AC 2011-1769: CREATING REAL-WORLD PROBLEM-BASED LEARNING CHALLENGES IN SUSTAINABLE TECHNOLOGIES TO INCREASE THE STEM PIPELINE

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Creating Real-World Problem-Based Learning Challenges in Sustainable Technologies to Increase the STEM Pipeline

Abstract

In this paper, we report on the progress of the *Problem Based Learning for Sustainable Technologies: Increasing the STEM Pipeline* (STEM PBL) project of the New England Board of Higher Education. This three-year National Science Foundation Advanced Technological Education (NSF-ATE) project is aimed at increasing student interest and preparedness in STEM-related careers by providing STEM educators across the U.S. with the training and resources needed to introduce PBL in their classrooms. Working closely with industry, government, and university collaborators involved in new cutting-edge sustainable technologies, the STEM PBL project team has created a comprehensive series of online multimedia PBL instructional materials referred to as "STEM PBL Challenges." The STEM PBL Challenges are designed to engage secondary and post-secondary students in authentic real-world problem solving focused on a broad range of contemporary issues of sustainability including solar and wind energy, clean water, energy efficient lighting, sustainable agriculture, and "green chemistry" in personal care products. A detailed discussion of the problems, collaborating partners, STEM PBL Challenge development process, and pre- and in-service teacher training program is presented.

Introduction

As a new generation of American students move through the educational pipeline, they are being challenged as never before with important issues such as global climate change, sustainability, and all things "green." The US Environmental Protection Agency defines sustainability as "meeting the needs of the present without compromising the ability of future generations to meet their own needs". The implications of sustainability are far-reaching and pervasive. They affect all aspects of life including how we generate energy, provide clean drinking water and grow food, manufacture goods and provide services, heat and cool our homes, and get to work and school each day[1,2,3].

With all of the attention given by policy makers and the media about the importance of sustainable technologies, student enrollment in science, technology, engineering and math (STEM) fields in the U.S., fields critical to the growth and advancement of sustainable industries, continues to lag behind other industrialized nations[1]. If the U.S. is to maintain its global economic and technological competitiveness, the educational system must produce more graduates interested and prepared to enter STEM related careers. To this end, educators must provide students with learning experiences that engage and motivate them by tapping into their natural creativity, imagination, and desire to solve the big problems of the world such as environmental sustainability, while at the same time develop the problem solving and critical thinking skills needed for lifelong learning. One instructional method capable of providing this type of learning experience is problem-based learning (PBL).

PBL is a learner-centered instructional method in which students learn by solving authentic real-world problems, actively and collaboratively. Research shows that PBL results in "deep" learning rather than "surface" learning, improves critical thinking and problem-solving skills, motivation for learning, and students' ability to skillfully apply knowledge in new and novel situations – skills deemed critical for lifelong learning [4,5,6,7,8,9]. Unlike traditional instruction in which students attend lectures, solve well-defined end-of-chapter homework problems, and engage in highly structured “cookbook” type laboratory activities, PBL is open-ended and contextualized, where student learning is driven by the problem itself.

While a number of different approaches to PBL have been described in the literature since first being introduced in medical schools in the 1970s, they all share the same basic learning process[10]. Working in small teams, students learn “how to learn” by engaging in a recursive process that includes problem analysis, independent research, brainstorming, and solution testing.

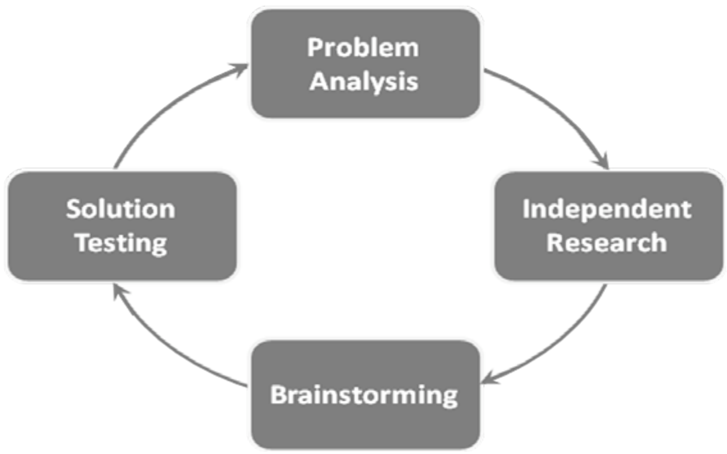


Figure 1 – Problem solving cycle

In PBL, students are presented with an open-ended problem with little or no content preparation. Working in small teams, they collaboratively reflect upon prior knowledge to identify what they know, what they need to learn, and what (if any) special constraints may apply. After working together to analyze and frame the problem, students create a plan for acquiring the knowledge and skills necessary to solve the problem that includes setting specific learning goals, identifying required resources, establishing a timeline, and monitoring their knowledge and comprehension. During this process, the instructor serves as a facilitator or consultant, guiding students through the problem solving process and providing instruction on an “as needed” basis.

