Integrating Laboratory Activity Into a Junior High School Classroom

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***Abstract*—This paper presents a wind power system laboratory activity and an outline for evaluating student performance in this activity. The work described here was to design and implement the laboratory to assist teachers in achieving the teaching objective of this activity. The laboratory teaching activities introduce energy sources, wind energy technology, electricity storage, and wind power system testing. The wind power system testing activity includes eight topics: setting up the experimental module, operating instruments, wind velocity measurement, rotor diameter activity, wind speed activity, blade angle activity, blade number activity, and data summary. These laboratory activities were first introduced in a Taiwanese junior high school in 2007. This laboratory activity effectively introduced students to wind energy technology through activity participation. The objective of this activity is for the students to gain not only an understanding of the concept of wind power electricity generation, but a greater confidence in investigating, questioning, and experimenting with renewable energy ideas. The students are able to relate the experiments to electronic and computer engineering.**

***Index Terms*—Experimental module, junior high school, laboratory activity, renewable energy, wind power system.**

I. Introduction

RESEARCH shows that traditional classroom lectures are not the best teaching approach [1]. Traditional lectures encourage passive learning, often creating a mismatch between the way teachers teach and the way students learn. Educators are constantly seeking new ways to actively engage students. Actively involving students leads to deeper questioning, improved attendance, and more lasting interest in the subject compared to lecturing alone [2], [3]. Hands-on activities and demonstrations have been developed and documented for teaching students. Researchers have also proposed methods for creating hands-on learning in the classroom that help shift the focus from the teacher to the student [4]. Some laboratories use technology and hands-on manipulative tools to discover concepts and theorems [5]. Laboratory instruction helps students develop their experimental skills and ability to work in teams, learn to communicate effectively, learn from failure, and be responsible for their own results [6]. The availability of different activities tends to make the study of technology more popular at secondary school. Diong *et al.* [7] suggested that students learn and retain much more of what they experience directly or practice doing, as opposed to what they only hear or see. In an example of hands-on learning, Tan *et al.* [8] presented a student experiment on the development of distributed control systems. This paper describes the hardware and software design considerations that allow the student users to access the sensors and to be able to activate actuators linked on the distributed control system, remotely and effectively, using a commonly available Web browser.

Renewable energy is an ideal topic for middle and high school classrooms. Teachers can use a unit on renewable energy to teach the basic scientific principles of converting energy from one form to another, or of generating electricity. Teachers can incorporate laboratory activities on renewable energy into a unit on the environmental impact of energy use [9]. Traditionally, the renewable energy laboratory activity has not been part of the K-12 curriculum. Thus, it is not surprising that most teachers lack a firm understanding of wind power practices, uses, and concepts. Few teachers learned about wind power laboratory activity while in school. Therefore, a teacher feeling comfortable integrating it into their class will generally require that they engage in teacher professional development that focuses on wind power concepts and pedagogical strategies to teach this discipline [10].

In the future, when much of the electricity used at home and in the workplace is expected to be generated by solar, wind, biomass, and geothermal power, an understanding of renewable energy is expected to be a requirement for scientific literacy. Renewable energy is an important and economical energy source for electricity generation. Major sources of renewable energy include hydro, biomass, geothermal, solar, and wind energies. Given the rapid growth in renewable energy for electricity generation and the need to keep students abreast of current engineering developments and trends, developing an instructional course in renewable energy is both necessary and timely [11]. A wind power system transforms the kinetic or moving energy of the wind into mechanical or electrical energy that can be harnessed for practical use. Harnessing wind for electricity generation is the most common use of wind energy today. Wind turbines generate electricity for homes and businesses and for sale to utilities.

What teaching there has been of how wind power generates electricity has been somewhat haphazard. Therefore, the curriculum needs an innovative pedagogy that develops and reinforces learning in this area. Schools have started new approaches

Manuscript received December 25, 2008; revised April 11, 2009. First published August 07, 2009; current version published February 03, 2010. This work was supported by the National Science Council of the Republic of China, Taiwan, under Contract No. NSC 96-2515-S-018-005.

