AC 2010-1725: PROBLEM-BASED LEARNING IN SUSTAINABLE TECHNOLOGIES: INCREASING THE STEM PIPELINE

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Problem-Based Learning in Sustainable Technologies: Increasing the STEM Pipeline

Abstract

In this paper, we present the "*Problem Based Learning for Sustainable Technologies: Increasing the STEM Pipeline*" or "STEM PBL" project, a new three-year National Science Foundation Advanced Technological Education (NSF-ATE) project of the New England Board of Higher Education (NEBHE) aimed at increasing the STEM pipeline through problem-based learning (PBL) focused on sustainable technologies. We will discuss how the STEM PBL project team is partnering with industry and research universities who are breaking new ground in sustainable "green" technologies to create a comprehensive series of multimedia PBL instructional materials designed to engage secondary and post-secondary students in real world problem solving with a focus on sustainable technologies. Professional development for teachers and faculty in PBL instructional methods using the STEM PBL materials as well as the development of an online course for in-service STEM teachers and a classroom-based course for pre-service STEM teachers will be discussed. Descriptions and examples of the new multimedia STEM PBL instructional materials will also be presented.

Introduction

As a new generation of American students move through the educational pipeline, they are inundated with information regarding sustainable technologies and all things "green." Sustainable technology involves design and innovation that provides for our current needs without sacrificing the ability of future generations to sustain themselves[1]. Inherently multidisciplinary, sustainable technology requires a holistic approach to understanding the social, economic, and environmental impact that technological innovation poses on the earth and its limited resources. From alternative energy such as wind, solar, and geothermal, to energy efficient lighting, buildings and vehicles, to enabling technologies such as nanotechnology, biotechnology and photonics, in the 21st century sustainable technology will play an increasingly important role in the world in which we live.

The implications of sustainability are far-reaching and pervasive, affecting 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. A growing number of companies and organizations have begun to embrace the idea of sustainability from the perspective that protecting the environment makes good business sense. In education, federal, state, and privately funded programs are creating educational resources for teachers and students aimed at increasing awareness of the importance of sustainability and environmental responsibility. Unfortunately, even with all of the focus and attention given by policy makers and the media about the importance of sustainability, student enrollment in science, technology, engineering, and math (STEM) fields in the U.S., fields critical to the development of sustainable technologies, continue to lag behind other industrialized nations.

The U.S. Bureau of Labor Statistics predicts that from 2004 to 2014, the number of jobs in STEM occupations will grow by 22 percent, twice the rate of all other occupations[2]. According to a recent NSF report[3], however, the United States is experiencing a chronic decline in homegrown STEM talent and is increasingly dependent upon foreign scholars to fill workforce and leadership voids. This concern was echoed by former Microsoft Chair Bill Gates, who in March 2008 warned Congress the shortage of engineers and scientists is so acute that "if we do not reform our educational system, American companies will not have the talent to innovate and compete"[4]. Clearly, if the United States is to maintain its competitive edge in the global economy, we must increase the pipeline of interested and qualified students prepared to enter STEM careers, not only at the baccalaureate and advanced degree level, but also at the sub-baccalaureate degree level including associate degree and certificate level *engineering technicians*.

One of the reasons for declining enrollment in many engineering technology programs is that students are often "turned off" by the way technical subjects are taught; traditional classroom lectures followed by "cook-book" type laboratory experiences that provide little opportunity to actively engage in creative *real-world* problem solving. Engineering technicians are problem solvers – individuals who skillfully apply their knowledge in solving real-world problems. Working side-by-side with engineers and scientists, engineering technicians are the "hands-on" side of an engineering team, responsible for designing experiments, building and troubleshooting prototypes, analyzing and interpreting data, and presenting experimental results to peers, supervisors and customers. If the U.S is to attract more students into STEM-related careers, they must be provided with learning experiences that captivate and motivate them through engagement with authentic real-world problems that appeal to their natural creativity, imagination, and passion, while at the same time develop their problem solving and critical thinking skills [5,6,7,8,9,10]. One instructional method capable of providing this type of learning experience is PBL.

Problem Based Learning

PBL is an instructional approach that challenges students to "learn how to learn" through collaborative real world problem solving. Used extensively in medical education since the 1970's, PBL has emerged as an exciting and effective alternative to traditional lecture-based instruction in STEM education. Unlike project-based learning in which students complete a project after they have mastered course material, PBL students learn course material in the process of solving a problem. In PBL, the problem itself drives the learning. Students are active participants in their own learning, placed into a problem situation where problem parameters are not well defined and more than one outcome is possible.

PBL usually involves four steps: problem analysis, self-directed learning, brainstorming discussions, and solution testing (see Figure 1). In the first step, students are presented with a problem and asked to identify what is known and unknown and if any constraints apply. After working together to analyze the problem and its requirements, students then create their own plan for acquiring the knowledge necessary to solve the problem. The instructor acts as a facilitator as students independently seek out the information and resources needed to fill in their knowledge gaps. Once the self-directed learning phase is complete, the group reconvenes to brainstorm possible solutions and then devise a test plan to validate their solution. If the solution does not adequately address the problem, the cycle is repeated. Student groups then present their final solution for peer review and comment and reflect on their learning experience.

