this fact. During this discussion, the early windmills in Europe and the US (used as water pumps) were explained. The big deal is how to build an efficient wind turbine to maximize the power production.

Figure 13: Pinwheels made by students compared to commercial ones

Then, it was explained that the maximum efficiency of wind turbines is about 59% (Betz law) without any mathematical formulations. This discussion was continued by testing a low tech small wind turbine (Figure 14). The test verified that the wind turbine cannot operate well with the wind from fan (Figure 14). Then, the more sophisticated wind turbine was introduced (Figure 15). The students could immediately realize that the new model worked much better. Then, they examined the blades of two models and compared them. Their attention was drawn to the profile and cross section of the blades as well as the twist on the blade length. They were asked what the blades resembled to (airplane wings).

Figure 14: Low tech small wind turbine

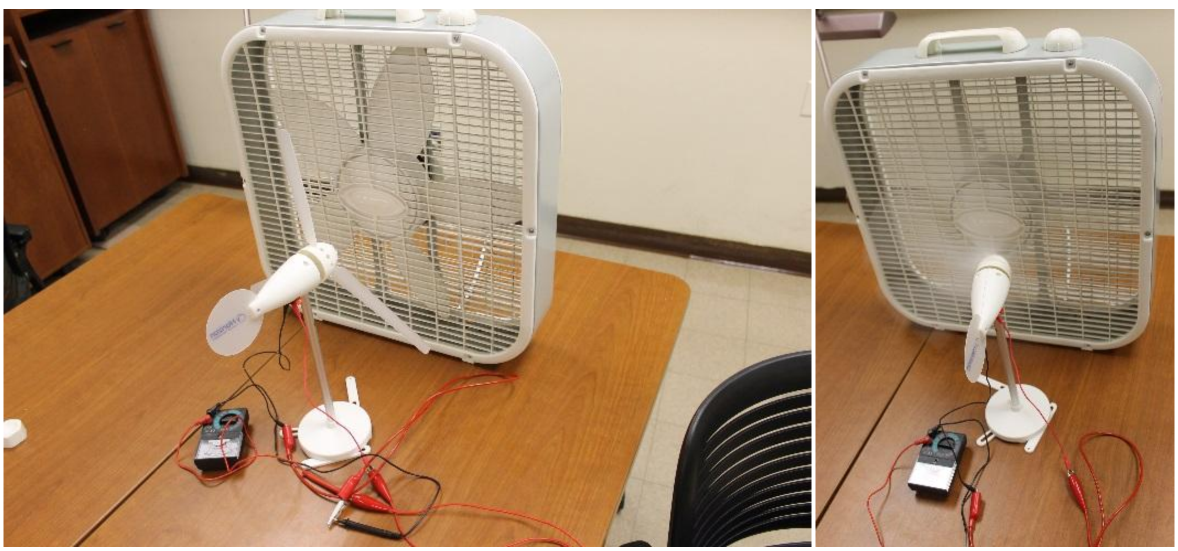

Figure 15: More sophisticated small wind turbine

Then, they started to test the model (Figure 15). The simple experimental setup is shown in Figure 15. They measured the wind speed and used the OCV of the power produced by the turbine as an indication of the performance of the wind turbine.

They tested the performance at various pitch angles of the turbine blades (Figure 16). They realized that at the pitch angle zero the turbine did not rotate. With a little increase in the pitch angle (less than 10°), the turbine rotated at a very high speed but it could not self-start or it took a long time to speed up. Then, they observed that at a high pitch angle, the turbine could start easily but the speed was not as high as the speed at the low pitch angle. Next, the instructor explained that how in early generations of wind turbines, due to the fixed pitch angle, designers had to compromise between these two characteristics of wind turbines but modern turbines have a variable pitch angle. Therefore, they can start at a high pitch angle while being able to operate at a low angle with a high efficiency.

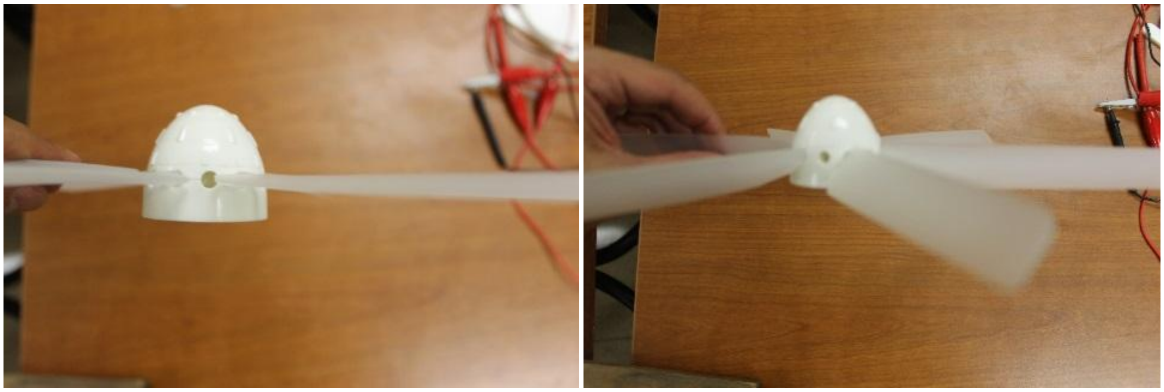

Figure 16: Pitch angles of the turbine blades

Moreover, the students tested the various shapes of blades (Figure 17). Also, they compared the turbines with various blade numbers, 2 to 6 blades (Figure 18), and were able to observe the effects of each variable on the performance of the turbine.

