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) project aimed to provide area middle school teachers with an applied mathematics and science curriculum package based on Photo-Voltaic (PV), wind power, and hydrogen fuel-cell fundamentals. The MSETI –AREA project has established a partnership between the university and selected area middle schools for the improvement of students' mathematical and scientific skill sets, improve their technological literacy by creating an environment where they must understand and figure out relationships among basic mathematics, science and engineering technology applied to renewable energy fields in order to mentor and manage effectively, and to give them 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 such as nationwide solar electric project promote mathematics and science for middle school teachers and students. The objectives of this paper are listed as follows; to show how an eco-friendly applied research project is adapted for the undergraduate teaching and research curriculum, to gain community and state support for funding, and to illustrate how student design projects can serve as an excellent marketing tool to promote science and engineering technology among high school students.**

Key words: Renewable Energy, Science, Technology, Engineering, Teacher, Student

I.INTRODUCTION

According to the National Science Board (NSB)'s *Science and Engineering Indicators 2004*, enrollment in undergraduate engineering and science programs in the United States has been in decline since the 1980s[1]. Clearly, there is a continued need for increased enrollment and retention in science and engineering. Science, Technology, Engineering, and Mathematics (STEM) have become increasingly central to our 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 non-profit entities to promote innovation and to prepare an adequate supply of qualified STEM workers[2].

The MSETI - AREA project utilizes an undergraduate senior design project, the energy bike "UNI e-Bike", which is introduced through a series of after school visits and weekend professional development workshops during the fall 2008 of the academic year. Teachers who have already completed the workshop are now implementing the conventional and renewable energy concepts in their classroom by checking out the "e-Bike", PV solar cells, and model wind generators. This creates an environment where young students must understand and figure out relationships among basic mathematics, science and engineering technology applied to renewable energy fields. The overall goal of this project is first to work with teachers to develop a curriculum based on an exciting applied research. The "UNI e-Bike" project also introduced teachers and students to what energy efficiency and energy conservation mean by generating their own electricity using pedal-power and energizing a number of loads such as inefficient incandescent light bulbs, small appliances, and energy efficient compact fluorescent light (CFL) bulbs where they can observe light density, heat release, and overall energy usage in kWh. Students also calculate cost of overall electricity they use and discuss on monthly average charges to educate themselves as well as their own parents on energy cost and efficiency.

II. PROBLEM DEFINITION

According to the National Science Board (NSB)'s *Science and Engineering Indicators 2004*, enrollment in undergraduate engineering and science programs has been in decline since the 1980s. Furthermore, NSB urges 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[1]:

"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."

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 non-profit entities to promote innovation and to prepare an adequate supply of qualified STEM workers that are capable of translating knowledge and skills into new processes, products, and services[2,3,4,5,6].

III. PROJECT DESCRIPTION

This MSETI-AREA project was sponsored by Iowa Math and Science Education Partnership (IMSEP) and established a partnership on Math-Science-Engineering Technology in Iowa on Applied Renewable Energy Areas between UNI College of Natural Sciences and Cedar Falls-Waterloo area community schools, specifically UNI Price Lab School, Waterloo West and East High Schools. 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 skill sets, their technological literacy by creating an environment where they must understand and figure out relationships among basic mathematics, science and engineering technology applied to renewable energy fields in order to mentor and manage effectively, and to give them a professional skill-set for successfully applying mathematics and science to technical projects with 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.

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. Renewable energy applications such as wind, solar, and hydrogen-fuel cell theory and applications are covered in this curriculum.

A. 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 may already have some idea of what that means. Wind energy has become the least expensive renewable energy technology in existence and 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 Cedar Falls and Waterloo. Utilizing a mast-mounted anemometer (wind meter) and a simple relationship as shown in Equation 1 that relates the power generated by a wind-turbine and the wind parameters allows the students to directly measure wind speed and to vividly relate this easily felt force-of-nature to electrical measurements.

$$P = 0.5\rho A\, C_p v^3 \eta_g \eta_b = kv^3 \qquad (1)$$

where,

P = electricity generated in Watts (W)

v = wind speed in m/s

k is an engineering coefficient representing the following:

ρ = air density (about 1.225 kg/m^3 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

Equation (1) shows that how students will be using a simple mathematical relation for observing wind speed versus produced electricity.