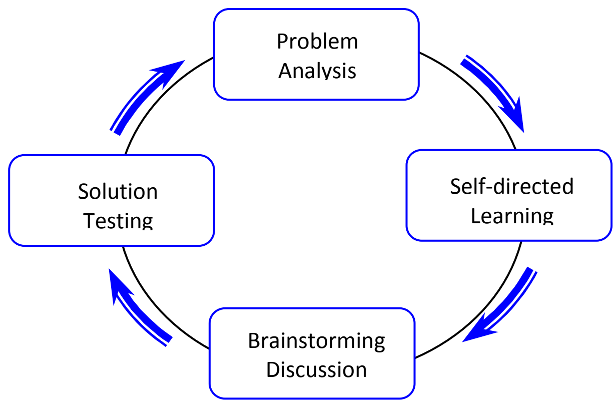

Figure 1- The PBL problem solving cycle

Research shows that compared to traditional lecture-based instruction, PBL improves student understanding and retention of ideas, critical thinking and problem-solving skills, motivation and learning engagement, and the ability able to adapt their learning to new situations – skills deemed critical to lifelong learning[11,12,13,14, 15,16].

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. While some progress has been made in the development of curriculum materials and professional development opportunities for teacher and faculty in PBL through NSF-ATE projects such as TheCaseFiles®[17], the PHOTON PBL Project[9], Project ProBase[16], and others, more work is necessary to provide students in secondary and post-secondary STEM courses with educational experiences that not only develop their problem solving and critical thinking skills, but also heighten their awareness of STEM related career opportunities.

To address these issues, the STEM PBL project will build upon the successes of the NSF-ATE PHOTON PBL project launched in 2006, in which eight multimedia PBL "Challenges" were developed in partnership with photonics industry and university partners and field-tested by more than 50 STEM educators from secondary and post secondary institutions across the U.S.. The PHOTON PBL Challenges are self-contained multimedia instructional modules designed to develop students' problem solving ability and understanding of photonics concepts and applications. The eight PHOTON PBL Challenges currently available online at http://pblprojects.org include:

- *Stripping with light, fantastic!* - PhotoMachining Inc. in Pelham, NH needs to develop a laser-based process for stripping the coating from 50 micron wire.

- *DNA Microarray Fabrication* - Boston University graduate students need to determine the best starting exposure time for a DNA microarray fabricator.
- *High Power Laser Burn-In Test* - IPG Photonics in Oxford, MA needs a way to run 100-hour unattended burn-in tests on a 2-kilowatt laser.
- *Shining Light on Infant Jaundice* - Partners Photodigm, Drexel and SMU ask, "Can technology provide a safe and effective portable home treatment for newborn jaundice?"
- *Watt's my light?* - The package on an energy-saving light bulb says the 26 watt fluorescent has the same light output as a 100 watt incandescent. Can Cal Poly Pomona students verify this statement?
- *Of mice and Penn* - UPenn McKay Orthopaedic Research Lab graduate students study the healing of tendon injuries using mouse tendons. Can optics provide a non-contact method for measuring mouse tendon properties?
- *Hiking 911* - Two boys are lost in deep woods in rough terrain. Penn State Electro Optics Center (EOC) needs to recommend the best technology to locate them.
- *Blinded by the Light* – A man is arrested for blinding a pilot with a laser pointer. Is he innocent or guilty? Make your case.

Similarly, the STEM PBL project will develop six additional PBL Challenges focusing on sustainable technologies to bring real-world problem solving experiences into STEM classrooms to develop students' critical thinking and problem solving skills and to expose them to the exciting career possibilities in sustainable technologies. Professional development opportunities for in-service and pre-service STEM educators will develop teachers' capacity for incorporating PBL instructional methods in their classrooms.

The STEM PBL project proposes to increase the STEM pipeline through four primary goals:

1. Develop six multimedia STEM PBL "Challenges" focused on sustainable technologies in collaboration with industry and university partners designed to appeal to secondary and post-secondary STEM students. Topic areas will include alternative energy (wind, solar, geothermal, and biomass), environmental safety and protection, lighting, nanotechnology, and biotechnology.
2. Create and implement a web-based professional development course for in-service STEM educators in PBL methodology and the implementation of the PBL Challenges in the classroom.
3. Develop a model one-semester classroom course in PBL instructional methods using the STEM PBL Challenges for use in pre-service technology and engineering teacher education programs.
4. Conduct research on the efficacy of PBL in STEM education to inform future development of PBL instructional materials.

The three-year project, which commenced in September 2009, will prepare up to 60 secondary and post-secondary STEM educators from across the U.S how to incorporate PBL instructional methods into their courses.

The Anatomy of a PBL Challenge

The PBL Challenges[18,19,20] provide students with authentic real-world problems presented in a multimedia format designed to emulate the real-world context in which the problems were encountered and solved. 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 by students engaging in PBL for the first time. Each PBL Challenge contains five main sections that are illustrated in Figure 2:

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 re-enactment of the brainstorming session engaged in by the partner organization's technical team
5. *Problem Solution* - A detailed description of the organization's solution to the problem

The *Problem Discussion* and *Problem Solution* sections are password protected, allowing instructors to control the flow of information and pace of instruction. This feature gives students the opportunity to brainstorm and test their own solutions while providing a "safety net" in the event that they experience difficulty and need further direction. Each of the five main sections contains additional information and resources (i.e., scripts, websites, spec sheets, etc.) designed to guide the student through the problem-solving process.

