Promoting STEM to Young Students by Renewable Energy Applications

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Abstract

The Math-Science-Engineering Technology in Iowa on Applied Renewable Energy Areas (MSETI - AREA) projects are aimed at providing area school teachers with an applied mathematics and science curriculum package based on photovoltaic (PV) power, wind power, human power, and hydrogen fuel-cell fundamentals. The MSETI – AREA project has established a partnership between the University of Northern Iowa (UNI) and selected area high schools and middle schools for the improvement of students' mathematical and scientific skill sets. Through this project, students improve their technological literacy by creating an environment in which they understand and figure out relationships among basic mathematics, science, and engineering technology that are applied to renewable energy fields. In order to mentor and manage the learning environment effectively, students are given a professional skill set for successfully applying mathematics and science to technical projects with diverse teams throughout their careers. The use of a number of renewable energy and energy efficiency based hands-on projects is also used to promote mathematics and science for middle school teachers and students.

Introduction

The USA has failed to capture youth's interest in scientific and mathematical ideas. As John Glenn (2000) announced, worst of all, we are not challenging their imaginations deeply enough. According to the National Science Board's (NSB) *Science and Engineering Indicators*, enrollment in undergraduate engineering and science programs in the United States has declined since the 1980s (Glenn Commission, 2000). Clearly, there is a continued need for increased enrollment and retention in the fields of science and engineering. Science, Technology, Engineering, and Mathematics (STEM) have become increasingly central to economic competitiveness and growth in the United States.

Recently, the NSB presented an action plan to address pressing issues in US STEM education (National Action Plan, 2007). In this action plan, the Board identified priority actions that should be taken by all stakeholders who are working together cooperatively to achieve measurable improvements in the Nation's STEM education system. The Board concluded that the Nation is failing to meet the STEM education needs of US students, which has serious implications for a scientific and engineering workforce in the 21st century. The Board believed that addressing this issue is absolutely essential for the continued economic success of the United States and its national security. According to the Board report, all American citizens must have the basic scientific, technological, and mathematical knowledge to make informed personal choices, to be educated voters, and to thrive in the increasingly technological global marketplace. As a final action, the NSB recommended actions that ensure students are taught by well-prepared and highly effective STEM teachers. These recommendations include strategies for increasing the number of such teachers and improving the quality of their preparation by (a) developing strategies for compensating STEM teachers at market rates, (b) providing resources for the preparation of future STEM teachers, (c) increasing STEM teacher mobility between districts by creating national STEM teacher certification standards, and (d) preparing STEM teachers to teach STEM content effectively (National Action Plan, 2007).

Due to the clear need for the engineering and science workforce in the near future, considerable numbers of educators at colleges have taken on creative recruitment and promoting activities to help increase student enrollment in STEM fields. Recruitment efforts for engineering and science fields are definitely not restricted to the near past. Bozynski and McCowen (1995) describe a student initiated summer recruitment camp for engineering called Science Quest aimed at elementary school children in Kingston, Canada, through Queen's College, which started in 1988. Each student carried out two projects every day for one week, in addition to one group project that lasted one week. The individual projects ranged from casting to design related projects, with hands-on experiences. The authors explain the expansion of this summer program due to its success. More recently, Tester et al. (2004) describe a Design4Practice (D4P) curriculum enhancement implementation to increase recruitment and retention of students in engineering fields. Their study was aimed at identifying best practices in recruitment and retention of students in engineering fields that could be applied to their curriculum through the Multicultural Engineering Program (MEP). The authors note that "service learning" can be applied in the education protocol. With strong service-related activities, not only can the college students tackle environmental issues, such as renewable energy, but the practice can also be expanded to high school students. Gleason et al. (2010) describe an Engineering Math Advancement Program (E-MAP) that is aimed to help students with calculus in preparation for engineering; the program, in addition, offers "living-Lab" hands-on exercises, field trips, and a service-oriented project that gets the students involved in the community. The authors report that the retention of students increased by 12% in three years after the implementation of the E-MAP. Henry et al. (2004) describe the creation of student learning communities as a recruitment tool. Finally, a study performed at the University of Illinois at Urbana-Champaign (Johnson, DeStefano, & Mustari, 2010) revealed through student surveys that some of the factors that would assist with student recruitment and retention include providing more connections to the engineering workforce, providing more orientation for incoming students, increasing the quality of instruction, improving the process of selecting teaching assistants, and improving the engineering curriculum.