Photo-Voltaic 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 in that they give off no noise and require practically no maintenance. PV cells are a familiar element of the scientific calculators owned by many students. Their operating principles and governing relationships are unfortunately not as pedagogically simple as that of wind-turbines. However, they operate using the same semiconductor principles that govern diodes and transistors and the explanation of their functioning is straightforward and helps to make more intuitive many of the principles covered in semiconductor electronic classes.

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

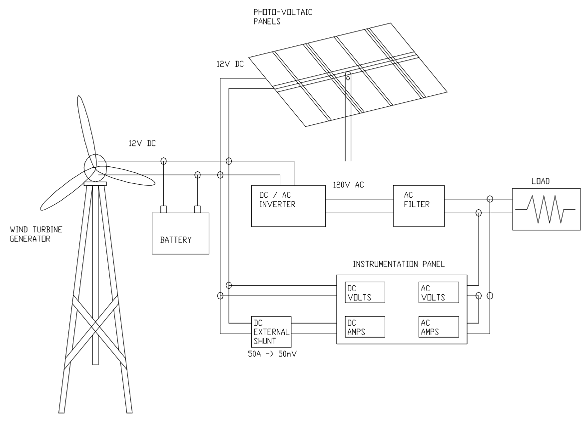


Figure 1. UNI 1.5 kW Wind-Solar Hybrid Power and Data Acquisition System.

B. 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 design and construction of an energy bike "UNI e-Bike" project. The "UNI 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, tape player and other small appliances either directly from the generator or from a deep cycle battery used as energy storage. The cyclist in fact may feel the difference in energy efficiency of the different loads such as energy efficient CFLs and inefficient incandescent light bulbs.

"UNI e-Bike" has been used in this MSETI – AREA project extensively and is a fun, hands-on learning tool and an appealing way to engage young people in conversations about the environmental and economic benefits of energy efficiency and the use of energy efficient products. The bike also offers an opportunity to emphasize a link between saving energy, therefore assisting consumers to make informed energy choices. Two weekend workshops were held in the fall semester of the 2008 academic year. Teachers who completed the workshop implemented the energy concepts in their classrooms with the e-Bike during the spring semester 2009 and created an environment where their students understood and figured out relationships among basic mathematics, science and engineering technology applied to renewable energy fields.

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 2008-2009, students realized that when they had to generate electricity to run one 50W incandescent light bulb they must spend more mechanical energy than when they had to generate electricity to run two compact florescent light bulbs with even more light density obtained. They simply realized and practiced how important energy efficiency is in our daily lives. Students also calculated and read voltage, current, power consumption through different electrical loads and observe those values at the meter display provided in the system. Awareness of energy efficiency was clearly observed in this specific activity. Figure 3 shows e-Bike project activity during the Young Scientists' Camp in July 2008-2009 on campus.

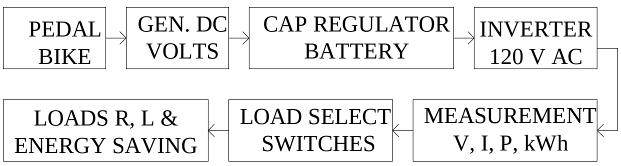


Figure 2. Overall functional block diagram of the UNI e-Bike.

Figure 3 shows student learning activities through e-Bike during 2008-2009 Young Scientists' Camp. Students and teacher comments in the camp were excellent in terms of learning basics mathematics and science on electricity and energy efficiency concepts.

Figure 3. Students at UNI Young Scientists' Summer Camp run e-Bike to learn and practice about basic

Mathematics and Science towards electricity generation and energy efficiency concepts.

Figure 4 illustrates a custom made load box with a display panel that helps teacher and students to read and record voltage, current, power, and energy values.

Figure 4. Load display panels that help teacher and students to read and record voltage, current, power, and energy values.

Table 1, Figures 5 and 6 illustrate sample data collection and graphical representation that students obtained through e-Bike test-drive.