For instructors, a comprehensive "*Teacher Resource*" section is included (see Figure 3) that provides technical background on the main concepts introduced, assessment strategies, implementation stories detailing how other instructors at different educational levels have implemented the PBL Challenge, and a standards alignment. By allowing students to gradually progress through the PBL Challenges along a developmental continuum, students can develop the knowledge, skills, and confidence to take responsibility for their own learning. Likewise, providing instructors with control over the learning process and user-friendly technical and pedagogical resources make it easy to implement PBL in their classrooms.

Another unique feature of the PBL Challenges is the "*Problem-Solvers Toolbox.*" The *Problem Solvers Toolbox* is a resource designed to help students develop a systematic approach to problem solving through a four-stage recursive process as illustrated in Figure 4.

- *Problem Analysis* – Identifying what is known, what is unknown and needs to be learned, and identifying any problem constraints to properly frame the problem.
- *Self-Directed Learning* – Setting specific learning goals, identifying necessary resources, and developing a timeline and strategy for achieving those goals.
- *Brainstorming* – Productively engaging in collaboratively learning to identify the best course of action for solving the task at hand.

- *Solution Testing* – Developing a viable test plan to validate the solution based on specific performance criteria.

Figure 2- PBL Challenge main screens. Top row: Challenge Overview, Challenge Introduction. Middle row: Organization Overview, Problem Statement. Bottom row: Brainstorming Discussion, Organization's Solution.

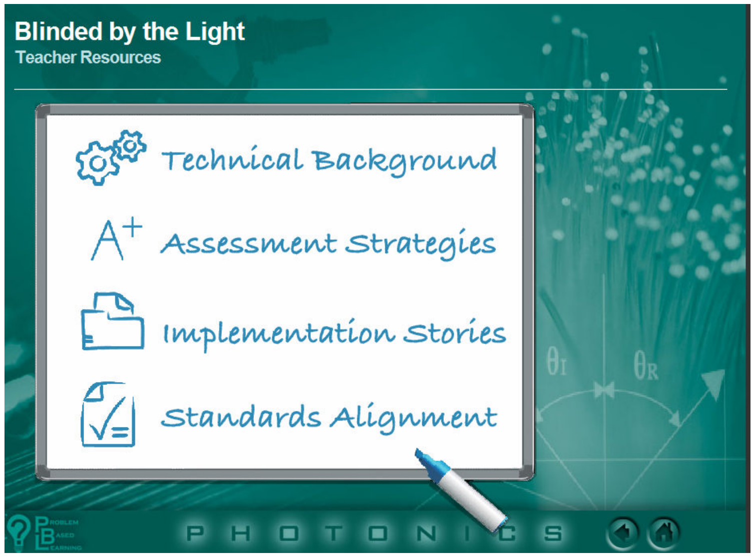

Figure 3 - Teacher Resource Frame

Figure 4 - Problem Solving Toolbox with icons representing Problem Analysis, Self Directed Learning, Brainstorming Discussion and Solution Testing

For each of the four processes, students click on an icon that reveals a "*Whiteboard"* graphic designed to emulate an actual classroom whiteboard. The *Whiteboards,* shown in Figure 5, provide a systematic method for students to capture their thoughts, ideas, and learning strategies during each stage of the problem solving process. Students may cycle through the whiteboards several times for a given problem, revising their problem solution each time until they converge on an optimal solution. For instructional purposes, the *Whiteboards* can be projected onto an actual classroom whiteboard using an LCD projector.