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Digital Object Identifier 10.1109/TE.2009.2022547

to enhance student learning in science [12], [13]. Most often, experiments on wind power systems are absent, or sporadic. This is reasonable, considering time and resource restrictions, but the result is that few students underestimate wind power concepts. As a consequence, the activity described here allows teachers to engage students in wind power experiments to counteract this gap.

Educational experiments are designed not only to expose the students to newer technology, but also to test their synthesis and comprehension skills on the material covered in previous lectures [14]. Not only is this an important first step in promoting renewable energy technologies, but renewable energy is an ideal topic for the science classroom. Laboratory activities can help students understand renewable energy technologies. Teachers are often expected to design instructional activities that integrate theoretical knowledge and promote creative thinking [15]. Studies have shown that constructivist learners tend to explore the concepts involved in laboratory activities, deeply resulting in a richer understanding [16]. In developing the experimental module for this student laboratory activity, the first goal was to capture and maintain the attention and interest of the student. To make the content attractive, this effort paid a lot of attention to constructing clear and straightforward ways to introduce teaching concepts. The philosophy of education gains its roots from Piaget's constructivism, which describes a learner as actively constructing knowledge instead of simply receiving knowledge transmitted from the teacher to student. Hands-on learning environments are beneficial to student attitudes and learning [17].

In 2006, the author developed several laboratory activities that provide convenient and flexible methods for teaching students in Taiwan about photovoltaic systems [18]. The key areas explored in these laboratory activities were: experimental setup, operating instruments, constructing photovoltaic cells, measuring irradiance, measuring light, measuring temperature change, and data summary.

This paper describes a similar set of several laboratory activities that provide a convenient and flexible way for junior high school students in Taiwan to learn about wind power systems. The key steps in these laboratory activities involve setting up the experimental module, operating instruments, measuring wind velocity, a rotor diameter experiment, measurement of wind speed, a blade angle experiment, a blade number experiment, and data summary. An instruction Web site and teaching materials also complement the syllabus. The wind power system contains ideas for practical activities as well as wind turbine lectures, which gradually build a process that gives students the opportunity to experiment with the module. The module makes it possible to record the voltage generated by a real wind turbine at different wind velocities, rotor diameters, wind speeds, blade angles, and blade numbers.

This paper begins by addressing the concept of wind power as appropriate for junior high school students. It then defines a set of wind power system experiments that include the necessary laboratory activities. It is worth noting that a laboratory must serve many students. Therefore, this paper also focuses on the organization and syllabus of the activity and on resource allocation. It then details a variety of activities that broaden junior high school students' knowledge of wind power systems. Finally, the laboratory activity is described, showing how it makes the module easy to use and fun. It helps students gain not only an understanding of wind power electricity generated, but gives them a greater confidence in investigating, questioning, and experimenting with renewable energy ideas, particularly for electronics and computer engineering students. These outreach activities help students gain an overview of wind power systems.

The current work also presents students with a development and validation process for technology design. As well as the laboratory activities instructing students in important wind power principles [19], this process helps students to accelerate the rate at which they perform the laboratory experiments so that they can complete them within a set time. By minimizing the time spent familiarizing students with laboratory equipment and basic principles, students can complete the actual laboratory activity in the shortest possible time.

II. Energy Sources

Students are first given an introduction to the different types of energy sources, which covers the following basic information. At least 12 major energy sources are currently in use throughout the world today: wind, solar, hydropower, geothermal, biomass, hydrogen, ocean wave, petroleum, natural gas, coal, uranium, and propane. Energy sources are classified as renewable and nonrenewable. Renewable energy sources can be replenished within a short period of time, while nonrenewable sources may take millions of years to form, and their supplies are limited. The 12 energy sources can be classified into two categories [20]: 1) Renewable Energy—wind, solar, hydropower, geothermal, biomass, hydrogen and ocean wave; and 2) Nonrenewable Energy—petroleum, natural gas, uranium, coal and propane.