Once the required knowledge has been acquired, students reconvene to share what they have learned and brainstorm possible solutions where ideas are openly exchanged without criticism or judgment. By expressing ideas and listening to what others say, students are able to gauge their own level of understanding, increase their knowledge and understanding by integrating new ideas with prior knowledge, and converge on a problem solution that represents the collective knowledge and understanding of the group.

Upon developing a preliminary solution, the team must test the solution to see if it produces the desired outcome identified in the problem analysis phase. Solution testing requires that students develop a coherent and replicable test plan that addresses specific criteria for a successful solution. If test results do not successfully validate the solution, the problem-solving process is repeated until an acceptable solution is developed. Students then present their final solution for peer review, after which the instructor leads a reflective discussion where students reflect on their learning experience and compare and contrast results[11, 12, 13].

While the benefits of PBL have been well documented, there are some obstacles limiting its adoption in STEM education. Among the key issues are: (1) the overall lack of curriculum materials and resources, (2) the lack of professional development opportunities to help teachers learn how to effectively incorporate PBL in their existing curriculum, and (3) pre-service teacher education programs often do not prepare secondary STEM teachers in PBL instructional methods[3].

In this paper, we report on the progress of the *Problem Based Learning for Sustainable Technologies: Increasing the STEM Pipeline* (STEM PBL) project of the New England Board of Higher Education. This three-year National Science Foundation Advanced Technological Education (NSF-ATE) project is aimed at increasing student interest and preparedness in STEM-related careers by providing STEM educators across the U.S. with the training and resources needed to introduce PBL in their classrooms. Working closely with industry, government, and university collaborators involved in new cutting-edge sustainable technologies, the STEM PBL project team has created a comprehensive series of online multimedia PBL instructional modules, six in total, referred to as "STEM PBL Challenges." The STEM PBL Challenges are designed to engage secondary and post-secondary students in authentic real-world problem solving focused on a broad range of contemporary issues of sustainability including solar and wind energy, clean water, energy efficient lighting, sustainable agriculture, and "green chemistry" in personal care products.

In addition to the six new STEM PBL Challenges, the STEM PBL project has created and implemented an online professional development course for in-service STEM educators focused on PBL methodology and the implementation of the STEM PBL Challenges in the classroom. The project has also developed a model one-semester classroom course in PBL instructional methods using the STEM PBL Challenges for use in pre-service Technology and Engineering Technology Education (TEE) programs and is currently engaged in research on the efficacy of PBL in STEM education to inform future development of PBL instructional materials. A detailed discussion of the STEM PBL Challenge development process, problems, collaborating partners, pre- and in-service teacher training program is presented.

The STEM PBL Challenge Model

The STEM PBL Challenges build upon the PBL model developed through a prior NSF-ATE project, PHOTON PBL, in which eight multimedia PBL Challenges were developed in partnership with photonics industry and university partners and field-tested by more than fifty STEM educators from secondary and post secondary institutions across the U.S and in Romania. The PBL Challenges are designed to be implemented using three levels of structure ranging from highly structured (instructor led) to guided (instructor guided) to open-ended (instructor as consultant). This unique scaffolded approach provides students with the necessary resources, tools, and support to guide them through a developmental continuum aimed at minimizing the stress and anxiety often encountered when experiencing PBL for the first time [3,11,12,13]. The eight PHOTON PBL Challenges and the six new STEM PBL Challenges as well as a wide array of instructional resources for implementing PBL in the classroom are currently available online at no cost by the New England Board of Higher Education at http://pblprojects.org.

Each STEM PBL Challenge contains five main sections:

1. *Introduction* - An overview of the topic to be explored
2. *Company/University Overview* - An overview of the organization that solved the problem to set the context of the problem
3. *Problem Statement* - A re-enactment of an authentic real-world problem as originally presented to the organization's technical team
4. *Problem-Discussion* - A password-protected re-enactment of the brainstorming session engaged in by the partner organization's technical team
5. *Problem Solution* - A password-protected description of the organization's solution to the problem

Figure 2 – Selected frames from a STEM PBL Challenge

A unique feature of the STEM PBL Challenges is the *Problem-Solvers Toolbox*, a resource designed to help guide students through the problem solving process. The Problem Solver's Toolbox four icons each link to a *Whiteboard* graphic designed to emulate an actual classroom whiteboard. The *Whiteboards,* shown in the lower right corner of Figure 2, provide a systematic method for students to capture their thoughts, ideas, and learning strategies during each stage of the problem solving process. For instructors, a comprehensive password-protected *Teacher Resources* section is included that provides technical background on the main concepts introduced, assessment tools and strategies, and implementation stories detailing how other instructors at different educational levels have implemented the PBL Challenge, and a standards alignment. Several frames from a STEM PBL Challenge are shown in Figure 2.

The topic areas for the STEM PBL Challenges were selected from a number of different sources including scientific literature, technical journals, government agencies, media resources, and industry and research university partners. The STEM PBL Challenge industry and organizational partners were identified through a network of personal contacts, industry groups, environmental organizations, university collaborators, and advisory board members. In total, six companies and organizations representing a broad cross section of sustainable technologies were selected as project partners.