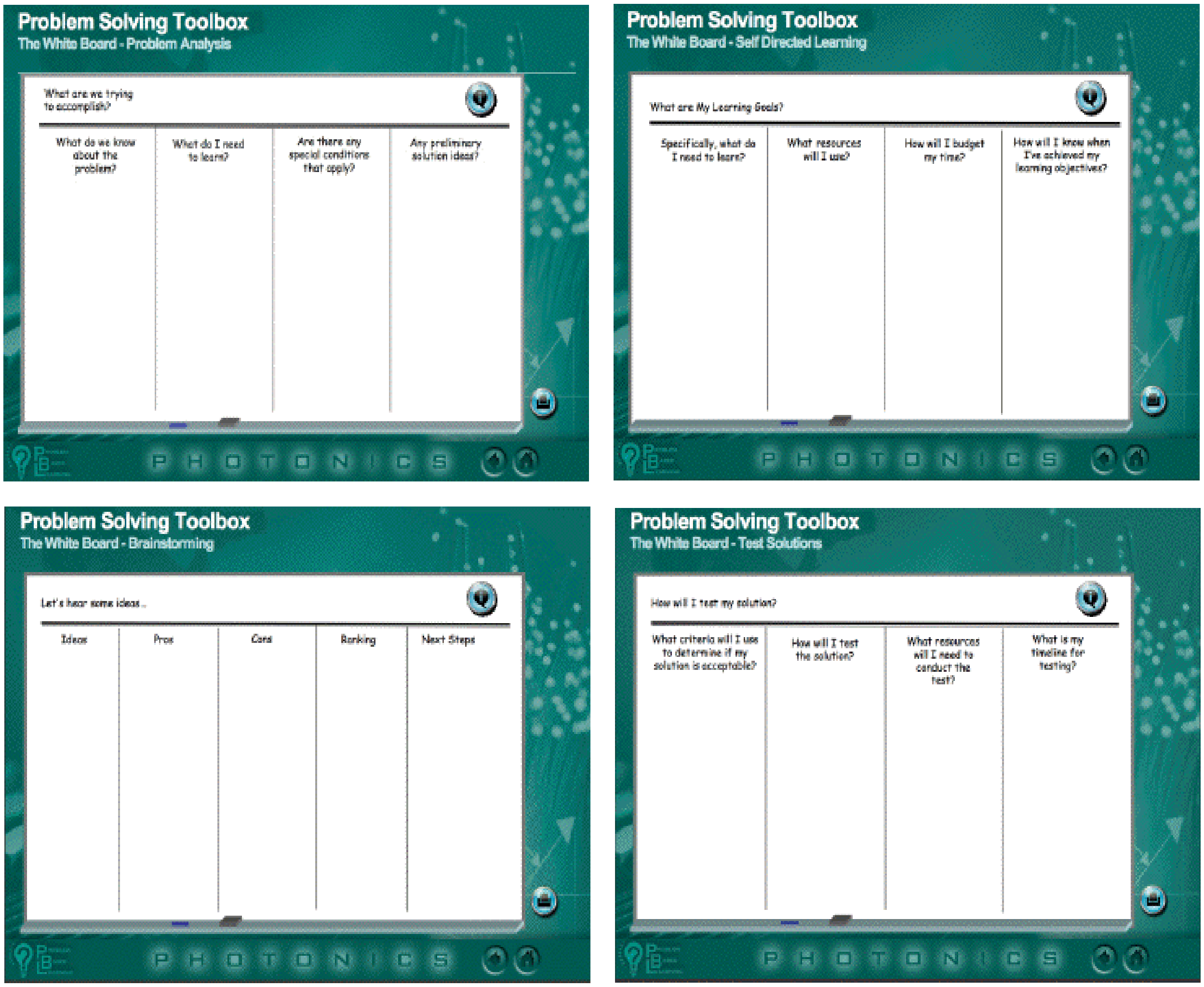

Figure 4 - The PHOTON PBL Whiteboards for (clockwise from upper left) Problem Analysis, Self Directed Learning, Brainstorming, Testing Solutions.

Assessing student learning in PBL often presents a unique challenge for educators accustomed to traditional assessment methods used in lecture-based instruction. The method used to assess student learning in the PBL Challenges is based on a three-pronged "adaptive expertise" model adapted from the Vanderbilt-Northwestern-Texas-Harvard-MIT (VaNTH) Research Center for Bioengineering Educational Technologies[21, 22] which involves three measures: content knowledge, conceptual knowledge, and problem-solving ability (see Figure 5). A weighted average calculated for the three measures results in a final composite score. Specific weights may be assigned by the instructor depending on the specific course format.

To assess *content knowledge*, the PBL Challenges include a test bank consisting of multiple-choice questions, closed-ended problems, and higher-level thought provoking questions centered on specific technical content associated with the particular problem. *Conceptual knowledge* refers to a student's understanding of and relationship between key concepts underlying a particular domain of knowledge. To assess conceptual knowledge, the PBL Challenges include a list of main concepts related to the topic being explored, a reference or “expert” concept map for instructors, detailed instructions for students on how to construct a concept map, and a concept map scoring rubric. Assessing *problem solving ability* involves both formative and summative assessments. Formative or *in-process* assessment is accomplished via the *Whiteboards*. As students collaboratively engage a problem by completing the four *Whiteboards*, they reflect upon and elucidate their current state of understanding, their thought processes, and problem solving strategies. Research shows that verbalizing the thought process while engaging in problem solving improves metacognition, which is essential for effective problem solving[23]. Summative or *post-process* assessment is accomplished through a *Final Challenge Report.* The *Final Challenge Report is* a reflective journal that requires students to provide a detailed summary and critical analysis of the problem-solving process employed in solving the PBL Challenge. Researchers maintain that this final reflective exercise is essential in the development of effective problem-solving skills[24]. A scoring rubric is provided to grade the *Final Challenge Report.*

