Problem-Based Learning in Photonics Technology Education

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ABSTRACT

Problem-based learning (PBL) is an instructional approach in which students learn by actively and collaboratively solving authentic problems encountered in real-world situations. Research demonstrates that PBL improves students' learning and retention, motivation, critical thinking and problem-solving skills, and their ability to skillfully apply knowledge in new and novel situations – skills deemed critical for lifelong learning. In this paper, we present the Photon PBL project, a three-year National Science Foundation Advanced Technological Education (NSF-ATE) project aimed at developing, in partnership with photonics industry and university partners, a comprehensive series of multimedia PBL instructional materials and training for photonics technology educators from across the US and abroad. Results from first-year pilot testing of multimedia PBL instructional materials, problem development and implementation strategies are detailed.

Keywords: Problem-based learning, optics, photonics, PBL, critical thinking, problem-solving

1. INTRODUCTION

Problem-based learning (PBL) is an instructional approach in which students learn by actively and collaboratively solving authentic problems encountered in real-world situations. Research demonstrates that PBL improves students' learning and retention, motivation, critical thinking and problem-solving skills, and their ability to skillfully apply knowledge in new and novel situations – skills deemed critical for lifelong learning [1,2,3,4,5]. Unlike traditional lecture-based instruction, where information is passively transferred from instructor to student, PBL students are active participants in their own learning, thrust into unknown learning situations where the parameters of the problem may not be well-defined and the task at hand ambiguous – just like in the real world. Given the demands of the new global innovation economy for creative, teamwork-oriented problem-solvers capable of adapting to the ever-changing needs of business and industry, PBL represents an exciting alternative to traditional lecture-based instruction.

PBL typically involves a four-phase recursive process that includes problem analysis, self-directed learning, brainstorming, and solution testing as illustrated Figure 1. In the problem analysis phase, students are presented with a real-world problem by the instructor, and as a team, tasked with "dissecting" the problem to identify what is known, what is unknown, any special conditions and constraints that may apply, what knowledge and skills must be acquired, establishing criteria for success, and developing initial hypotheses regarding possible solutions. Once the problem is properly framed, students individually engage in self-directed learning to acquire the knowledge and skills necessary to solve the problem. Self-directed learning requires that students set specific learning goals to guide their learning and a plan for monitoring and evaluating their learning and comprehension, a metacognitive process shown by research as being the cornerstone of the learning process. Upon acquiring the requisite knowledge and skills identified in the problem analysis phase, students reconvene in a brainstorming session to elucidate their ideas in a collaborative effort to evaluate possible solution strategies with the goal of converging on an optimal solution. Once a tentative solution has been agreed upon, students then test their solution to determine whether or not it meets the criteria for success established in the problem analysis phase. Solution testing involves developing a detailed test plan and procedure with performance benchmarks. If the solution is acceptable, students present their results to faculty and peers in a formal presentation. If the solution is deemed unacceptable, the process is repeated. During the problem-solving process, the instructor acts as a facilitator or consultant, guiding the students through the process and providing information or

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instruction on an "as needed" basis. By shifting the responsibility for learning onto the students, they are more likely to develop the knowledge, skills, and attitudes necessary to engage in life-long learning [5,6,7].