Table 1 - STEM PBL Problem-Based Learning Topic Areas and Partners

Topic	Problem Description	Challenge Partners
Wind Energy	Extracting energy from a novel compact shrouded wind turbine.	- FloDesign Wind Turbine, Inc - Western New England College
Energy Efficient Solid State Lighting	Using solid state lighting to provide energy efficient illumination in submarines	- RLS Fiber Systems, Inc
Sustainable Agriculture	Reviving and old cranberry bog to make it water efficient and reduce the amount of chemical fertilizers and pesticides needed	- U.S. Department of Agriculture Natural Resources Conservation Service - Plymouth County Conservation District - Cape Cod Cranberry Growers' Association
Clean Water	Storm water remediation to restore the health of a county watershed in Philadelphia	- Tookany/Tacony Frankford Watershed Partnership
Solar Energy	Retrofitting an older building with solar panels in Tucson, AZ	- SPG Solar, Inc. - City of Tucson - Pima County Community College
Green Chemistry	Developing environmentally friendly personal care products	- Johnson & Johnson, Inc. (Currently Under Development)

The criteria for selecting problems suitable for PBL Challenges required that the problems:

1. Address an salient issue related to sustainability to capture the interest of students
2. Are open-ended with more than one possible solution
3. Are ill-structured to challenge students and promote inquiry
4. Are interdisciplinary in nature requiring collaboration and teamwork
5. Have been solved by the organization and the solution well documented.

Once a potential partner company or organization was identified, initial phone conversations with company representatives and the STEM PBL project team were held to explore possible challenge problems. Based on the criteria listed above, the problem was selected and evaluated to ensure that it was at a level appropriate for secondary and post-secondary STEM students.

Next, the STEM PBL project team visited each partner organization for a 1 ½ day PBL Challenge production meeting. The meetings typically began with an introductory presentation of the project goals and objectives and a sample demonstration of a PBL Challenge. Following the introduction, a partner organization provided a guided tour of their facilities, which was recorded on video and narrated to be included in the PBL Challenge to provide students with a first-hand look at the environment in which the problem was solved.

The next step was to video record the PBL Challenge problem statement. During this step, the personnel at the partner organization who solved the problem were asked to re-enact the scenario in which the problem was originally encountered, being careful to include specific details and any constraints that may have applied. This often involved a manager in a conference room or laboratory setting presenting his/her team with the problem needing to be solved. Partner organization team members were reminded to make the re-enactment as authentic as possible. At the end of the site visit, all video recordings were transcribed and edited to create the script for the Challenge.

Following the recording of the problem statement, the partner organization team was asked to recreate the brainstorming session in which they discussed possible solutions. The purpose of the brainstorming discussion is to provide hints that might guide a student toward a possible solution without revealing the exact details. During the brainstorming session, the team members were recorded discussing the various ideas and strategies used in solving the problem. To make the video more believable, the organization team members were asked to bring a change of clothing to give the impression that the problem statement and brainstorming session took place on separate days. Team members were also asked to bring notebooks to model careful note taking/journal keeping. In addition to guiding students toward the solution, the brainstorming discussion emphasizes that collaboration and teamwork skills are a critical part of solving real world problems and that real-world problems are inherently interdisciplinary, requiring knowledge and input from different disciplines.

The final step in creating a PBL Challenge was to record the organization's solution. Unlike many traditional open-ended PBL resources, the STEM PBL Challenges include the organization's solution against which students can compare and contrast their own solutions. For ease of production, the STEM PBL Challenge videos use a voice-over-still-photo technique with voice actors providing the audio. Video effects such as pan-and-scan (the "Ken Burns effect" available in Apple's iMovie) and interspersing actual video footage create the "look and feel" of the location where the problem was solved. The final drafts of the PBL Challenges were then reviewed for technical accuracy by the partner organization before being field-tested by teachers.

The STEM PBL Challenges

To date, five of the six STEM PBL Challenges have been developed and are currently being field tested by 30 secondary and post secondary STEM educators from institutions across the U.S. In the following section, we provide a brief description of the partner company or organization, the challenge problem, and the organization's solution.

Challenge 1: RSL Fiber Systems, LLC

RSL Fiber Systems[14] in East Hartford, CT worked with the United States Navy to develop a fiber optic illumination system called Remote Source Lighting (RSL). This technology involves generating light in one location and then transporting the light through fiber optic cable to another location up to 250 meters away. Applications include navigation, area illumination, security, and signaling lights. This allows the Navy to lower maintenance costs, reduce system down time, increase system ruggedness, and improve safety. RSL Fiber Systems has also been involved in a number of innovative lighting projects to replace conventional lights with light emitting diodes (LEDs) for US Navy ships.

The U.S. Navy asked RSL Fiber Systems to design an ergonomic and energy efficient lighting system for submarines, which have no natural light exposure. Research shows that sailors working in an environment without natural sunlight suffer greater stress and are less alert so they may make more mistakes on the job. The challenge presented to students is how to create a lighting system that mimics natural sunlight, promotes an 18-hour circadian rhythm, and is energy efficient.