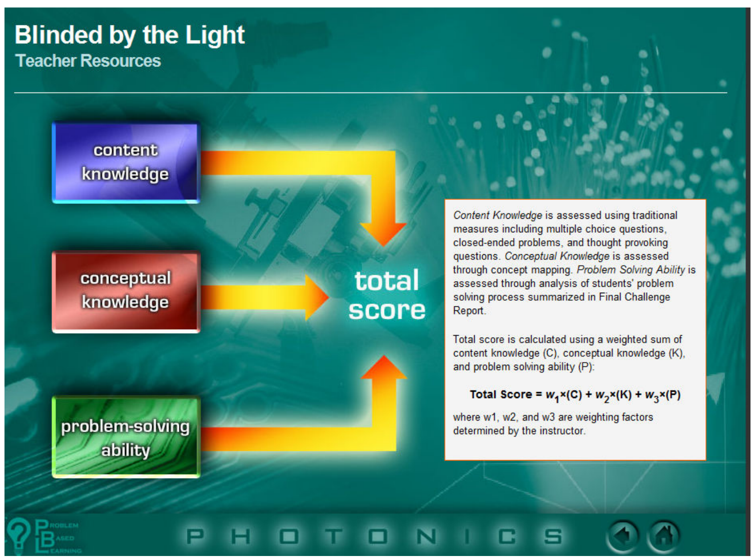

Figure 5 – Student Assessment in PBL

Creating the STEM PBL Challenges

The first step in developing a PBL challenge[25] is to enlist the aid of industry and research university collaborators who had potential problems that would make engaging PBL Challenges. Three PBL Challenges are being developed during the 2009-2010 academic year; three more will be developed during the 2010-2011 academic year. Salient topics relating to sustainable technology are identified from a number of different sources including contemporary literature, technical journals, government, media resources, and industry and research university partners. Criteria for selecting problems suitable for PBL Challenges requires 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, and (5) have been solved by the organization and the solution well documented. Table 1 provides a partial list of Challenge topics and potential Challenge development partners.

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

Sustainable Technology Topic area	Problem Description	Tentative Industry or Research University Sponsor
Wind Energy	How to extract energy from a novel compact shrouded wind turbine.	- FloDesign Wind Turbine, Inc - Olin University - Western New England College
Energy Efficient Lighting	Using solid state lighting to provide energy efficient illumination	- RLS Fiber Systems, Inc - Connecticut Center for Advanced Technology
Smart Grid Sensor Network	Using Smart Grid technology to improve efficiency of electrical power distribution	- ISO New England - National Grid, Inc - Boston University Smart Grid Consortium - Springfield Technical Community NSF-CCLI Sensor Network Project
Environmental Protection	Waste water management and purification	- Tookany/Tacony Frankford Watershed Partnership
Green Building Technology	Passively heat a building	- Touzour Trane Energy Systems
Solar Energy	Solar cell fabrication	- Konarka - Solyndra

Once a suitable problem and sponsoring organization has been identified, the STEM PBL project team visits the sponsoring organization for a one- or two-day production meeting. The meetings typically begin with a presentation of the PBL project's goals by the STEM PBL project team followed by a tour of the facility which is recorded on video and narrated to provide students with a first-hand look at the environment in which the problem was solved. The video tour is an important component of the PBL Challenge as it sets the context for solving the problem and provides students with a glimpse into the real world in which they may someday apply their problem solving skills.

The next step is to record the actual PBL Challenge problem statement. It is critical during this step that the engineers, scientists and technicians at the partner organization reenact the original problem statement as it was originally encountered, being careful to include specific details and any constraints that may apply. This often involves an engineering manager in a conference room or laboratory setting presenting his/her team with the problem to be solved. For example, for the FloDesign Wind Turbine Challenge, the engineering manager in a conference room tasks the company's engineers and technicians to work with undergraduate engineering students from Olin University and Western New England College to develop a novel method for extracting energy from a compact shrouded wind turbine. The manger explains on a whiteboard that they need a way to extract energy from the turbine without any additional moving parts, such as the gears and linkages commonly found in a blade-type wind turbine, so that reliability is increased and cost minimized. While parameters such as rotational velocity, turbine dimensions, shroud material, and required output power were specified, other problem parameters were undefined.

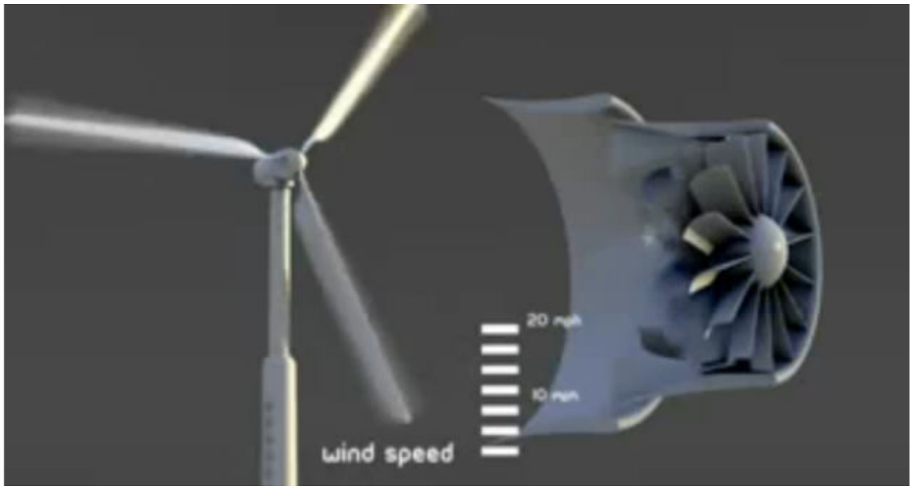

Figure 6 – Wind Turbines: Common Blade-Type Wind Turbine (left) versus FloDesign Compact Shrouded Wind Turbine (right) (Image reproduced with permission from FloDesign, Inc.)