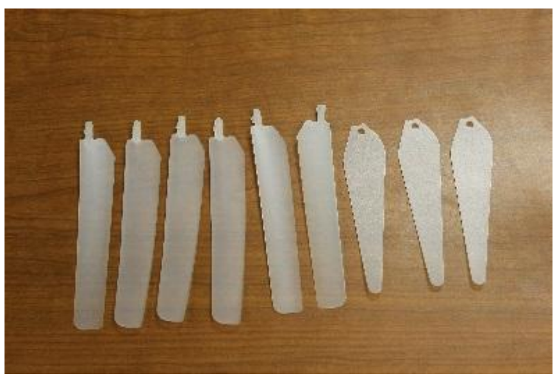

Figure 17: Various turbine blade shapes

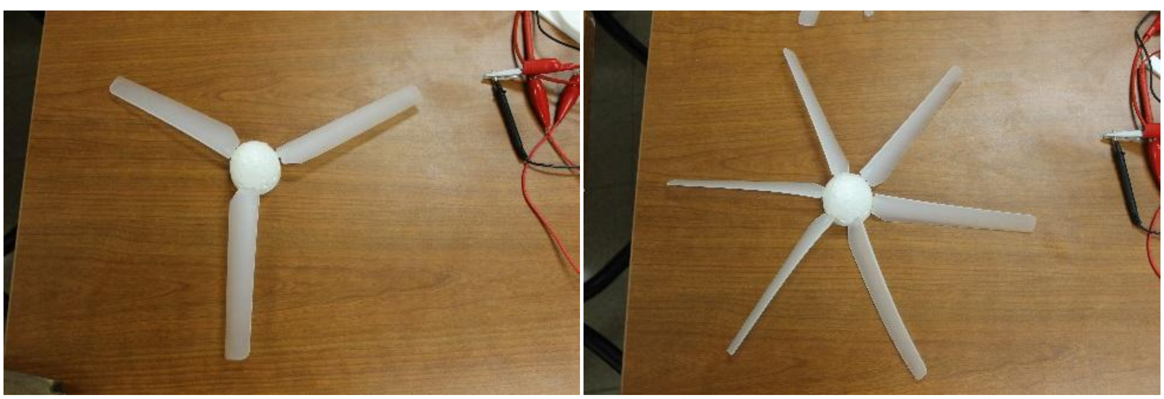

Figure 18: Turbines with various number of blades

As the next activity, the student toured the residential wind turbines (both horizontal and vertical wind turbines), solar PV units, and weather station installed on the roof of the engineering building (Figure 19).

Figure 19: Residential wind turbines (both horizontal and vertical wind turbines), solar PV units, and weather station installed on the roof of the engineering building

Fuel cells

Finally, after a discussion on the energy storage using batteries and flywheels, the students were introduced to the idea of hydrogen economy and how hydrogen can be used as an energy carrier. Then, the students were introduced to the concept of fuel cells and their internal operations and had a chance to observe their operation through several demonstrational units (Figure 20).

Figure 20: Fuel cell demonstrational units

Conclusion

The students' learning was continuously monitored through various quizzes. The comparison of the students' performance in the pre-and post-quizzes was very encouraging and the students showed a significant and meaningful improvement in their understanding of energy-related topics. Some of the questions used in these quizzes are as follows:

1) List as many forms of energy as you can come up with.
2) What are the different sources of renewable energy? List all forms that you are aware of.
3) What is the difference between energy and power?
4) kW.hr is the unit of …............................. .
5) What is the frequency of electricity in the US?
6) What is the voltage of electricity in the US?
7) What is the cost of electricity per unit of energy in your neighborhood?
8) How can you determine if a source of energy is renewable?
9) Explain how wind is generated (very briefly)?
10) A solar cell produces electricity with voltage of 10 Volt and current of 5 Amp. Determine the power output of the cell.
11) Draw a typical diagram of voltage as a function of current for a resistor.
12) List three draw backs of renewable energy sources?
13) Other than solar photovoltaic cells (PVs), how solar energy can be exploited?
14) Wind energy is ….. .
    a. Potential energy
    b. Kinetic energy

15) What is a fuel cell and how does it work?

Furthermore, the students showed a remarkable improvement in their technical writing and oral presentation skills. The students were encouraged to support their observation and conclusion by quantitative results from experiments. One of the problems in the student observations was that in some occasions they provided quantitative results without sufficient evidence. But they were gradually overcame this and other problems and at the end of the program they could observe an experiment, describe it scientifically, and orally present their observation. Also, the students' written feedback indicated that they had enjoyable time in the class and the class setting helped them to both have fun and learn better.

References

[1] National Renewable Energy Laboratory (NREL), "Science Projects in Renewable Energy and Energy Efficiency: A guide for Secondary School Teachers", http://www.nrel.gov/education /pdfs/educational_resources/high_school/re_ee_projects.pdf

[2] National Renewable Energy Laboratory (NREL), "Research Projects in Renewable Energy for High School Students", http://energy.gov/sites/prod/files/2014/06/f16/highschool_ projects.pdf

[3] Illinois Valley Community College, "Renewable Energy Projects for the Classroom", http://www2.ivcc.edu/mimic/nsf/Resources%20for%20Teachers/Renewable%20Energy%20Projects%20-%20Handbook.pdf

[4] The Union of Concerned Scientists, "Renewables Are Ready: A Guide to Teaching Renewable Energy in Junior and Senior High School Classrooms", http://www.ucsusa.org /sites/default/files/legacy/assets/documents/clean_energy/renewablesready_fullreport.pdf

[5] http://www.builditsolar.com/Projects/Educational/educational.htm

[6] http://www.cleanlineenergy.com/learn/teachers/renewable-energy