Table 1. Data recording and graphical analysis for 50 W, 12 V incandescent light bulb run by a bicycle generator with pedal power.

	Time	**Power**	**Current**	**Volt**
Step	t(s)	P (W)	I(A)	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

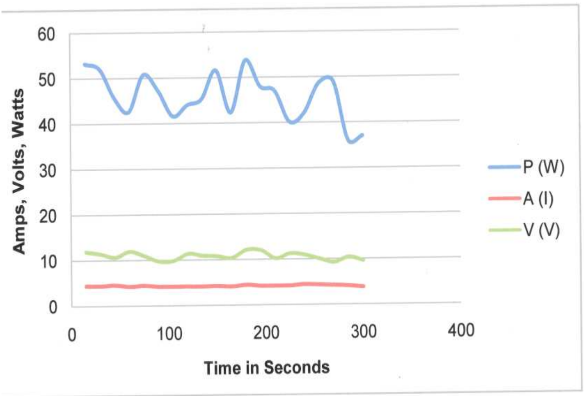
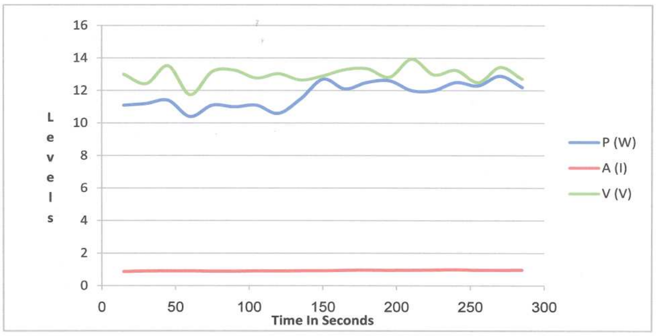


Figure 5. Graphical analysis for 50 W, 12 V incandescent light bulb run by a bicycle generator with pedal power.



(a)

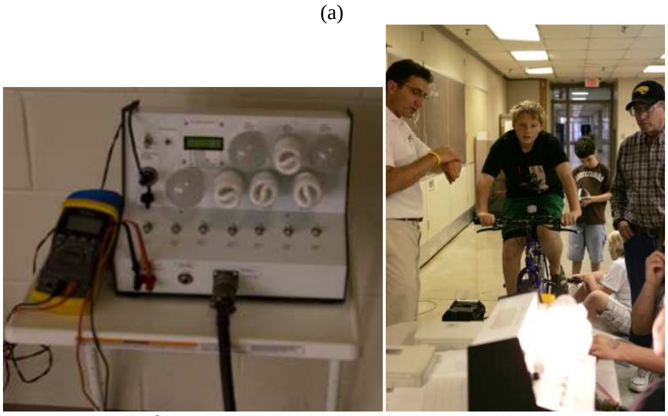

(b) (c)

Figure 6. (a) Graphical analysis for 15 W, 12 V, CFL bulb run in (b) by a bicycle generator driven by a junior high student (c).

C. 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 purpose and added to the curriculum through the IMSEP grant. The previously available 500 W Hydrogen-fuel test system, a custom-designed system for Hydrogen fuel-cell research, is more appropriate for teachers and students demonstration purposes only.

The Hampden Model H-FCTT-1 Fuel-Cell Technology Trainer [7] as seen in Figure 7 will allow 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 automotive 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 between the different technologies. A switch located on the panel allows for switching between the fuel-cell and an external source.

Basic Mathematical Relations

DC Electrical Power = Voltage*Current, $P = V * I$ [Watts]

Energy Used = Power * Time, $W = P * t$ [kWh]

Local electric utility companies such as Cedar Falls Utility and MidAmerican charge each homeowner for every kWh of energy consumed. For example, if the energy consumption at home is 700 kWh per month then the monthly charge will be about: \$0.10/kWh * 700 kWh = \$70 and \$840 per year *considering the cost of electricity is about \$0.10 per kWh.*