Following the problem statement, the partner organization's technical team is asked to recreate the brainstorming session in which they discussed possible solutions. During the brainstorming session, the team members are recorded discussing the various ways to approach the problem. This often results in the original problem parameters being reiterated to frame the problem for discussion (e.g., someone says, "OK. What do we know?"). In some cases, failed attempts at a solution are presented to be used as a "springboard" for new ideas. To make the video more believable, the technical staff is asked to bring a change of clothing to give the impression that the problem statement and brainstorming session took place on separate days. The purpose of the brainstorming discussion is to hints that might guide a student toward a possible solution, but the exact details of the solution are not revealed. For example, in the FloDesign Wind Turbine Challenge, the engineering students are shown in a conference room discussing the nuts and bolts of how a typical wind turbine generates electricity. They discuss how the gear box is needed to increase the rotational velocity of the generator and reliability and cost issue associated with approach. In their discussion on electrical generators, one of the engineering students comments on how the compact shrouded wind turbine actually looks like a generator, which prompts another student to say, "Why can't the turbine itself be an electrical generator?" 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. It also emphasizes that real-world problems are inherently interdisciplinary, requiring knowledge of traditionally separate disciplines such as electrical and mechanical engineering. The videos also show the technical team referring to their laboratory notebooks, reinforcing the importance of record keeping and communication skills.

The final phase of the PBL Challenge production meeting is to record the organization's solution to the problem. Unlike many traditional open-ended PBL resources that do not provide a concrete solution, the PBL Challenges include the partner organization's solution against which students can compare and contrast their own solutions.

While the problem statement, discussion, and solution are video recorded, variations in audio and video quality can present a problem for final video production quality. To circumvent this problem, the recorded videos are edited and transcribed to create a script using the actual words of the participants. The PBL Challenge videos are actually still photographs created using a voice-over-still-photo technique with voice actors providing the audio. Using video effects such as pan-and-scan (the “Ken Burns effect” available in Apple’s iMovie® HD) and interspersing actual video footage, the PBL Challenges effectively create the “feel” of the location where the problem was solved. Partner organization have also provided or helped to locate additional video, print and web resources, and other documents describing the organization’s solution. The final draft PBL Challenges are then reviewed for technical accuracy by representatives of the organization before being field-tested by teachers.

Web-Based Professional Development for In-Service Educators

The STEM PBL project will recruit and train STEM educators from across the US teachers in PBL instructional methodology and the implementation of the STEM PBL challenges using the online professional development model developed through a prior NSF-ATE project PHOTON2[26,27,28]. Grounded in adult learning principles, the main tenets of the PHOTON2 model are that in order for online professional development to be effective in producing positive change in teaching practice, instruction must include (1) a sufficient number of contact hours over a span of time to enhance faculty processing and problem-solving skills, and (2) resources and opportunities for faculty to engage in ongoing professional communication with each other and with experts. Research shows that providing teachers with continuous professional development over a prolonged period of time of up to one year or more has been shown to yield application rates of 80 percent or better as opposed to the typical 10-20 percent found short-term professional development workshop models[19].

Over the 2009-2010 academic year, thirty secondary, community college, and four-year college and university in-service STEM educators were recruited nationwide to take part in a 15-week online course. The online course will be conducted in three 5-week sessions 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 perform better in short-term sessions with time in between to reflect on the experience and begin to plan implementation of the course material in their own classrooms. Experienced PBL instructors from the PHOTON PBL project will also be enrolled in the course as mentors and will monitor discussions and provide guidance to new faculty. Course participants will work in small teams of 3-4 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 will work 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. From session to session, the participants will be given greater autonomy as more responsibility is placed on them to self-direct their own learning. The course structure, from highly structured to open-ended will emulate the way instructors will use Challenges with their own students. Between online class sessions, participants will collaborate with each other, PHOTON PBL mentors and the STEM PBL project team to explore how best to incorporate the PBL Challenges into their own classroom and curriculum.

The online course will be preceded by a two-day introductory workshop held in July 2010 at the Boston University Photonics Center to acquaint participants with the online learning environment and the PBL Challenges, and to create a learning community to foster online collaboration. All participants will be added to the PBL listserv; an email listserv managed by the New England Board of Higher Education and composed of nationwide network of PBL educators, educational researchers, and industry mentors. Employees of partner industries and research universities will also participate in the listserv to provide ongoing technical support to educators. In-service teachers will act as mentors to the pre-service teachers enrolled on the listserv.

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

In addition to providing professional development to in-service teachers in PBL methodology and incorporating STEM PBL Challenges in existing STEM classes, the STEM PBL project will also create a model course in PBL methodology using the STEM PBL Challenges for *pre-service* technology and engineering education students for implementation in middle and secondary school education. During the first year of the project, an existing required classroom course in instructional technologies at Central Connecticut State University (CCSU) will be adapted to include instruction PBL methodology and applications. The course is currently offered once per year and is required of all Technology and Engineering Education (TEE) majors (pre-service teachers) at CCSU. Approximately 15 undergraduates enroll in the class each year. The adaptations required to incorporate PBL theory into the current course framework will be completed prior to the spring 2011 semester, when the new PBL-based version of the course will be delivered for the first time.

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 multi-media 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, along with the details and outcome of the course, to technology and engineering education faculty at national and international conferences and education associations in order to facilitate replication of the course and broaden its potential impact. Student created Challenges will be disseminated through the NEBHE PBL web site.