Recently, as part of the recruitment efforts, a summer workshop was designed and implemented to train local area high school teachers, prepare them for research, and educate them about careers in engineering, engineering technology and the nuclear power industry. Texas A&M Corpus Chris Campus, Engineering Technology faculty took the initiative to train teachers in this summer camp (Karayaka, Mehrubeoglu, Yildiz, & Caruso, 2011). An outreach effort was organized to advertise and promote the workshop to local area public and private high and junior high schools. After a considerable effort of visits and networking, a total of twenty teachers with a variety of science, math, and technology specialties participated in this week-long program held in July of 2010. Moreover, a group of Industrial Technology program faculty at Sam Houston State University offered six workshops to promote STEM subjects through hands-on renewable energy activities both on campus and at off campus locations. Workshop instructors developed curricula and summarized equipment and tools needed for their classes for the promotion of STEM subjects (Yildiz, Kingman, Coogler, & Karayaka, 2011).

The MSETI - AREA (Math-Science-Engineering Technology in Iowa on Applied Renewable Energy Areas) project utilizes undergraduate senior design projects, such as the energy bike ("e-Bike,=") that were introduced through a series of after-school visits and weekend professional development workshops during the fall of 2008. Teachers who have completed these workshops are now implementing the conventional and renewable energy concepts in their classrooms by having students learn about the e-Bike, PV solar cells, and model wind generators. This learning creates an environment in which young students become familiar with relationships among basic mathematics, science, and engineering technology that are applied to renewable energy fields. The overall goal of this project is to work with teachers to develop a curriculum based on exciting applied research. The e-Bike project also introduced teachers and students to the meaning of energy efficiency and energy conservation; they learned this by generating their own electricity by using pedal power and by energizing a number of loads, such as inefficient incandescent light bulbs, small appliances, and energy efficient compact fluorescent light (CFL) bulbs, where they observed light density, heat release, and overall energy usage in kWh. Students also calculated the cost of overall electricity they use and discussed monthly average charges to educate both themselves and their parents about energy cost and efficiency. The UNI e-Bike has been used in this MSETI – AREA project extensively, and it is a fun, hands-on learning tool that appeals to young people and engages them in conversations about the environmental and economic benefits of energy efficiency and the use of energy-efficient products. The e-Bike system includes a number of loads, such as incandescent and compact florescent light bulbs that can easily be switched on and off by students while they ride the bike. It also offers an opportunity to emphasize a link between saving energy and making informed energy choices. Two weekend workshops were held during the fall semester of the 2008 academic year. Teachers who completed the workshop were to implement the energy concepts in their classrooms with the e-Bike during the spring semester 2009, thus creating an environment where their students can figure out relationships among basic mathematics, science, and engineering technology as applied to renewable energy fields.

Problem Definition

The NSB supports partnerships between universities and local schools to increase the mathematics and science abilities of high school graduates. In his foreword to the national report *Before It's Too Late*, John Glenn summarized the state of mathematics and science education across the country when he stated that:

> We are failing to capture the interest of our youth for scientific and mathematical ideas. We are not instructing them to the level of competence they will need to live their lives and work at their jobs productively. Perhaps worst of all, we are not challenging their imaginations deeply enough (Glenn Commission, 2000).

In addition to the Glenn Commission, other researchers believe that part of the underlying problem of STEM education is the lack of a clear definition of what the implementation of STEM education should accomplish. According to Lantz (2009a), there have been attempts to define the desired results of STEM education, including the four recommendations outlined by the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine, but still little to no consensus exists. These four recommendations begin to define the function of STEM education and they do little to describe what it should look like (form) in the classroom. Morrison (2006) outlined several functions of STEM education as suggestions that students should be (a) problem-solvers, (b) innovators, (c) inventors, (d) self-reliant, (e) logical thinkers, and (f) technologically literate. Lantz (2009b) also identified the meaning of "T and E" in STEM education in the United States. According to Lantz's statement, one of the misconceptions was that STEM education consists only of the two bookends: science and mathematics. It is important to learn and apply how "T and E" fit into the transdisciplinary nature of STEM education. The engineering part of STEM education relates to emphasis on the process and design of solutions, not simply on solutions themselves. The technology part allows for a deeper understanding of the three other parts (S, E, and M) of the STEM education.