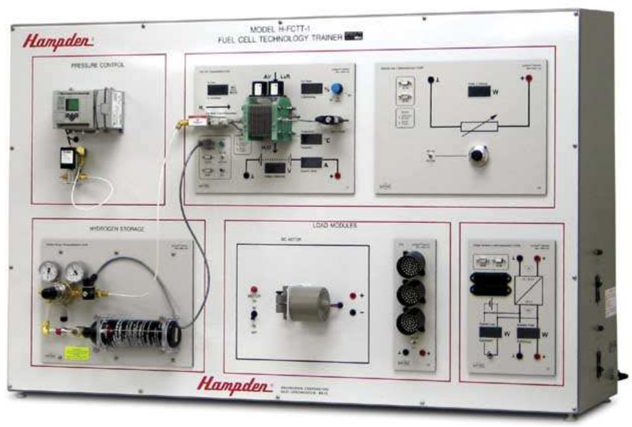


Figure 7. Hampden Model H-FCTT-1 Fuel-Cell Technology Trainer

The two fall MSETI-AREA workshops introduced area teachers to these PV cells, wind, and Hydrogen fuel-cell modules. Discussion and demonstrations aimed to increase their content and pedagogical knowledge of this exciting new area of current research on renewable energy sources. These workshops assisted in the development of a new curriculum, Figure 8, and therefore aimed to increase the coursework in mathematics and science available to junior high and middle school students during the spring semester 2009. The ultimate goal of this new curriculum is implementation in the classroom which will overall increase the performance of State of Iowa's students in math and science courses.

The goal of these workshops was for teachers to develop their own curriculum based on presented materials and available testbed that focuses on renewable energy concepts. The project used as a tool for fundamental pedagogical research in methodologies for the inclusion of renewable energy content in science classes. Additionally, the project is used as part of formal credit-based undergraduate, and teacher preparation classes. Two undergraduate students, one education major with science minor, and another undergraduate assistant are currently assisting principal investigators on the curriculum implementation and designing a website that will allow participants and teachers beyond the local area access to course materials on renewable energy sources.

Implementation of Curriculum Outline

Day 1: Exploration of Renewable Energy Concepts - SOLAR

Day 2: Exploration of Renewable Energy Concepts - 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 8. Implementation of Curriculum Outline

To evaluate the effectiveness of the workshops as well as test content knowledge of the teachers, participants were asked to fill out surveys before and after attending the workshop and the outcomes are reported in this paper. Project PIs OBSERVED the participants in the classroom teaching the renewable energy concepts on one of the first 3 days during spring 2009.
Undergraduate assistants CONDUCTED 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 in STEM curriculum and a number of lesson plans are provided for workshop participants[8]. Project Lead the Way and STEP activities are other very useful on line material available to STEM educators [8,9,10,11].

Figure 9 SHOWS activities from weekend professional development workshops.

Figure 9. Activities from weekend professional development workshops

IV. TEACHER EXPECTATIONS FROM A STEM WORKSHOP ON RENEWABLE ENERGY

There were 20 teachers from 12 different schools; majority of them from junior high schools, few from high schools, and one from an elementary school. Participant teacher data indicates that this experimental curriculum to promote Math and Science Education is promising and needs to be enhanced to more schools. The following are comments from teacher surveys.

I want to find out up-to-date information on renewable energy 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. Also 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 energy.

Receive ways I can encourage my students to enjoy math, science, and technology.

Learn ways that I can use renewable energy as a parent, and educator.

Learning new stuff, having materials/resources to take with me, and gaining useful materials for classroom instruction.

I would like to learn about renewable energy resources for my own knowledge. I want to make informed decisions politically and for my own household.

I am very interested in renewable energy as a citizen. It is indeed a matter of national security.

I expect to learn about the different RE applications and to find some curriculum that I can apply in my classes.

I hope to become more aware of current renewable energy trends to enhance my personal life. I also want to build an information base that I can use in my social studies classes.

I would like to get ideas, applications, lesson plans for use in class that will help students see the practical applications of math 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 math and science.
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.

V. SOLAR POWERED BOAT PROJECT AND TELEMETRY SYSTEM

There are more than 20 million motorized pleasure boats in the world. The united states alone has approximately 10 million such boats. Worldwide these boats may emit approximately 472,000 metric tons of oil and products into the atmosphere [12]. Another 236,000 metric tons of oil & oil products everyday year is leaked into the water due to the low efficient two-stroke motors used in these watercrafts. The amount oil and oil predicts run off is equivalent to more than seven times the amount spilled by the Exxon Valdez in Alaska in 1989.