The STEM PBL project team will also work with the Connecticut Community College's College of Technology's (COT) *Technology Pathway* program to increase awareness of the career opportunities in TEE education for graduates of associate degree technician programs. COT is a consortium of the technology programs in the twelve community colleges in Connecticut.

Researching the Efficacy of PBL in STEM Education

PBL has been used successfully in the medical profession, business, nursing and other professions for decades with great acclaim. In a review of the literature, research shows that students in PBL courses perform better academically, have a higher retention rate, and are generally more satisfied than students in traditional lecture-based courses. Research also shows that students in PBL courses exhibit improved levels of metacognitive self-regulation, intrinsic goal orientation, task value, use of elaborative learning strategies, critical thinking, and peer learning as compared to students in traditional lecture-based instruction[30,31,32]. Research also shows, however, that PBL requires time and effort in gaining acceptance and that more effort is needed in developing skill in facilitation and attitude toward self-directed learning[15]. In a meta-analysis conducted by researchers at Middlesex University[33] involving 91 citations, results showed that variations in instructional methods, implementation, and assessment of learning outcomes yielded inconclusive evidence upon which to provide robust answers to the questions about the efficacy of PBL. The researchers concluded that while PBL appears to be a promising alternative to traditional lecture-based methods of instruction, more research is needed to assess its efficacy.

To address the need for more research on the efficacy of PBL, especially in STEM education, the STEM PBL project is currently working with researchers from the University of Connecticut's NEAG School of Education to conduct quantitative and qualitative research on the efficacy of the STEM PBL Challenges with regard to students' problem-solving and critical thinking skills, metacognitive development, self-efficacy, motivation, and learning style adaptation. Researchers will also examine the extent to which specific online professional development activities contribute to changes in teaching practices (i.e., transfer of training) among participating faculty. The research will result in a series of published articles and may also provide research opportunities for graduate students pursuing advanced degrees in education at the University of Connecticut.

Conclusion

In this paper, we presented the STEM PBL project, a new three-year National Science Foundation Advanced Technological Education (NSF-ATE) NEBHE project aimed at increasing the STEM pipeline through problem-based learning (PBL) focused on sustainable technologies. We discussed how the STEM PBL project team, building on the prior work of the NSF-ATE PHOTON PBL project, is now working with industry and research universities breaking new ground in sustainable and green technologies to create a comprehensive series of multimedia PBL Challenges designed to engage secondary and post-secondary students in real world problem solving in sustainable technologies. A detailed description of the PBL Challenge model was presented as well as the process in which the STEM PBL Challenges are created in partnership industry and academia. We described the online professional development course scheduled to be offered over the 2010-2011 academic year for in-service STEM teachers in PBL instructional methods using the STEM PBL Challenges. We also described the development of new classroom course in PBL instructional methods for pre-service TEE teachers scheduled for implementation in fall 2011. Finally, we presented a discussion on the research activities scheduled to take place in partnership with the University of Connecticut to evaluate the efficacy of the new multimedia STEM PBL Challenges with regard to student learning outcomes and transfer of training among participating faculty.