STEM education has become increasingly central to U.S. economic competitiveness and growth. Long-term strategies to maintain and increase living standards and promote opportunity will require unprecedented coordinated efforts among public, private, and nonprofit entities to promote innovation and to prepare an adequate supply of qualified STEM workers who are capable of translating knowledge and skills into new processes, products, and services (Dugger & Gilberti, 2002; Tims, Turner, & Schillinger, 2008; Science and Engineering Indicators, 2006; Teach Engineering, 2007; U.S. Department of Education, 2007).

Objectives of the Study

Upon completion of the workshops, participants should be able to:

- Familiarize themselves with the basic operation of renewable energy sources and energy conversion principles
- Learn how to locate renewable energy teaching materials from authentic resources
- Understand relationships among basic STEM components as applied to renewable energy fields
- Learn to develop a curriculum to promote STEM through renewable energy among young students
- Learn to successfully demonstrate fundamental concepts of renewable energy by hands-on activities
- Link the hands-on energy concepts to the appropriate mathematical equations.

Project Description

This MSETI-AREA project was sponsored by the Iowa Math and Science Education Partnership (IMSEP); it established a partnership on Math-Science-Engineering Technology in Iowa on Applied Renewable Energy Areas between the UNI College of Natural Sciences and Cedar Falls-Waterloo area community schools, specifically UNI Price Lab School and Waterloo West and East High Schools. Engineering technology is the profession in which knowledge of mathematics and natural sciences gained by higher education, experience, and practice is devoted primarily to the implementation and extension of existing technology for the benefit of humanity (Engineering Technology, 2010). Renewable energy applications, such as wind, solar, and hydrogen fuel-cell theory and applications are covered in this curriculum. The immediate goals of the MSETI-AREA included development of partnerships with area middle schools and junior high schools to improve students' mathematical and scientific skills as well as their technological literacy by creating an environment in which they must understand relationships among basic mathematics, science, and engineering technology as applied to renewable energy fields. This is done in order to mentor and manage students effectively, and to give them a professional skill set for successfully applying mathematics and science to technical projects via diverse teams throughout their careers. A secondary goal was to use a number of renewable energy based hands-on projects to promote mathematics and science for middle school teachers and students.

Study of PV-Solar Power, Wind Power, and Wind Speed through Basic Mathematical Equations and an Actual Solar-Wind Hybrid Power System testbed at UNI

Renewable energy sources are quickly becoming a topic of much discussion. Many young students have probably heard the terms *solar* and *wind power*, and they may already have some idea of what they are. Wind energy has become the least expensive renewable energy technology and it has gained the interest of scientists and educators the world over. Specifically in Iowa, students may have seen wind energy in action as many wind turbines are present within 50 miles from the cities of Cedar Falls and Waterloo. Utilizing a mast-mounted anemometer (wind meter) and a simple relationship (as shown in the following equation) that relates the power generated by a wind turbine and the wind parameters will allow the students to directly measure wind speed and to vividly relate this easily felt force of nature to electrical measurements.

$$P = 0.5\rho A\, C_p v^3 \eta g\ \eta b = kv^3$$

where,

P = electricity generated in Watts (W)

v = wind speed in m/s

k = an engineering coefficient representing the following:

ρ = air density (about 1.225 kg/m3 at sea level, less higher up)

A = rotor swept area, exposed to the wind (m^2)

Cp = Coefficient of performance (.59 to .35 depending on turbine)

η_g = generator efficiency and η_b = gearbox/bearings efficiency

The equation shows how students use a simple mathematical relation for observing wind speed versus the electricity produced.

Photovoltaic or PV cells, known commonly as solar cells, convert the energy from sunlight into direct current (DC) electricity. PVs offer added advantages over other renewable energy sources because they produce no noise and require little maintenance. PV cells are a familiar element of the scientific calculators owned by many students. PV powered calculators' operating principles and governing relationships are unfortunately not as pedagogically simple as those of wind turbines. However, PV-powered calculators operate using the same semiconductor principles that govern diodes and transistors. The explanation of their functioning is straightforward, and it helps to make many of the principles covered in semiconductor electronic classes more intuitive.