The PBL Challenge reinforces students understanding of the biological effects of lighting, photometric and radiometric principles and measurements, fiber optics and electro-optic devices. Specifically, student will need to understand:

- When dealing with illumination, lumens (rather than watts) are the quantity of interest. Illuminance is lumens per square meter ("lux").
- LEDs can provide high luminous output with low energy consumption and are available in a variety of formats that allow spectral control.
- Optical fiber can be used to bring light to enclosed spaces from light sources located at a distance.
- The amount, spectral distribution, timing and duration of light important to circadian rhythms are very different from light needed for vision.
- Color temperature is often used to refer to the hue of "white" light.
- Losses in fiber optic systems are usually given in decibels; system losses can be used to determine total light throughput.

The RSL Fiber Systems solution involved developing a fiber optic lighting system using LEDs that varied the color temperature of the light delivered to a submariner's workspace over a 6 hour work shift. The system was designed to change the relative amount of red, blue, and green light generated by the LEDs in such a way that when combined, the color temperature of the light transitioned from cool red to hot blue and back to cool red at shift's end to simulate natural sunlight. This helps stimulate the circadian rhythm system in a way that is more natural, allowing submariners adjust to their 18-hour workday.

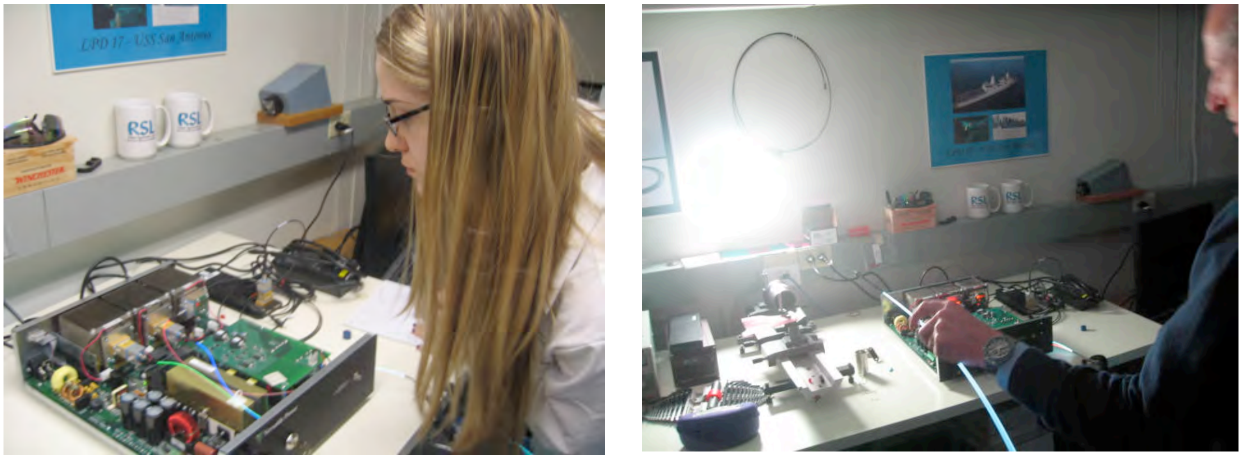


Figure 3 – RSL Fiber Systems optical fiber lighting system

RSL Fiber Systems has developed a number of optical fiber lighting systems for the U.S. Navy using halogen and other light sources. The advantage of fiber-delivered light is that the light source may be located at a distance from where the light is needed, reducing the need for electrical connections in the work area. Maintenance is also simplified, since a light from a single source can be brought to several locations via fiber optic cable.

LEDs were chosen for this application to reduce electrical energy usage and because they have very long lifetimes requiring infrequent maintenance and/or replacement. They are also resistant to vibrations and moisture, important considerations on submarines. Although this system uses LEDs, future systems may use red, green and blue lasers to produce white light of variable color temperature.

Challenge 2: FloDesign, Inc.

FloDesign Corporation[15] located in Wilbraham, MA, is a research and development company utilizing state-of-the-art aerospace technologies to develop, prototype, patent and market new products for other companies. Since 1990, FloDesign has successfully developed products for companies such as Rolls Royce, Sikorsky Aircraft and others.

FloDesign Wind Turbine Corporation is a spin-off from the parent company. Its mission is to develop, fabricate and test a novel mixer ejector wind turbine that uses an innovative shrouded design to draw more wind flow into the machine. The new design can potentially generate over three to four times the useful energy compared to a similarly sized conventional wind turbine. Working with faculty and students from the Engineering Department of Western New England College in Springfield, Massachusetts, plus its unique aerospace technology, allows FloDesign to be innovative, comprehensive, and efficient