Two-stroke motors that run on a mix of oil and gas may have eight times more pollutant than standard four-stroke engines since approximately 25% of the fuel might be emitted half - burned through the exhaust into the water. Many Iowans are aware of agricultural pollution in Iowa's lakes and rivers, however, oil and gas leaks from boats - also require developing eco-friendly boat technologies. UNI e-Boat was designed and built by four senior design students in the academic year of 2007-08 to promote clean boat technologies in Iowa lakes and rivers. Students and faculty attend a World Championship on solar electric boating at the end of the academic year as part of the project completion. The competition is a five day event that includes engineering design covering a technical report review, project display, workmanship, and on-the-water competition covering maneuverability and sprint qualifying, slalom, sprint, and endurance. The UNI solar boat team won the third overall place in June 2009 and June 2010 in Fayetteville, Arkansas in the 16th and 17th World Championship of Intercollegiate Solar Boating [13].

A. Design Specifications Considered

The UNI Team has identified several key features in the design of the new boat. These specifications include weight Optimization, hull shape, power constraint, simplicity, and speed Control.

B. Weight

The weight of the bare hull must be below 70 pounds and the boat in the sprint configuration must weigh less than 350 pounds including driver.

C. Hull Shape

The hull must be a long and narrow monohull style as shown in Figure 10. A combination planning / displacement hull works best at the international competition for solar boats based on previous experience and research.

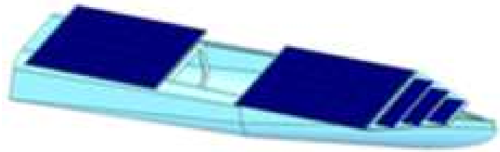


Figure 10. UNI Solar Boat Hull Design completed by Solid Works ™.

The United States alone has approximately 10 million such boats.

D. Power

Two to three 15 HP permanent magnet DC electrical motors for the sprint race are used. Another very efficient and reliable 5 HP DC motor for the endurance race is used. Specific battery packs designed to maximize electrical power for the sprint and endurance races. The most efficient, cost effective, reliable and commercially available Photovoltaic (PV) panels are used for the battery charging. Solar PV array must be easy to install and remove with reliable electrical connectors.

E. Simplicity

The hull design must be simple and without complex features. The drive train must be easily modified between sprint and endurance configuration. The solar array must be easy to install and remove.

F. Speed Control

The motors must have a stable and reliable speed control. Speed control should not be very complicated to avoid on-board problems during the event as shown in Figure 11.

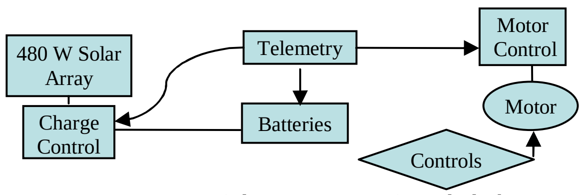


Figure 11. UNI Solar Boat Design - Control Block Diagram

The UNI team used both Solid Works and Pro-E software to model the new boat. With the team's extensive use of CAD, it was easiest to change the material of the hull to water and have Solid Works ™ calculate the new mass. Buoyancy is created by the displacement of water. As modeled, the boat displaces 288 pounds of water when submerged.

Solid Works calculates the weight of the hull with the actual foam material to be only 40 pounds. With all other components taken into account, the boat weighs approximately 230 pounds in a race trim. The weights are listed in Figure 2. This will yield a safety factor of: (288 – 230) / 288 = 0.2014 or 20.1 %. These calculations show that the UNI e Boat, in the event of capsizing, will not sink and has a safety margin of 20.1 %.