Bibliography

1. Carmichael, Carol. "A Primer on Sustainable Technologies." Institute for Sustainable Technologies, Georgia Institute of Technology, 2003, http://www.sustainable.gatech.edu (accessed September 22. 2009).
2. National Science Foundation. "Science and Engineering Indicators." 2004, http://www.nsf.gov/statistics/seind04 (accessed November 27, 2009).
3. Abrams, James. "Gates Seeks More High-Tech Visas." *Associated Press*, Washington DC, March 12, 2008.
4. National Science Board. "An Emerging and Critical Problem of the Science and Engineering Labor Force." 2004, http://www.nsf.gov/statistics/nsb0407/nsb0407.pdf (accessed December 20, 2009).
5. American Association of State Colleges and Universities. "Strengthening the Science and Mathematics Pipeline for a Better America." *Policy Matters*, 2 (11) (2005).
6. Johnson, M. J., & Sheppard, S. D., "Students Entering and Exiting the Engineering Pipeline – Identifying Key Decision Points and Trends," Paper presented at the Frontiers in Education Conference, November, 2002.
7. Kimmel, H., & Cano, R. "K-12 and Beyond: The Extended Engineering Pipeline." Paper presented at the Frontiers in Education Conference, October, 2001.
8. Camp, T.. "The Incredible Shrinking Pipeline." *Inroads: SIGCSE Bulletin*, *34* (2) (2002): 129 – 134.
9. Massa, N.M., Audet, R., Donnelly, J., Hanes, F., Kehrhahn, M., & Bell, A. "Photon PBL: Problem-Based Learning in Photonics Technology Education." Paper presented at the Photonics North: Education and Training in Optics and Photonics (ETOP) Annual Conference, Ottawa, Canada, June 2007.
10. Massa, N. M., Masciadrelli, G. J., & Mullett, G. J. "Re-Engineering Engineering Technician Education for the New Millennium." Paper presented at the ASEE Annual Conference, Portland, Oregon, June, 2005.
11. Savery, J. R., & Duffey, T. M. "Problem based learning: An instructional model and its constructivist framework." In *Constructivist learning environments: Case studies in instructional design*, edited by B. G. Wilson, Englewood Cliffs, NJ: Educational Technology Publications, 1996.
12. J.J. Kellar, W. Hovey, M. Langerman, S. Howard. L. Stetler, H. Heilhecker, L. Arneson-Meyer and S. Kellogg. "A Problem Based Learning Approach for Freshmen Engineering," *Conference Proceedings Session F2G*, Frontiers in Education 2000, Kansas City, MO, October, 2000.
13. Perrenet, J.C., Bouhuijs, P.A.J., & Smits, J.G.M.M. "The Suitability of Problem-based Learning for Engineering Education: Theory and Practice." *Teaching in Higher Education*, 5(3) (2000): 345-358.
14. Barrow, H.S. "A Taxonomy of Problem Based Learning Methods." *Medical Education*, 20 (1986): 481-486.
15. Zubaidah, S. "Problem–Based Learning: Literature Review." *Singapore Nursing Journal*, 32 (4) (October-December 2005): 50-54.
16. Daugherty, M.K. "Problem-Based Learning for K-12 Engineering." *Proceedings of the 9th International Conference on Engineering Education,* San Juan, PR, July 23- 28, 2006.
17. http://www.thecasefiles.org
18. Massa, N. M., Dischino, M., Donnelly, J., Hanes, F. "Assessing Student Learning in Problem-Based Learning." Paper presented at the SPIE/OSA Education and Training in Optics and Photonics (ETOP) Conference, Wales, UK, July, 2009.
19. Massa, N. M., Dischino, M., Donnelly, J., Hanes, F. "Problem-Based Learning in Photonics Technology Education." Paper presented at the Annual Meeting of SPIE, San Diego, CA, August, 2008.
20. Massa, N.M., Audet, R., Donnelly, J., Hanes, F., Kehrhahn, M., & Bell, A.. "Photon PBL: Problem-Based Learning in Photonics Technology Education." Paper presented at the SPIE/OSA Photonics North: Education and Training in Optics and Photonics (ETOP) Annual Conference, Ottawa, Canada, June, 2007.
21. Vanderbilt-Northwestern-Texas-Harvard/MIT Engineering Research Center: http://www.vanth.org/index.htm.
22. Pandy, MG, Petrosino, AJ, Austin, B and Barr, R., "Assessing Adaptive Expertise in Undergraduate Biomechanics. *Journal of Engineering Education*," 93 (2004): 211-222.
23. Domoinowski, R.L., "Verbalization and Problem Solving," In D.J. Hacker, J. Dunlosky, and A.C. Graesser (eds.), *Metacognition in Educational Theory and Practice*, 25-35. Mahwah, NJ: Erlbaum, 1998.
24. Polya, G.. *How to Solve It: A New Aspect of Mathematical Method*, *Second Edition*. Princeton, NJ: Princeton University Press, 1957.
25. Donnelly, J., Dischino, M., Hanes, F., Massa, N. M.. "Creating and Using Industry-Based Problem Based Learning Challenges in Photonics: Lessons Learned." Paper presented at the SPIE/OSA Education and Training in Optics and Photonics (ETOP) Conference, Wales, UK, July, 2009.
26. Massa, N. M., Kehrhahn, M., Donnelly, J., Hanes, F., & Washburn, B. A. "PHOTON2: A Web-Based Professional Development Model for Photonics Technology Education." Paper presented at the SPIE Annual Conference, Ottawa, Canada, September, 2004.

27. Massa, N.M., Vallieres, K. M., Kehrhahn, M., & Bell, A. “Project PHOTON2: A Year in Review.” Proceedings of the SPIE/OSA Education and Training in Optics and Photonics (ETOP) Annual Conference, Marseille, France, October, 2005.
28. Massa, N.M., Vallieres, K. M., Kehrhahn, M., & Bell, A.. “Learner Interaction and Self-Regulation in Web-Based Professional Development.” Proceedings of the ASEE Annual Conference, Portland Oregon, June, 2005.
29. Saylor, P. R., & Kehrhahn, M. T. “The influence of the implementation of a transfer management intervention on transfer of training,” In O.A. Aliaga (Ed.) 2001 AHRD Conference Proceedings. Baton Rouge, LA: AHRD, 2001.
30. J.J. Kellar, W. Hovey, M. Langerman, S. Howard. L. Stetler, H. Heilhecker, L. Arneson-Meyer and S. Kellogg, "A Problem Based Learning Approach for Freshmen Engineering," Conference Proceedings Session F2G, Frontiers in Education 2000, Kansas City, MO, October, 2000.
31. Perrenet, J.C., Bouhuijs, P.A.J., & Smits, J.G.M.M, “The Suitability of Problem-based Learning for Engineering Education: Theory and Practice”, *Teaching in Higher Education*, 5 (3) (2000): 345-358.
32. Sunger, S., Tekkaya, C., “Effects of Problem-Based Learning and Traditional Instruction on Self-Regulated Learning”, *The Journal of Educational Research,* 99(5) (May/June, 2006).
33. Newman M., “A pilot systematic review and meta-analysis on the effectiveness of problem-based learning”, On behalf of the Campbell Collaboration Systematic Review Group on the Effectiveness of Problem-based Learning, Newcastle upon Tyne, UK: Learning and Teaching Support Network-01, University of Newcastle upon Tyne, 2003. http://www.hebes.mdx.ac.uk/teaching/Research/PEPBL/PSR-PBL.pdf (accessed August 28, 2009).