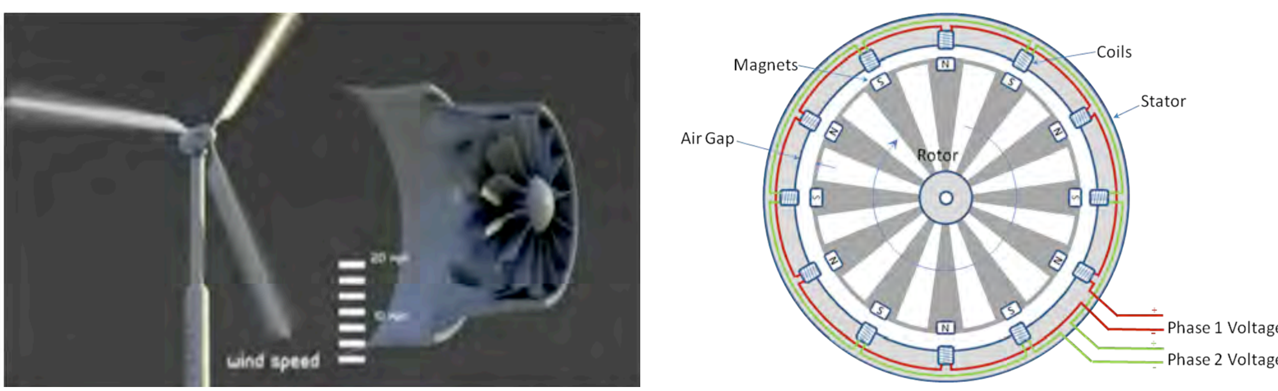
Although the idea of wind power has overwhelming public support, many people do not want huge, unsightly towers located near their homes and businesses. Excessive noise and danger to flying birds are also concerns. FloDesign Wind Turbine Corp. wants to design, develop, fabricate and test a new smaller, quieter and more efficient wind turbine. This new design idea can potentially generate over three to four times the useful energy compared to a similarly sized conventional wind turbine. The challenge to students is how to extract electrical energy from this new turbine design in a way that minimizes cost and increases reliability.

The PBL Challenge reinforces students understanding of the wind power, rotational dynamics, electrical generation, energy conversion, and electromagnetic energy. Specifically, student will need to understand:

- How wind turbines work
- Faraday's Law of Induction
- How an electrical generator creates electricity

The FloDesign Corp. solution, developed by a team of engineering students from a local college of engineering, was called "The Integrated Permanent Magnet Configuration" or IMP. Based on specification provided by FloDesign Corp., a scale model was built using the rapid prototyping capabilities of the engineering school's laboratory and tested to validate the design.

The IMP concept involved attaching a permanent neodymium magnet to each of the turbine's 60 rotor blades with alternating polarity, and 60 equally spaced stationary coils of wire to the stator of the turbine to effectively convert the turbine into a two-phase electrical generator. The design eliminated the need for the costly electrical generator and gearbox found in traditional turbines, saving money and improving reliability. Each of the 60 coils was wound from 24-gauge enameled magnet wire and wrapped around an iron core to strengthen the field in the coil. A simplified schematic of the prototype design is shown in Figure 3 (Note: Figure 3 was drawn with only 12 coil/magnet pairs for clarity).



(a) (b)

Figure 3 – (a) Wind Turbines: Common Blade-Type Wind Turbine (left) versus FloDesign Compact Shrouded Wind Turbine (right) (Image reproduced with permission from FloDesign, Inc.); (b) Simplified diagram of the FloDesign solution

Challenge 3: Cape Cod Cranberry Partners

The Cape Cod Cranberry Partners Challenge brought together partners from three organizations who worked to revive an old cranberry bog. The U.S. Department of Agriculture Natural Resources Conservation Service (NRCS) [16] was established by Congress in 1935 to protect the nation's farm land. Since that time, NRCS has expanded to become a conservation leader for all natural resources, ensuring private lands are conserved, restored, and made more resilient to environmental challenges. Experts from many science and technology disciplines work together with landowners to benefit the soil, water, air, plants, and animals.

The Plymouth County Conservation District[17] in Plymouth, MA was established by state legislation over 50 years ago. Today, as then, it is a local environmental agency dedicated to wise land use and conservation of natural resources. The district provides leadership to set priorities for local conservation activities and it works hand-in-hand with NRCS to achieve them.

The third partner is the Cape Cod Cranberry Growers' Association[18]. Established in 1888, it is one of the oldest farmer organizations in the country. The goal of the Association is to "Enhance the economic viability of the Massachusetts cranberry grower's by supporting and promoting the cranberry growers of Massachusetts."

Traditional cranberry farming is very water intensive. It also uses a large amount of chemical fertilizers and pesticides that can runoff into the local water supply. The challenge to students is to devise a plan to revive an old cranberry bog to make it water efficient, reduce the amount of chemical fertilizers and pesticides needed, and minimize the amount of chemical fertilizers and pesticides released into surrounding streams.

The PBL Challenge reinforces students understanding of the biological effects of pesticides and fertilizer on plant growth and water resources, heat and cold on plant growth, drought and flooding on plant growth, and irrigation technology. Specifically, student will need to understand:

- Cranberries are grown in wetlands or uplands with a high water table
- Water is key for growing cranberries, for both flooding and irrigation
- Environmental regulations govern the use of chemicals, how they are applied and how runoff is treated after application
- Sensors may be used to automate irrigation

The project had several components, most relating to water management. First, a 2,000-foot long storm-water bypass canal was built under NRCS supervision so that the flowing water does not come in contact with the cranberry bog. Flumes allow water to be directed onto the bog for flooding or held in the canal after chemical application. This was a major step forward in water quality preservation and water conservation.