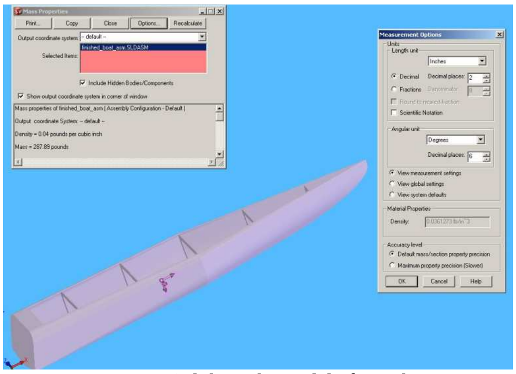


Figure 12. Solid Works model of UNI boat

Figure 13 shows a data logging using designed telemetry system for the solar boat project where pw stands for power, *Mtrv* is motor voltage and *Battv* is battery bank voltage charged by solar array. Figure 14 illustrates a student work for the telemetry system design. Telemetry is a state-of-the-art technology that allows the remote measurement and reporting of information of interest to the system designer or operator. Telemetry typically refers to wireless communications (i.e. using a radio frequency system to implement the data link), but can also refer to data transfer over other media, such as a telephone or computer network or via an optical link. In fact, telemetry has been a key factor in modern motor racing. Engineers are able to interpret the vast amount of data collected during a test or race, and use that to properly tune the car for optimum performance. Systems used in some series, namely Formula One, have become advanced to the point where the potential lap time of the car can be calculated and this is what the driver is expected to meet. Some examples of useful measurements on a race car include accelerations (G forces) in 3 axes, temperature readings, wheel speed, and the displacement of the suspension.

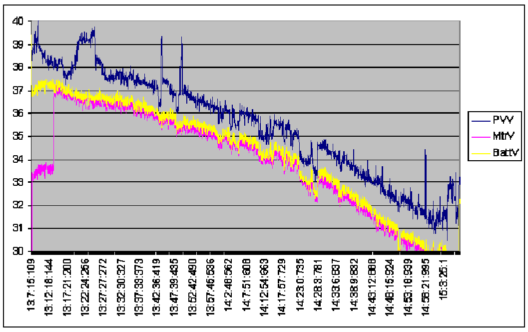


Figure 13. Data Logging from solar boat parameters.

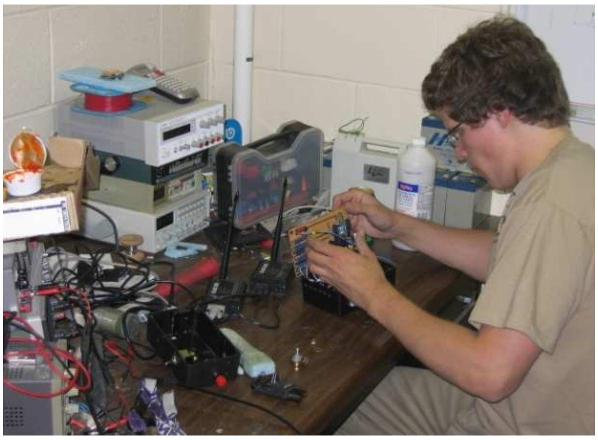


Figure 14. Student design work on telemetry system.

Figure 15 illustrates a sample data logging and graphical display for the solar boat parameters during a test drive. This communications device enhanced the boat performance as well as overall team performance in the competition. This system included an MDR29x Wireless 900 MHz Modem and a Plug-a-Pod microprocessor from NewMicros.com.

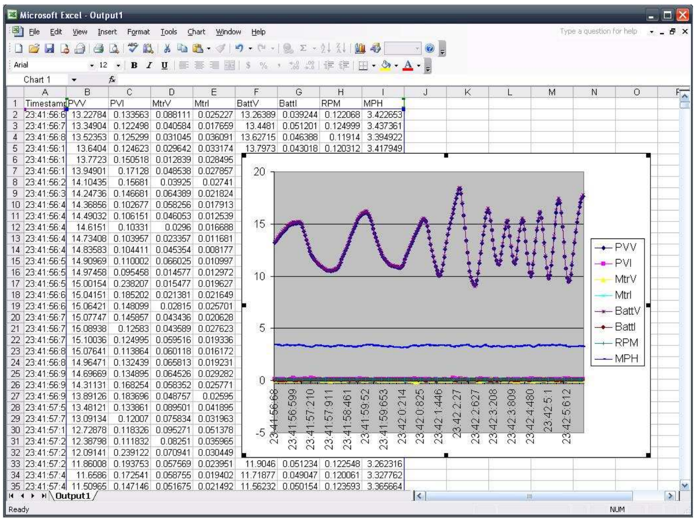


Figure 15. Sample data logging and graphical display.