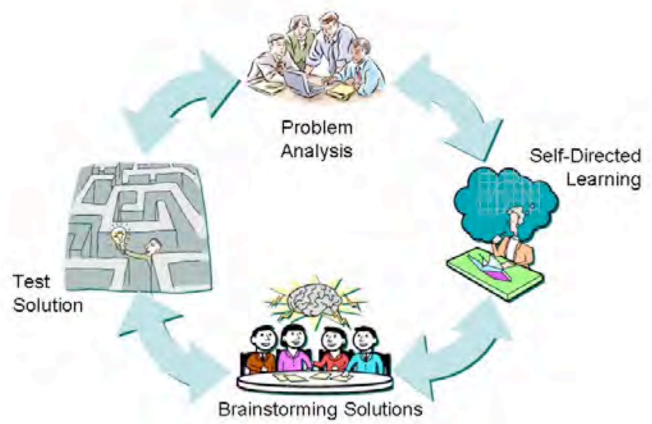


Figure 1 – Problem Solving Cycle

While PBL has been demonstrated as an exciting alternative to lecture-based instruction [7,8,9,10,11,12], one of the challenges with adopting this instructional approach in photonics technology education is the lack of instructional resources and professional development opportunities available to teachers and faculty. To address this need, Photon PBL, a three-year National Science Foundation Advanced Technological Education (ATE) project is (1) developing a series of eight multimedia PBL "Challenges" in partnership with the photonics industry and universities, (2) providing ongoing professional development and support for teachers and faculty in the use of PBL in technology education, and (3) conducting research on the efficacy of PBL in developing problem solving and critical thinking skills in students [13]. In this paper, we present results from first-year field testing of the Photon PBL Challenges and associated instructional materials. We also discuss the Challenge development process, classroom implementation and assessment strategies, and future research plans for examining the efficacy of problem-based learning in photonics technology education.

2. THE PHOTON PBL CHALLENGE DESIGN

The PBL Challenges provide students with real-world problems to solve in a multimedia format designed to emulate the real-world context in which the problems were encountered and solved. Each Photon PBL Challenge contains six main multimedia components. Figure 2 illustrates various components of the Photon PBL Challenges.

a. An introduction to the main topic upon which the challenge was based
b. An introduction to the company or university lab where the problem was encountered to set the context for the problem
c. A re-enactment of the problem statement by the actual people tasked with solving the problem
d. A re-enactment of the brainstorming session (problem discussion) with the actual people involved in solving the problem
e. A presentation of the problem solution by a member of the technical staff involved in solving the problem
f. A Problem Solving Toolbox to help guide students through the problem-solving process

A common complaint among students introduced to PBL for the first time is the stress and anxiety associated with open-ended problems and self-directed learning. Most students are accustomed to traditional lecture-based methods of instruction in which information is passively "transferred" from the instructor to the student in an environment that is well-structured and where problem parameters are clearly defined and closed-ended. In PBL, however, students are thrust into an uncertain, self-directed learning environment, where there are no "clean" problem solutions and the responsibility for learning is place squarely on the shoulders of the student often eliciting frustration and anxiety [8]. This frustration and anxiety can not only lead to disengagement from the learning process among students, but can also create a stressful situation for faculty trying to transition to PBL from more traditional instructional methods.

Figure 2 – (a) Problem Introduction (b) Company/University Overview (c) Problem Statement (d) Problem Discussion (e) Problem Solution (f) Problem Solving Toolbox

To ease the transition from traditional lecture-based instruction to PBL, the Photon PBL Challenges employ a three-level scaffolded design to "ease" students into PBL and to encourage faculty adaptation. The three levels of structure range from Structured (Instructor Led), to Guided (Instructor Guided), to Open-Ended (Instructor as Consultant) depending on the technical nature of the problem and the ability level of the students. By allowing students and faculty the opportunity to gradually progress through the PBL Challenges along a developmental continuum, we believe students will be more likely to develop the skills and confidence needed to take responsibility for their own learning and faculty will be more likely to adopt PBL as an alternative instructional approach. In addition, each of the Photon PBL Challenges is available online with instructor passwords designed to control student access to the different sections of the Challenges, making it possible for instructors to set the pace of the Challenge.