The main water flow ditch running through the center of the bog was filled in and a new dike was constructed parallel to the canal and centered on the bog, creating two new bogs each approximately 200 feet by 1,100 feet (5.5 acres). Old cranberry vines were stripped and removed from the bog area. The material excavated from the squaring off of the bogs was used as solid fill to construct the dike and the peat removed from the excavation for the dike was used on the bottom of the squared off area as an organic confining layer. The entire area was sub-graded prior to the application the sand. Sand was laser leveled on the bog to a thickness of 6 inches. The bogs were replanted with a variety known as Steven's Vines at a rate of 2.0 tons per acre. Perimeter ditches were excavated along all dikes. On each bog there is an open center-line ditch with the ends piped to the perimeter ditch to allow bog equipment to traverse the sides. This design minimizes the distance required to install drainage from any trouble area to any discharge point. Figure 4 below shows a photograph of the revived bog.

(a) (b)

Figure 4 – (a) *Before*: Old abandoned cranberry bog; (b) *After*: Newly revived and environmentally friendly cranberry bog

A new irrigation system was also installed. A single fuel-efficient four-cylinder diesel motor with pump serves both bogs and each bog has a dedicated welded plastic main line. Pop up sprinkler heads that cover 50 foot x 40 foot area achieve 90% coverage and reduce watering time to less than 4 minutes for effective pesticide application in addition to protecting the environment from pesticide run off.   An electronically monitored pump automatically provides watering under frost and high temperature conditions conserving fuel and water, and reducing emissions for superior crop protection. Automated soil moisture sensors are planned for the near future.

Challenge 4: Tookany/Tacony-Frankford Watershed Partnership

The Philadelphia Water Department initiated the Tookany/Tacony-Frankford Watershed Partnership (TTF) [19] in 2000 with a mission to enhance the health and vitality of the Tookany/Tacony-Frankford Creek and its watershed. TTF was incorporated in 2005 as a non-profit organization that acts as the crucial link connecting residents, businesses and government as neighbors and stewards of this impaired, but critically important watershed. Through educational programming, community outreach, networking services, and project coordination, the partnership facilitates, supports, and initiates efforts to restore the health of the watershed and to mobilize its communities as watershed stewards.

The large impervious surfaces of an urban environment prevent rain from seeping into the ground where it can be taken up by the roots of plants and trees. In many parts of Philadelphia there are combined sewer systems where storm water and sewage share the same pipes and when it rains, a combination of sewage and storm water to flow untreated into local streams, including those eventually used for drinking water. The challenge to students is to develop a strategy to reduce the amount of storm water entering a sewer system without massive and expensive construction projects and with the full support of the local population.

This PBL Challenge introduces students to the concept of "green infrastructure" and simple cost effective techniques including the use of soil and vegetation to trap, filter, and infiltrate storm water can be implemented in urban environments to reduce the environmental impact of storm water runoff and pollution. Specifically, students will need to understand:

- Stormwater runoff is caused by rain and melting snow that fall on impervious paved surfaces and flows downhill through the force of gravity.
- Stormwater runoff picks up dirt and pollutants as it flows downhill into storm drains and ultimately into streams, rivers and lakes.
- Polluted storm water runoff can threaten public health and degrade wildlife habitat.
- Green techniques including rooftop gardens on city buildings, absorbent concrete, and street planters that intercept rainwater before it hits the ground can be used to protect the local watershed.

The TTF Watershed Partnership worked with the community around the Awbury Arboretum in Philadelphia where their office is located and developed several stormwater management projects using green infrastructure. Some project were done by the neighbors themselves and others were designed, constructed and financed by the TTF partners.

One project involved using 55-gallon rain barrels connected to the downspout of houses to collect rainwater that could be attached to a garden hose or soaker hose to water plants, wash the car, etc. In the immediate neighborhood, over 60 rain barrels have been installed so far.

Figure 5 – Rain barrel installation at a Philadelphia home

The Philadelphia Water Department supported several other projects around the Waterview Recreation Center by installing porous concrete sidewalk. The sidewalk soaks up rainwater and channels it into a perforated drain pipe under the sidewalk and into a subsurface gravel storage area that holds the water. There are also storm inlets in the street that lead water into the storage area beneath the sidewalk rather than sending it into the sewers; an overflow prevents flooding if the water rises too high. Perforated pipes connected to the storage area carry the water back to the land where it is used by trees chosen for an urban environment. On both side of the front stairs of the Waterview Recreation Center, flow-through planters were installed that take water from the building's downspout and direct it onto native plants with long roots capable of absorbing a large amount of water. A raised drain at the end of the flow-through planter siphons off excess water if it gets too high.

In Cliveden Park, a bioswale directs stormwater off the streets and into a green space where it can be used by plants. The land the park is built on is shaped like a bowl and the streets on either side carry a tremendous amount of water when it rains into the bowl. The Philadelphia Water Department routed pipes into the park from streets on each side, and the Pennsylvania Horticultural Society helped choose native plants and trees. Steps were built with planted areas on each level to break up the flow of water as it goes downhill. A raised drain at the base of the steps prevents flooding of the surrounding area.