Figure 1 exhibits wind-solar hybrid power and a data acquisition system that is located at the University of Northern Iowa. Area teachers were trained in professional development workshops to understand the operation of hybrid wind-solar power systems and the relationship between wind speed and solar radiation versus electricity generated. These types of small-scale hybrid wind-solar power systems work perfectly for the Cedar Valley area in Iowa since summer seasons are mostly sunny and winters are windy. Teachers were provided technical information to share with their students during the classroom implementation stage of the project.

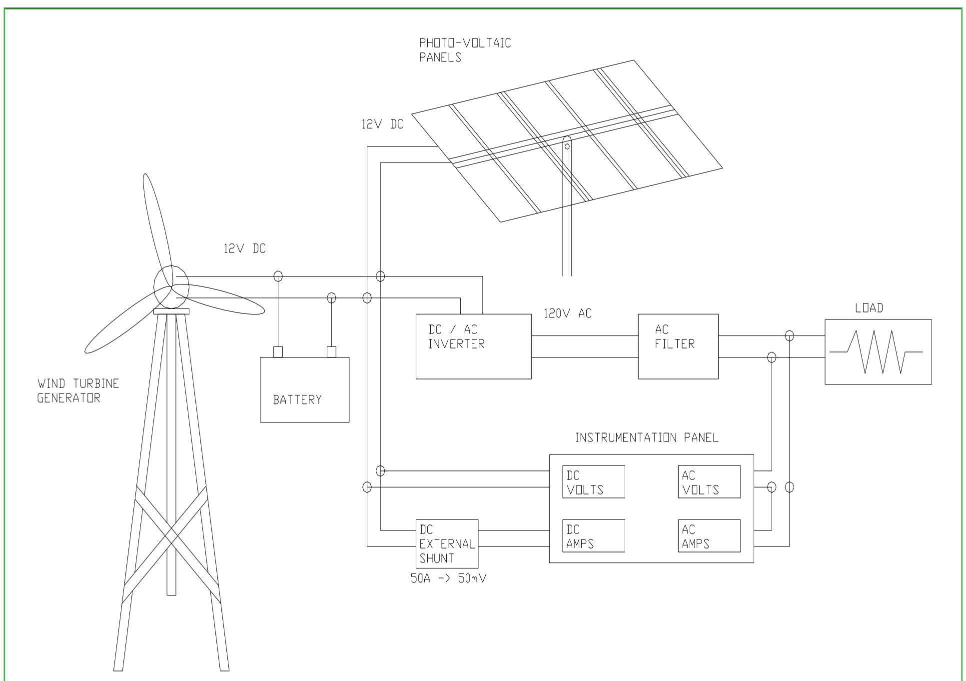


Figure 1. Wind/PV Hybrid Power Generation and Data Acquisition System.

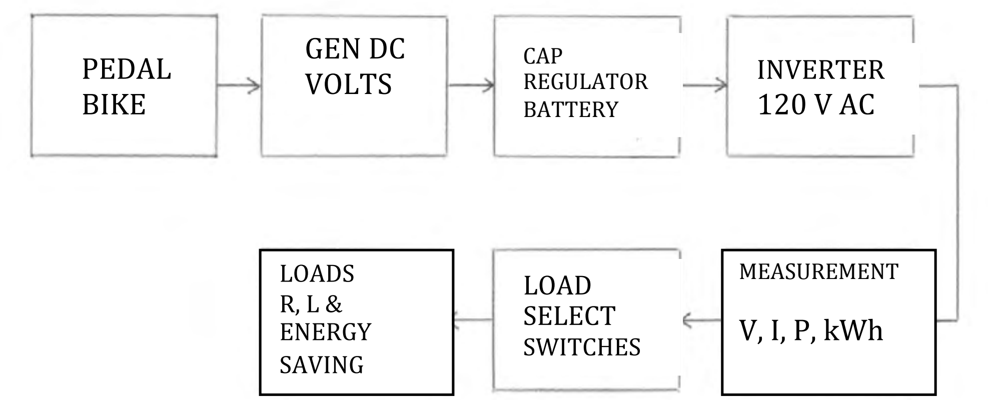


Figure 2. Overall functional block diagram of the e-Bike.

Study of UNI Energy Bike ("e-Bike") in Basics Energy Curriculum

One of the recent undergraduate senior design projects successfully completed in the EET program is the design and construction of an energy bike, commonly referred to as the e-Bike project. The e-Bike is a human-powered stationary bicycle equipped with a permanent magnet direct current (DC) pollution free (zero-emission) generator. The generator delivers electricity to a display board with a number of electrical loads of varying energy efficiency values. It allows the student cyclist to power incandescent and compact fluorescent light (CFL) bulbs, a radio, a tape player, and other small appliances either directly from the generator or from a deep cycle battery used to store energy. The cyclist typically can feel the difference in energy efficiency of the different loads, such as energy efficient CFLs and inefficient incandescent light bulbs.