UNI Solar Electric Boat Team investigated using telemetry for their project and worked very hard to secure an additional funding from UNI Provost's Office. Students wrote a program to monitor boat performance in real-time using Black Box™ Wireless 900 MHz modem and Plug-a-Pod™ microprocessor. Figure 16 shows a unique name entitled "The UNI Dater Bass" monitoring voltage, and current values of battery banks, PV panels, motor as well as motor speed. The telemetry system provided an enhanced operation of the UNI solar electric boat.

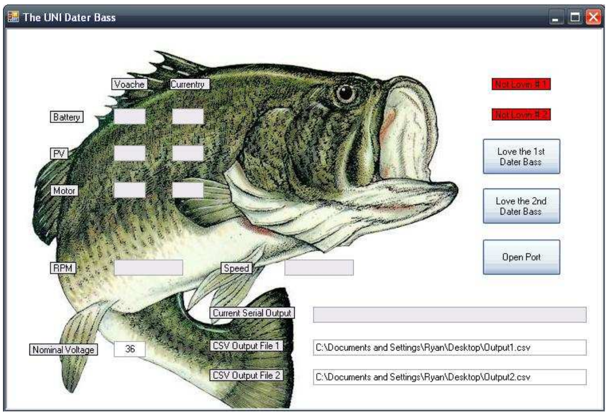


Figure 16. UNI “Dater Base” as a unique name to data base and monitoring.

VI. CONCLUSION

A successful partnership between two departments, Electrical Engineering Technology (EET) and Science Education in the College of Natural Sciences at UNI and local middle and high schools has been described. The proposed project aims at providing educators an exciting, hands-on and unique learning tool that will begin discussions about electrical power generation specifically from 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. The EET program at University of Northern Iowa has provided students with a quality learning experience culminating in the senior design course. In addition to bringing classroom theoretical knowledge to life in a variety of projects, students learn how to work collaboratively in teams to solve problems they may encounter in their careers after graduation[14]. The success that the EET senior design course has enjoyed through the complexity of this energy and communications project undertaken by the students is an excellent indicator of the validity of the course in the curriculum.

Similarly, engineering and engineering technology programs are strongly encouraged to incorporate renewable energy based capstone senior projects into their curriculum to promote eco-friendly energy technologies for a brighter future for our generations. Many interested local and regional, private or public elementary, junior high, and high school students and teachers have visited and received information on this project. Since the UNI solar boat team won the fourth overall place in June 2007, third overall places in 2009, and 2010 in Fayetteville, Arkansas in the World Championships of Intercollegiate Solar Boating, there have been a number of media coverage of the project. This has also increased awareness of Engineering and Engineering Technology among young Iowans whose families are mostly dealing with agriculture. There is no doubt that student recruitment has already been impacted positively as well. A detailed information, mission, full technical report, list of sponsors are available at http://www.cns.uni.edu/eboat/.

ACKNOWLEDGEMENTS

The Iowa Mathematics and Science Education Partnership (IMSEP) is greatly appreciated for the grant support for the MSETI-AREA project. IMSEP is a state-funded initiative led by the University of Northern Iowa, in partnership with Iowa State University, and the University of Iowa. IMSEP's goals are to improve mathematics and science performance of Iowa students; to prepare more high quality mathematics and science teachers for Iowa's schools; and to promote statewide collaboration and cooperation. Students worked in the UNI solar team project are Michael Boomer, Douglas Bechthold, Ryan Canfield, Benjamin Wagner, Hannah Loan, Damon Knowling, David Busemann, Abubakar Audio, Jialong Chu are greatly appreciated for their hard work and enthusiasm. Iowa Energy Center, Iowa Space Grant Consortium, John Deere Waterloo Works, and Bechthold Enterprises are also appreciated for their full and partial sponsorship for the project.

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