With the help of the City of Philadelphia, the TTF Watershed Partnership is transforming a vacant lot into a rain garden by redirecting stormwater from a frequently flooded street into a plot of unused land. Planted with trees and native plants, it will serve as a stormwater management demonstration site, community meeting space, and outdoor classroom. The neighborhood is also installing more public transit stops and is working with the City to design shelters with green roofs. Concerns over traffic is also being addressed through green infrastructure by building bump-outs into the roadway that hold native plants, therefore slowing the speed of cars, beautify the neighborhood and managing stormwater at the same time.

Challenge 5: SPG Solar & the City of Tucson, AZ

Tucson, AZ, located in sunny Pima County, has been steadily expanding its solar energy resources. As one of 25 Solar America Cities, Tucson is committed to improving the energy efficiency of city buildings and operations, and to increasing the city's use of solar energy. More than sixteen city buildings and several open spaces have been outfitted with solar installations and more are planned. Many private homes also sport rooftop solar installations and since 2009 all new single family homes and duplexes are required to include either a solar hot water system or plans for later installation of a solar hot water system in order to receive a building permit.

SPG Solar[20], headquartered in Novato, CA, earned a leadership position in the solar industry through their passion, dedication and commitment to providing the highest quality product for customers. With over 1,500 solar systems installed in the United States, SPG provides comprehensive turnkey services, managing the entire process through financing, installation, ongoing system monitoring & maintenance. SPG's clients have won awards for their solar systems from the Environmental Protection Agency, U.S. Department of the Interior, the American Institute of Architects, and many other organizations.

The city of Tucson has identified a number of buildings on which they want to place solar panels. One of these buildings, an older warehouse, was determined to have a roof structure unable to support a traditional solar array. In addition, because the building is a warehouse where surplus equipment is stored, the city requires a non-penetrating solar panel system to prevent roof penetrations leading to water leaks. The challenge to students is to find a light weight, non-penetrating solar panel solution that will supply a specified kilowatt-hour output for the building.

This PBL Challenge introduces students to the principles of solar energy, photovoltaic panels, power and energy calculations, and power conversion. Specifically, students will need to understand:

- How a photovoltaic panel converts light energy into electricity.
- How to determine the electrical output of a solar panel from solar irradiance.
- How to determine how many solar panels are required for a particular kilowatt-hour specification.
- The different types of solar panels available and their intended applications.
- How to determine the power-to-weight ratio and cost-benefit ratio for a particular solar panel application.

After analyzing roof loading capacity and output power requirements, and researching different options, SPG Solar selected a solar panel manufactured by Solyndra Corporation[21] of Freemont, CA. The Solyndra panel is a non-penetrating non-ballasted system weighing about 3.3 pounds per square foot, which was well within the weight limit of the warehouse roof.

Solyndra's solar panels are different than the typical photovoltaic panel in that each panel employs an array of cylindrical thin film solar cells rolled up inside of a glass tube. They are very lightweight in comparison to traditional flat panel arrays and do not need to be tilted toward the sun since the cylindrical geometry allows direct illumination on the top surface by direct and scattered sunlight and indirect illumination of the bottom surface by light reflected from the roof.

(a) (b)

Figure 6 – (a) Traditional solar panel installation (b) Solyndra solar panels

Another benefit of the Solyndra system is that wind can circulate around the tubes so there is no problem with uplift. This feature eliminates the need to penetrate the roof surface to secure the panels to the building structure and therefore preventing the possibility of any leaks in the roof. To enhance reflectivity of the roof, and hence the amount of light illuminating he back side of the solar panels, the roof was coated with a bright white elastomeric roofing material. While the cost per panel is higher than traditional panels, the installation is much simpler. The Solyndra system takes about 3 days to install, compared to two weeks for a penetrating or ballasted system. Once the panels are stacked on the roof, the legs are bolted onto each panel and the panels are clipped onto and plugged into the previous panel with two wires and the job is complete.

In total, 260 (182 Watts/73.9 volts DC/2.46 amps DC per panel) Solyndra panels were installed plus a monitoring system to keep track of temperature, irradiance, and wind speed. The final system is rated at 47.32 kW DC, which was converted to 35-36 kW AC using an electrical inverter that converts the DC power to AC power. There were also alarms installed on the system to alert the proper authorities via e-mail if there are any malfunctions in the system requiring a service call. Twenty-four hour monitoring of system output and ambient conditions is available on the web.

Professional Development for In-Service Educators

The STEM PBL project recruited 31 STEM educators from secondary and post-secondary institutions from across the U.S. to participate in a 15-week web-based course[3] in PBL instructional methodology using the STEM PBL challenges. The web-based course format was adopted from the professional development model developed through a prior NSF-ATE project, PHOTON2 [22, 23, 24], in which adult learning principles were applied in the design of the course to foster active and collaborative learning with the goal of producing positive change in teaching practice. The online course is broken into three 5-week sessions offered in fall 2010, winter 2011, and spring 2011, totaling 90 hours of coursework, with a break of 6-8 weeks between sessions. Experience gleaned from the PHOTON2 project revealed that participants performed better in short-term sessions with time in between to reflect on their learning experience and begin to plan implementation of the course material in their own classrooms [23, 24].