All energy sources have environmental, economic, and societal costs. Advocates, governments, and bureaucracies place differing emphases on the relative importance of these factors. The availability and cost of energy are determining factors in the economic health and growth of societies. The sooner clean, nonpolluting renewable energy provides a significant proportion of energy needs, the sooner all can benefit from cleaner air and a stable climate.

III. Wind Energy Technology

While many rural areas still use traditional windmills for pumping water, modern wind turbines consist of two major categories: horizontal axis turbines and vertical axis turbines.

The horizontal axis turbine is the most common turbine configuration used today. This turbine consists of a tall tower with a fanlike rotor on top that faces into or away from the wind. Most horizontal axis turbines built today have two or three blades, although some have more.

Vertical axis wind turbines are usually either Savonius or Darrieus [21]. However, neither turbine type is widely used today. The basic theoretical advantages of a vertical axis machine are that the generator and gearbox can sit on the ground and do not require a tower. Furthermore, unlike a horizontal axis machine, the vertical axis turbine does not require a mechanism

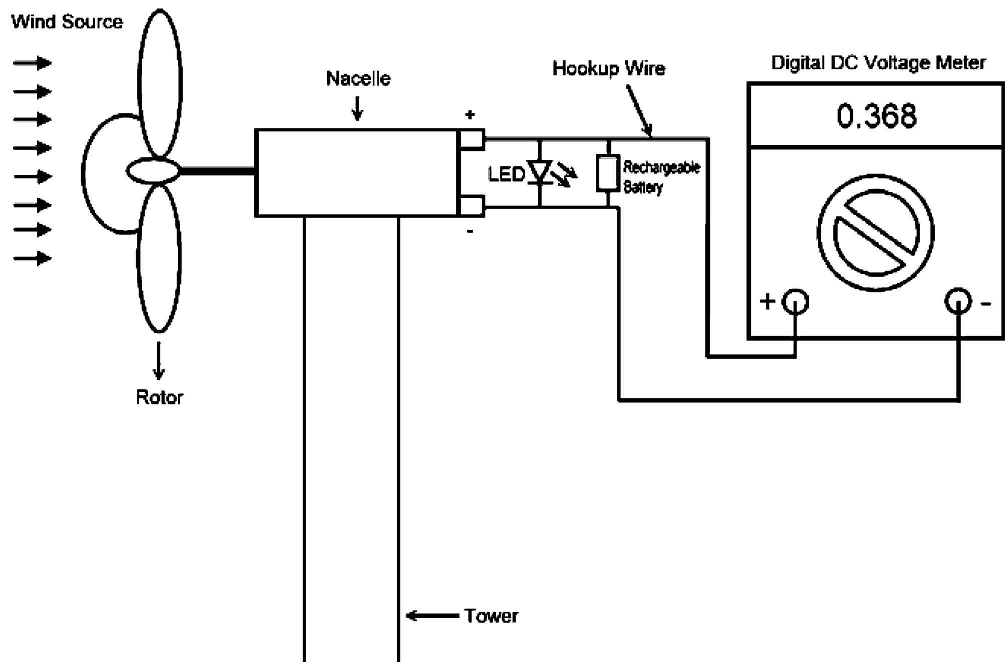

Fig. 1. The wind-powered generator circuit.

for turning the blades into the wind. The disadvantages of vertical axis wind turbines far outweigh their advantages. First, overall power-generating efficiency is not very impressive because wind speeds close to the ground are much lower. Furthermore, self-starting the system is not possible, and the network of guy wires needed to secure the apparatus may occupy valuable farmland normally used for grazing or planting. Finally, main bearings or other parts needing maintenance require dismantling the entire machine.

This laboratory activity uses a horizontal axis turbine for the experimental module.