A functional block diagram of the UNI e-Bike project is shown in Figure 2. One of the main objectives of this specific activity is to understand how electricity is generated and consumed efficiently. As this system was tested in the Young Scientists' Camp in July 2008, students realized that they must spend more mechanical energy when they had to generate electricity to run one 50W incandescent light bulb than when they had to generate electricity to run two compact florescent light bulbs with even more light density being obtained. They simply realized and practiced how important energy efficiency is in our daily lives. Students also calculated and read voltage, current, and power consumption through different electrical loads and observed those values at the meter display provided in the system. Awareness of energy efficiency was clearly observed by applying different mechanical inputs to the pedal-powered generator that ran incandescent and CFL light bulbs in this specific activity.

For example, student and teacher comments in the camp were excellent in terms of learning basics mathematics and science related to electricity and energy efficiency concepts. Figure 3 illustrates a custom-made load box with a display panel that helps teacher and students to change load levels and to read and record voltage, current, power, and energy values.

Figure 3. Load display panels that help teachers and students read and record voltage, current, power, and energy values.

Step	Time t(s)	Power P (W)	Current I(A)	Volt V(V)
1	15	53.2	4.3	11.91
2	30	52	4.4	11.41
3	45	45.6	4.57	10.67
4	60	42.6	4.25	11.95
5	75	50.7	4.45	10.97
6	90	47.3	4.2	9.76
7	105	41.6	4.18	9.85
8	120	44	4.2	11.37
9	135	45.3	4.15	10.94
10	150	51.6	4.25	10.8

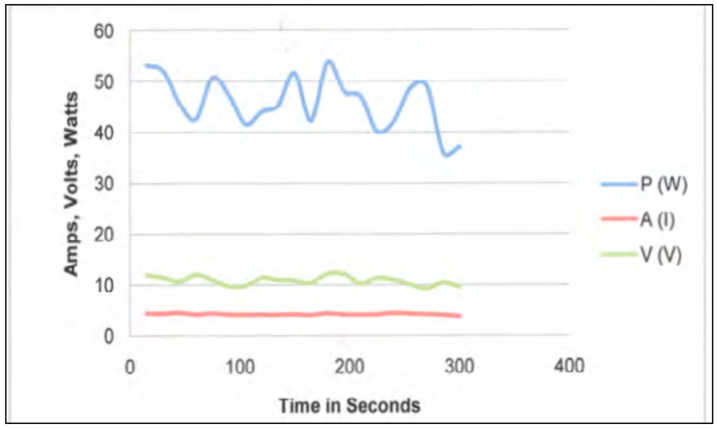


Figure 4. Data recording and graphical analysis for 50 W, 12 V incandescent light bulb run by a bicycle generator with pedal power.

Figures 4 and 5 illustrate sample data collection and graphical representation that students obtained at different load levels of the e-Bike test-drive.

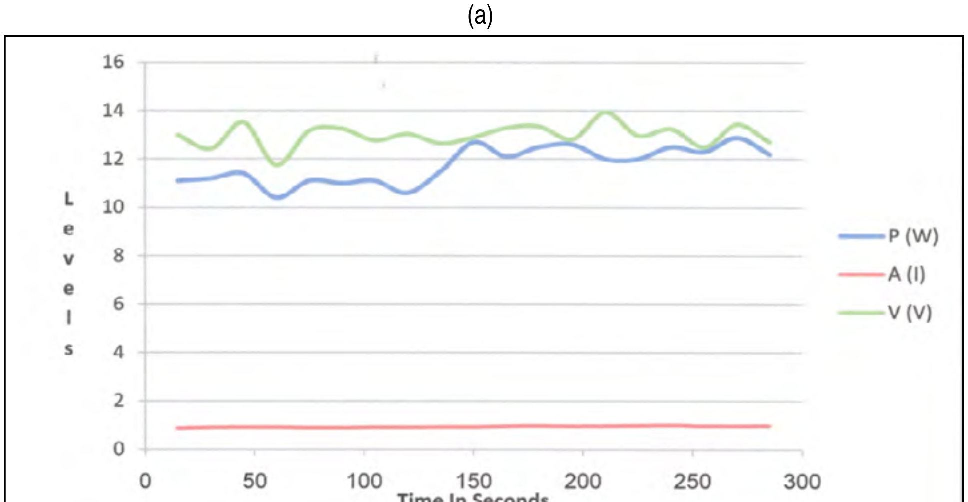
Figure 5 shows how students are involved in riding the bike (applying mechanical input power), generating electricity, running different loads, collecting data, and finally processing data into a spreadsheet-type of graphical environment.