Educators applied for participation in the STEM PBL project in regional alliances, a two- or four-year college paired with one or more high school partners in the same geographical area. In previous projects, this alliance model has led to increased cooperation among secondary and postsecondary schools and strengthened articulation opportunities for students.

Course participants were split into seven small teams of 4-5 teachers to model the dynamics of how the PBL Challenges will be used in their classrooms. Using Blackboard Vista® as a course delivery platform, participants worked to solve three STEM PBL Challenges, beginning with a Structured format (Session I), then a Guided format (Session II), and finally an Open-ended format (Session III) through threaded discussions and online chats. Over the three 5-week sessions, participants are given greater autonomy and more responsibility to self-direct their own learning. This gradual transition from highly structured to open-ended is designed to emulate the way in which instructors will use Challenges with their own students. To facilitate collaborative problem solving among participants, each team was assigned a separate problem-solving “wiki” at www.pbworks.com to emulate the Problem Solving Toolbox feature of the STEM PBL Challenges. Between online class sessions, participants were encouraged to collaborate with their alliance partners to explore how best to incorporate the PBL Challenges into their own classroom and curriculum. Participants were also added to the PBL listserv; an email listserv managed by the New England Board of Higher Education (NEBHE) composed of nationwide network of PBL educators, educational researchers, and industry mentors.

Results from the first 5-week session were encouraging. Of the seven teams, six presented solutions to the assigned Challenge (TTF Watershed Partnership); several of these were very detailed and showed cooperation among team members. Of the 31 educators recruited for the program, 29 educators participated in the first session of the course. Over the 5-week session, 15 educators were considered "active" (regularly posting comments) while 9 others visited the course sites on several occasions but did not contribute. Of the remaining participants, two were inactive because of health issues. Several efforts were made to personally contact non-active participants to offer assistance and encouragement, but in the end, a lack of time to commit to the course was the most common reason cited for inactivity.

During the break between the first two sessions, several participants implemented the TTF Challenge with their classes. They reported that while students generally enjoyed the Challenge, some students were not enthusiastic about the amount of research required to develop a solution. A common observation of participants is that high achieving students who do well with traditional instruction often seem more uncomfortable with PBL then lower achieving students who enjoy a chance to participate in a project on an equal footing with their peers.

After the first session concluded, several participant suggestions were implemented for Session 2: (1) the weekly calendar began on Wednesday (rather than Monday) to allow educators who accessed the course sites on weekends to more fully participate before new material was introduced; (2) the BlackBoard® home page was simplified and direct links to the other sites were added; and (3) two phone conferences were held with participants one week before the second session start date to allow those who were unsure about participating in the first session to practice using the communication features of the course web sites. This intervention resulted in 21 of 29 participants active on the course web sites within the first week of Session 2 compared with 13 of 29 in Session 1.

A Model Classroom Course for Pre-Service Technology and Engineering Educators

The STEM PBL project has created a model course in PBL methodology using the STEM PBL Challenges for Technology and Engineering Education (TEE) majors. Upon graduation, these new generation teachers will be prepared to teach middle- and high-school STEM courses using PBL methods. To accomplish this goal, an existing required classroom course in instructional methods (TE 399) at Central Connecticut State University (CCSU) has been redesigned to incorporate PBL theory and applications. The new course will be offered for the first time in spring 2011. The TE 399 course is required of all TEE undergraduates at CCSU and students must have taken at least one practicum course in the program and achieved junior status prior to enrolling.

Similar to the online course, students will work to solve three STEM PBL Challenges, first as a structured problem, then as guided and open-ended. As a capstone project for the course, students will use the pedagogical strategies and technical skills they acquire throughout the semester to develop an original multimedia PBL Challenge on a STEM topic of their choosing. As a result, a collection of STEM-related PBL learning tools will evolve and will be disseminated through the NEBHE PBL web site.

Conclusion

In this paper, we reported on the progress of the STEM PBL project, a three-year NSF-funded project aimed at increasing the STEM pipeline through PBL focused on sustainable technologies. Working closely with industry, government, and university collaborators involved in new cutting-edge sustainable technologies, five of the six proposed multimedia STEM PBL Challenges focused on sustainability technologies including solar and wind energy, clean water, energy efficient lighting, and sustainable agriculture have been completed and are undergoing field testing by educators across the U.S. A detailed description of the five PBL Challenges was presented. The remaining PBL Challenge, which involves "green chemistry" applied to personal care products is currently in its final stages of development in partnership with Johnson & Johnson Corporation and will be available in spring 2011. The online professional development course in PBL methods for in-service STEM educators which was launched in fall 2010 is currently in progress and showing promising results. Finally, the classroom course for pre-service TEE majors at CCSU has been developed and is scheduled to commence in spring 2011.

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