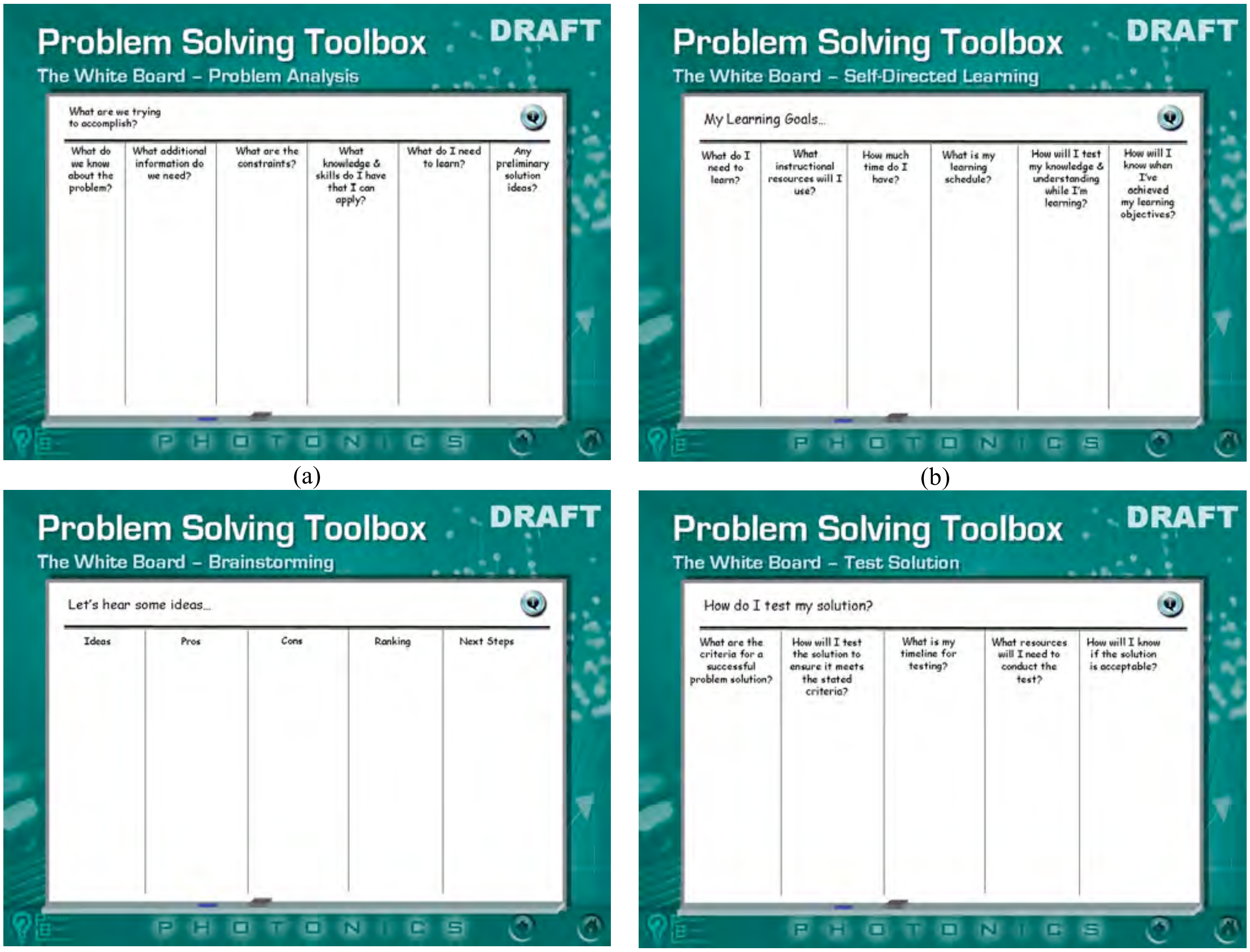
Structured Challenge (Instructor Led): In the structured approach, students are presented with the PBL Challenge in its entirety as a multimedia-based case study. This includes a multimedia introduction to the specific aspect of photonics on which the Challenge is based, a tour of the industry/university facility in which the problem was encountered, a re-enactment of the problem statement, group problem analysis and discussion, and problem solution (Figures 2a-2e) – all recorded at the industry/university partner site. The purpose of the structured approach is to introduce the student to the concepts, principles, and procedures associated with problem-based learning. In the structured approach, the instructor leads the students through each phase of the problem-solving process in a structured format which includes problem analysis, self-directed learning, brainstorming, and testing solutions. During the presentation of the PBL Challenge, the instructor has the option of pausing the multimedia presentation at specific points to encourage student discussion of the problem-solving process, technical content, and other situational factors and constraints that must be taken into consideration in the solution of the problem.