IV. Electricity Storage

Wind power has driven machinery for a long time. Wind-powered turbines have recently appeared in growing numbers as an environmentally friendly alternative to fossil fuels such as oil and gas. The wind-powered turbine in this activity is identical to a full-sized one. As the wind blows through the rotor blades, it causes the shaft to turn. Gear wheels connect the shaft to a generator, which produces electricity. Attached to the generator are a light-emitting diode (LED) and digital dc voltmeter. Fig. 1 shows the connected circuit. The turbine works when tested using a wind source. If the turbine faces the wind, the rotor should begin to turn. The LED lights up when the rotor is turning in one direction, but not when it turns in the other direction.

V. Laboratory Activity—Wind Power System Testing

The learning goals for the course are that, at its conclusion, a student should be able to:

- highlight the difference between renewable and nonrenewable energy sources;
- identify and distinguish between different forms of renewable energy;
- identify a wide variety of applications for renewable energy;
- explain the basic principles behind wind power turbines and electricity generation;
- explain how to operate an anemometer and a digital dc voltmeter;
- illustrate how the environmental effects of wind affect electricity generation;
- show an understanding of how wind power systems can produce different voltages.

The purpose of this activity is for students to construct a wind power system and operate two kinds of instruments. The defined activities are at an appropriate level for junior high school students in Taiwan. A panel of experts, including experienced researchers, university professors, and experienced engineers, evaluated these activities; they concluded that the teaching materials and experimental equipment were suitable for students.

These laboratory activities took place in the Erh-Shui Junior High School in Changhua County in Taiwan. Thirty-two students (14 female and 18 male; average 15 years old) participated in the natural and live technology course for 1 h a week over a period of 6 weeks.

1) Topic 1—Setting Up the Experimental Module: Before launching into the laboratory activities, students must first understand the setup for each experiment. They are therefore provided with a write-up that describes this setup and indicates how they should carry out the experiment. This experimental module combines an electric fan that provides a simulated wind source, a wind turbine, a digital dcvoltmeter, and an anemometer to create a wind power system. Fig. 2 shows the wind power experimental module.

Fig. 2. The wind power experimental module.

TABLE I
INFLUENCE OF DIFFERENT WIND SOURCE DISTANCES—AN EXAMPLE OF THE TABLE COMPLETED BY STUDENTS

Wind source distance (cm)	Voltage
10	3.87
15	3.37
20	2.98

*note: at wind speed 5m/s

TABLE II
INFLUENCE OF DIFFERENT ROTOR DIAMETERS—AN EXAMPLE OF THE TABLE COMPLETED BY STUDENTS

Rotor diameter(cm)	Voltage
5	1.88
10	2.36
20	2.98

*note: wind source distance 20cm

TABLE III
INFLUENCE OF DIFFERENT WIND SPEEDS—AN EXAMPLE OF THE TABLE COMPLETED BY STUDENTS

Wind speed (m/s)	Voltage
3	1.12
5	2.98
8	5.11

*note: at wind source distance 20cm

2) Topic 2—Operating Instruments: The experimental module uses an anemometer and a digital voltmeter. The students are given very clear, step-by-step instructions on how to operate these, as follows.

1. **Anemometer operating procedure:**
   1) Turn the meter ON (1) or OFF (0) with the POWER key.
   2) Select the measurement range for wind flow: m/s, km/h, ft/min or mile/h.
   3) Quickly and accurately read the anemometer measurement on the LCD.
2. **Digital dc voltmeter operating procedure:**
   1) Insert the black probe into the black "Ground" jack and the red probe into the red jack.
   2) Always start in the highest range of the function being measured before changing to a lower range. Note that these selection range areas are red. Be sure to match the red test probe jack to the red input and the black jack to the black input.
   3) Apply the test probes to the two points at which the voltage reading is to be taken. Be careful not to touch any energized conductors with any parts of the body.
   4) Turn the dial to the next lower range for a more accurate reading only if the reading is within that range.
   5) When measurements are completed, disconnect the test probes from the circuit under test.

3) Topic 3—Wind Source Distance Activity: By decreasing the wind source distance from the fan, the blade tip speed increases. The students are told to hold the wind turbine at distances of 10, 15, and 20 cm from the directional wind source and to record the voltage generated for all distances from the wind source in a table such as Table I.