Study of Hydrogen Fuel-Cell Science and Technology in the Curriculum

A fuel cell is an electrochemical cell in which the energy of a reaction between a fuel, such as liquid hydrogen, and an oxidant, such as liquid oxygen, is converted directly and continuously into DC electricity. A fuel cell consists of two electrodes sandwiched around an electrolyte. Oxygen passes over one electrode and hydrogen over the other, generating electricity, water, and heat. Therefore, a commercially available hydrogen fuel-cell trainer developed by Hampden Engineering Corporation was purchased for teacher and student interaction purposes and added to the curriculum through the IM-SEP grant. The previously available 500 W hydrogen-fuel test system, a custom-designed system for hydrogen fuel-cell research, is more appropriate for demonstration purposes only.

The Hampden Model H-FCTT-1 Fuel-Cell Technology Trainer (Hampden Engineering Corporation, 2008) allows students to create a grid independent power supply that uses only hydrogen as its fuel. The system will familiarize the students with fuel-cell power supply technology, an environmentally friendly method of generating power directly from a hydrogen reaction. Fuel cells are the most promising alternate energy supply and are already being used in a number of areas, including automo-

(a)



(b)

(c)

Figure 5. (a) Graphical analysis for 15 W, 12 V, CFL bulb run in (b) by a bicycle generator driven by (c) a junior high student.

tive technology and power-generation systems. The Model H-FCTT-1 can also be connected to an external energy source, such as a solar panel or wind generator, for comparison among the different technologies. A switch located on the panel allows for switching between the fuel cell and an external source.

Professional Development Workshops for STEM teachers

The two workshops that were introduced to area teachers on PV cells were wind and hydrogen fuel-cell basics. Discussion and demonstrations also included in the workshops were aimed at increasing the teachers' knowledge of this exciting new area of research on renewable energy sources. These workshops assisted in the development of a new curriculum, as shown in Figure 6, and therefore aim to increase the coursework related to mathematics and science that will be available to junior high and middle school students the following semester. The ultimate goal of this new curriculum is its implementation into the classroom, which should have an overall effect of increasing the performance of Iowa's middle school students in math and science courses.

The goal of these workshops was for teachers to develop their own curricula based on the presented materials focusing on renewable energy concepts.

To evaluate the effectiveness of the workshops and test content knowledge of the teachers, participants were asked to fill out surveys before and after attending the workshop; the outcomes are reported in this article. Project PIs observed the participants in the classroom teaching the renewable energy concepts on one of the first three days during the Spring 2009 semester.

Undergraduate assistants are currently conducting interviews with participating teachers after the week of implementation to determine the effectiveness of the curriculum and to collect information regarding students' level of understanding. Tryengineering.org offers excellent free material for educators of the STEM curriculum, and a number of lesson plans are provided for workshop participants (Try Engineering, 2007). Project Lead the Way has STEM activities that are available to STEM educators (Project Lead the Way, 2007). Clark and Ernst (2006) studied the integration of engineering, mathematic, scientific, and technological concepts with Visualization in Technology Education (VisTE) by an NSF-funded project.

Sample pictures of learning activities are shown in Figure 8.

Day 1: Exploration of Renewable Energy Concepts - SOLAR

Day 2: Exploration of Renewable Energy - WIND

Day 3: Exploration of Renewable Energy Concepts HYDROGEN FUEL CELL

Day 4: Experimentation and data collection of "e-Bike."

Day 5: Graphical representation and analysis for "e-Bike" and hydrogen fuel cell system data.

Figure 6. Implementation of Curriculum Outline

Teacher Expectations from a STEM Workshop on Renewable Energy

Twenty teachers from 12 schools participated in the STEM workshop on renewable energy. The authors believe that the data on teacher participation indicate that this experimental curriculum to promote Math and Science Education is promising and should be introduced to more teachers and more schools. The following are comments from teacher's surveys.