4) Topic 4—Rotor Diameter Activity: Wind turbine rotors have increased in size over the years because a bigger rotor can sweep a larger area, harvesting more energy from air molecules. The more air molecules, the more energy is delivered to the turbine. The energy available to the wind turbine is proportional to the swept area of the rotor. Students are told to hold the wind power turbine at distance of 5, 10, and 20 cm from a directional wind source, with the turbine directly facing the wind source. They are then instructed to record the voltage generated for all three diameters from the wind source in a table such as Table II.

5) Topic 5—Wind Speed Activity: The students are then told to hold the fan in a fixed position relative to the rotors, to investigate what happens when the fan is adjusted for different wind speeds, and to the voltage generated for all wind speeds tested in Table III.

6) Topic 6—Blade Angle Activity: In this section of the practical work, students compare the blade angles and the voltage generated. They first tilt the blades so that they are perpendicular to the end of the cork, then place the wind source in front of a working fan. If the propeller does not spin, they are instructed to rotate the blades until they are at a slight angle. They then place the propeller in front of the fan and continue tilting the blades in small increments until the propeller starts spinning. When this happens, the students measure the voltage produced. They continue tilting the blades of the propeller to determine which angle produces the greatest voltage. They record the voltage generated at 15° intervals in a table such as Table IV.

7) Topic 7—Blade Number Activity: Generally, wind turbines are driven by three blades. Students are asked to consider what happens if more or fewer blades are used. How does the number of blades affect the efficiency of the turbine? Using the same fan setting, students investigate if the turbines can be

TABLE IV
INFLUENCE OF DIFFERENT BLADE TILT ANGLES—AN EXAMPLE OF THE TABLE COMPLETED BY STUDENTS

Tilt angle	Voltage
15-degree	5.34
30-degree	4.62
45-degree	2.65
60-degree	1.66

*note: at wind source distance 20cm

TABLE V
INFLUENCE OF DIFFERENT BLADE NUMBERS—AN EXAMPLE OF THE TABLE COMPLETED BY STUDENTS

Blade number	Voltage
two	2.78
three	2.87
five	2.98

*note: at wind source distance 20cm

moved as far away from two blades as they were from three blades. What if five blades are used? They record the voltage generated for all blade number changes in a table such as Table V.

8) Topic 8—Data Summary: After completing these experiments, students summarize their data by answering the following questions.

1) List as many energy sources as you can think of.
2) Energy sources can be categorized as renewable and nonrenewable. How do these two energy sources differ?
3) What distance from the wind source is most efficient for generating electricity?
4) What rotor diameter generates the most electricity?
5) What wind speed generates the most electricity?
6) What blade angle generates the most electricity?
7) What blade number generates the most electricity?

VI. DATA COLLECTION AND DISCUSSION

A. Method

The experimental method followed provides some basic scientific information to students as they perform their experiments. Additionally, their active participation in the experiments improves their scientific skills (both practical and intellectual), increases their observational abilities, and helps ensure that information retention is permanent.

B. Questionnaires

In order to evaluate the success of this program in imparting knowledge about wind power generation, students were surveyed both before and after the course. The pre- and post-course questionnaires were prepared and reviewed by 10 education experts and underwent several cycles of review and modification. The questions assessed the students' level of knowledge on the laboratory activities topics: 1) List as many renewable energy sources as you can. 2) List as many nonrenewable energy sources as you can. 3) Could you identify two kinds of wind power turbines? 4) Could you operate an anemometer? 5) Could you operate a digital dc voltmeter? 6) What is the distance from the wind source efficient? 7) What is the most efficient rotor diameter? 8) What is the most efficient wind speed for generating electricity? 9) What is the most efficient wind turbine blade angle? 10) What is the most efficient number of wind turbine blades?