- *I want to find out up-to-date information on RE and how to bring it to the classrooms.*
- *I hope to get curriculum materials and ideas to utilize in various levels of chemistry related to energy. I hope to get information and ideas for possible club ideas for student to participate in outside of the classroom as well as hoping to forge a partnership with UNI for our high school students to work with UNI students on projects related to RE.*
- *Receive ways I can encourage my students to enjoy math, science, and technology.*
- *Learning new stuff, having materials/resources to take with me, and gaining useful materials for classroom instruction.*
- *To learn about renewable energy and how to use this knowledge in my classroom.*
- *I expect to learn about the different renewable energy applications and to find some curriculum that I can apply in my classes.*
- *I would like to get ideas, applications, lesson plans for use in class that will help students see the practical applications of math*

Goal 1:

Increase content knowledge of renewable energy sources – hydrogen fuel cells, solar and wind power.

Goal 2:

Demonstration and experimentation of UNI "e-Bike."

Goal 3:

Calculations, graphical representation and interpretation of "e-Bike" and hydrogen fuel cell system data.

Figure 7. Weekend professional development workshops

to alternative energy.

- *My expectations are to be able to introduce my students to renewable energy activities and labs. I also want to introduce more math to my science teaching.*
- *I am very interested in learning more about renewable energy. Also getting all students more interested in math and science.*
- *I would like to take back to students few examples of real world applications of STEM.*
- *I would like to incorporate some of the information in collaboration with both math and science. Especially our advanced 8th grade math and science students.*
- *I really want to take some hands-on applications of math and science back to my class to increase student interest in future careers.*

A survey was conducted to determine how satisfied participants were at the end of the workshops. Survey results are summarized in Figure 9 and Table 1.

Conclusion

The critical need for engineering education in K–12 classrooms in the United States has been highlighted in a number of reports as referenced throughout this article. Though it is still in its infancy, there is an emerging movement in engineering education across the country, as evidenced by the growth in Science, Technology, Engineering, and Mathematics (STEM) academies and programs in secondary schools, as well as the development and deployment of engineering curricula. However, rural school districts are often at a disadvantage without sufficient student populations, resources, or qualified teachers necessary to implement these specialized programs. Research suggests rural students are less likely to pursue engineering careers due in part to a lack of exposure to or unfamiliarity with the field. Collaboration between schools and institutions is an efficient way to promote engineering education by integrating renewable energy systems into coursework, which generates more student interest than providing equation-based curriculum. Renewable energy related summer camps and workshops have proven to generate more student interest and promote STEM education, especially in rural areas where there is a lack of teaching tools and equipment. Local companies may provide some funding and equipment for workshops. A successful partnership between two departments, EET (Electrical Engineering Technology) and Science Education in the College of Natural Sciences at UNI, and local middle and high schools has focused on providing educators with exciting, hands-on, and unique learning tools that will initiate discussions about renewable energy applications, energy efficiency, and energy conservation in their young students' lives. These discussions lead directly into data analysis, mathematical calculations, and scientific interpretation of experiments performed by the students themselves.

Figure 8. Activities from weekend professional development workshops

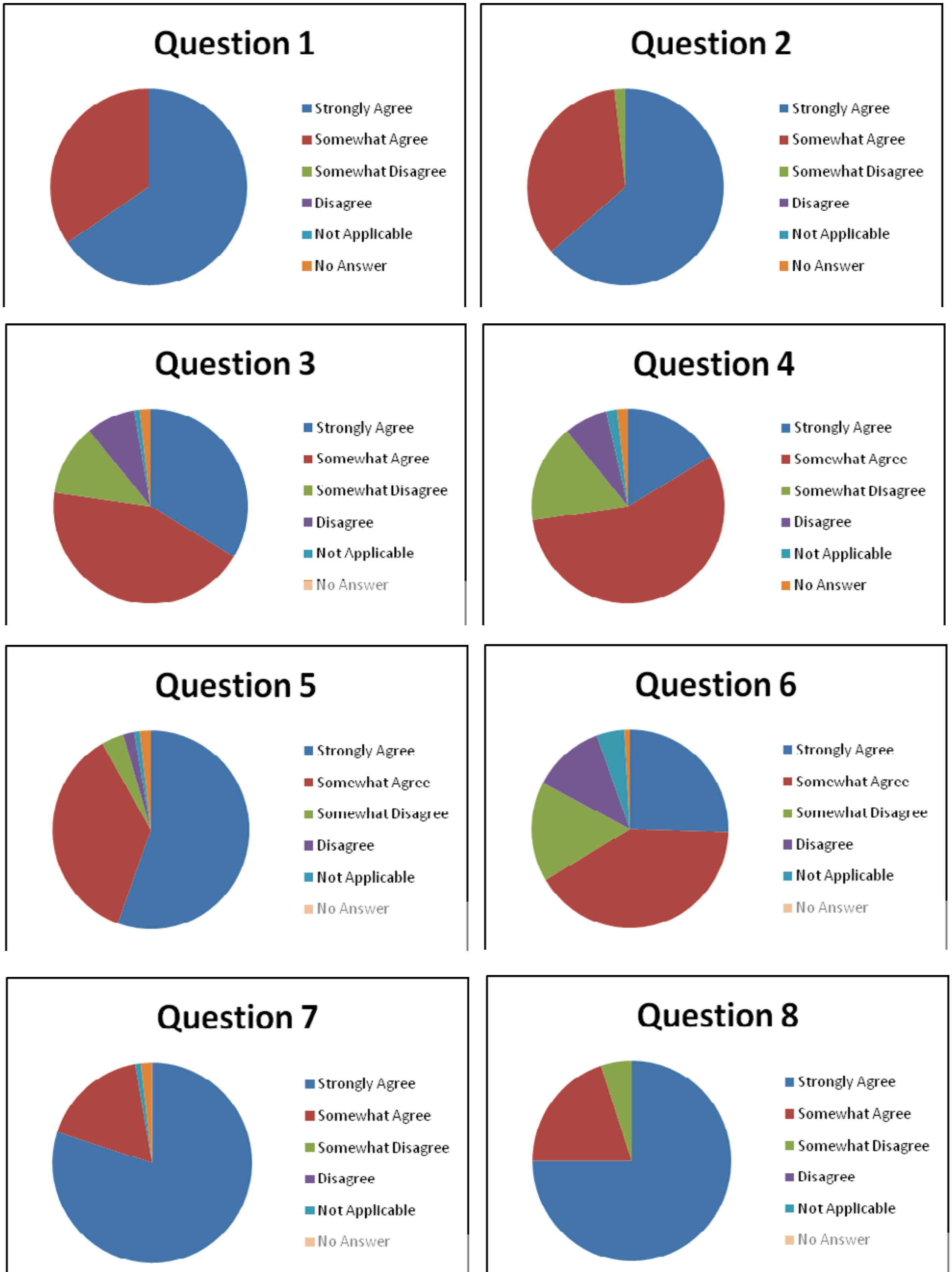


Figure 9. End of workshop survey completed for STEM teachers.

Questions	Strongly Agree (%)	Somewhat Agree (%)	Somewhat Disagree (%)	Disagree (%)	Not Applicable (%)	No Answer (%)
Question 1: Have you found the presentation useful to improve your knowledge on renewable energy applications?	65.45	34.55	0.00	0.00	0.00	0.00
Question 2: Have you found the presentation useful to improve your knowledge on energy efficiency and efforts on reduction of carbon foot print?	63.64	34.55	1.82	0.00	0.00	0.00
Question 3: Are Mathematical relations and calculations selected in this presentation appropriate for your skill level?	33.64	43.64	11.82	8.18	0.91	1.82
Question 4: Do you think solar, wind and hydrogen fuel cell power applications will help you as a student to understand math better?	16.36	56.36	16.36	7.27	1.82	1.82
Question 5: Do you think renewable energy would be a good tool to promote science and technology majors in college for women, students of color and under-represented students?	55.45	36.36	3.64	1.82	0.91	1.82
Question 6: Would you be interested in this Applied Renewable Energy Curriculum promoting Math and Science added to your school's curriculum?	25.45	40.91	16.36	11.82	4.55	0.91
Question 7: Overall quality of instruction was appropriate and useful for this class.	80.00	17.27	0.00	0.00	0.91	1.81
Question 8: I am interested in future workshops/summer research activities in these or similar subject matters at UNI.	75.00	20.00	5.00	0.00	0.00	0.00

Table 1. Summary of Survey Results

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