TABLE VI
t-TEST RESULTS OF THE EXPERIMENTAL AND CONTROL GROUPS ACCORDING TO THEIR PRETEST SCORES

Group	N	M	SD	df	t
Control	16	5.69	0.60	30	0.53
Experimental	16	5.56	0.73		

* $p < 0.05$

C. Sampling

This study utilizes a quasi-experimental, nonequivalent control group design that is a suitable alternative to an experimental design when randomization is not possible. The nonequivalent control group design can be utilized as a nonequivalent comparison group design involving two treatments. Since the subjects in this design were not randomly assigned, entire classes of students were randomly assigned to either the experimental group or the control group. Both groups took a pretest and a post-test. This study sampled 32 students from the intact class at the Erh-Shui Junior High School in Changhua County in Taiwan. Each group contained 16 students. The control group was taught using only traditional oral lectures. The experimental group participated in the laboratory activities. Both groups spent the same amount of time in the classroom. This study assumes that the average time spent studying outside the classroom is the same in both groups.

D. Data Analysis

A pretest and post-test survey was distributed to both the control group and the experimental group in the classroom before the course started, and then again at the end of the course. Students had unlimited time in which to reply. SPSS software was used to analyze the research data. The significance level was set to 0.05 for all statistical analyses. A Likert-type scaled tracked responses, ranging from 0 to 10, with higher numbers indicating higher levels of interest or importance. A pretest was executed to equalize the experimental and control groups. Table VI indicates both the mean M and the standard deviation SD of the student pretest responses, according to which the experimental and control groups exhibited no significant differences ($t = 0.53$, $p > 0.05$). These results confirm that the experimental and control groups were identical.

E. Results

To determine if there was a significant difference between the post-test score averages of the experimental and control groups, an independent t-test at the 0.05 significance level was performed. Table VII presents these test results. A close examination of Table VII reveals that the experimental group produced post-test score averages that differ significantly from those of the control group. The experimental group obtained a higher mark average than the control group, indicating that the proposed design increases the academic success of students. The results of this test exhibit significant statistical difference between

TABLE VII
t-TEST RESULTS OF THE EXPERIMENTAL AND CONTROL GROUPS ACCORDING TO THEIR POST-TEST SCORES

Group	N	M	SD	df	t
Control	16	7.88	0.62	30	4.13*
Experimental	16	8.75	0.58		

* $p<0.05$

the groups ($t = 4.13$, $p < 0.05$). This significant difference between the post-test scores of the experimental and control group students might well have been expected, since the experimental group had a better grasp of wind power concepts as a result of their laboratory activities.

The findings of this work can be summarized as follows: 1) Both groups had very similar pretest results. 2) The posttest results demonstrate that the laboratory activities were of great value to the experimental group. 3) The students in the experimental group were more successful than the control group students. Further analysis of the results demonstrates that laboratory activities significantly enhance learning.

VII. CONCLUSION

This paper describes a laboratory activity for teaching wind power concepts to junior high school students. The students can carry out the laboratory activity during class to learn the concepts, practicalities, and uses of wind power. Assessment results indicate that the proposed laboratory activity is successful in meeting these goals.

Given the advances in wind power system conversion technologies and the continued growth in renewable energy and its impact on electrical power systems, it is important and timely to develop wind power system laboratory activities. The students in this research were generally excited about and receptive to these activities. Students participating in these laboratory activities found them extremely informative and enjoyable.

This entire laboratory activity only required one simple inexpensive setup. At the end of the activity, students had: 1) a firm understanding of the wind power concept, from both a theoretical and a practical standpoint; 2) knowledge of major renewable energies, their potentialities, and possible pitfalls; 3) the ability to perform laboratory experiments and record data generated by a real wind turbine; and 4) an understanding of the renewable energy concept.

The work described here was the first offering of these activities, and future improvements are planned, which may include additional problem exercises and laboratory sessions using computer simulation models. The latter is particularly important since simulation enhances understanding of the fundamental concepts presented in the classroom. Teachers considering offering lessons in renewable energy can use these materials as a starting point.

The experimental activities described are an example of one of the directions in which students might need to adapt. The introduction to some renewable energy concepts and technology can provide students of electrical engineering (EE) and computer science (CS) with the knowledge of future technical directions.

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