Guided Challenge (Instructor Guided): Once introduced to the PBL process using the structured approach, students progress to the guided approach. As in the structured approach, students are presented with the multimedia introduction to the Challenge, re-enactment of the problem statement and problem discussion to guide the problem solving process (Figures 2a-2d), but the solution is held back until the end. Working in small teams, students use whiteboards (Figure 3) to work through the problem solving process. Access to the problem solution is blocked through the use of a password available only to the instructor. During this phase the instructor acts as a guide or facilitator to ensure that students stay on track, but refrains from providing solutions or answers to specific questions. This strategy is intended to further develop students' ability to think critically by allowing them to actively engage in the problem-solving process, but at the same time providing a safety net so that learning occurs without risk of failure. After converging on and presenting their own solutions to the problem, students are presented with the industry/university partner solution and a subsequent group reflection activity is conducted to compare and contrast results.

Open-Ended (Instructor as Consultant): In the open-ended approach, students are presented with the most realistic representation of the problem as it would be encountered in the "real world" – a true problem-based learning challenge. Students are provided only with information from the introduction, overview and problem statement (Figures 2a-2c), and are required to formulate their own solutions as part of a mock design team. Drawing on the problem-solving skills developed through engagement in the structured and guided approaches, students take to the whiteboards to engage in the four-phase problem-solving process. During this process the instructor acts as a consultant, providing hints or clues on request, but for a price (e.g., points deducted from a mock budget). Only after the solution has been presented by the student design teams in a mock design review is the actual industry/university problem-solving process and solution revealed. Student processes and solutions are then reviewed and critiqued against that of the industry/university partner and recommendations for improvements are discussed.

The cornerstone of the PBL Challenges is the problem-solving process itself. Building on the work in PBL of the CaseFiles© project [9] and of VaNTH-ERC [14] (Vanderbilt-Northwestern-University of Texas-Harvard Engineering Research Center), the Photon PBL Challenges include problem-solving tools and resources designed to help students develop the critical thinking and problem-solving skills needed to be successful lifelong learners. One important problem-solving tool embedded in the Photon PBL Challenges is called "*The Whiteboards*," which are designed to guide students through the recursive problem-solving cycle (Problem Analysis, Self-Directed Learning, Brainstorming, and Test Solutions; see Figure 3).

Through the use of simulated whiteboards (whiteboard images that can be projected onto an actual classroom whiteboard) students are provided with a systematic method for documenting their understanding and thought process in an easy and convenient manner as they work through the problem-solving process. Upon being presented with the problem, student teams use the whiteboards to analyze and frame the problem, engage in self-directed learning to acquire the knowledge and skills needed in solving the problem, brainstorm possible solutions, and test those solutions. Upon completion of the Challenge, students can summarize the problem-solving process captured in the whiteboards using a reflective journal that is included as a problem-solving resource. This active learning strategy is designed to model the problem-solving process and help develop students' ability and confidence to engage in problem-based learning.



(a) (b) (c) (d)

Figure 3 – The Whiteboards: (a) Problem Analysis (b) Self-Directed Learning (c) Brainstorming (d) Test Solution

The Photon PBL Challenges include a comprehensive set of instructor resources to help teachers implement each Challenge in the classroom. Resources include technical overviews and tutorials, assessment tools, and Photon PBL case studies that describe the various implementation strategies employed by field testing institutions. Teachers are also provided with access to a dedicated BlackBoard® website containing additional PBL and technical resources as well as discussion board and chat room capability for ongoing support and peer collaboration. Technical overviews and tutorials include a detailed description, analysis, and solution for each Challenge problem as well as supplemental materials and websites related to the problem and the solution. The assessment tools include research-based methods and strategies [15] for assessing student performance in PBL that include content knowledge, conceptual knowledge, and problem-solving strategies.

3. PHOTON PBL CHALLENGE DEVELOPMENT PROCESS

3.1 Recruiting Industry and University Partners

The goals for the first year of the Photon PBL project were to develop three prototype multimedia PBL Challenges for field testing and to provide professional development to teachers and faculty in their use. In the months prior to being awarded the Photon PBL project, potential photonics industry and university partners were solicited by the New England Board of Higher Education (NEBHE) to participate in the project. Initial selection of industry and university partners was based on past relationships developed though prior photonics-related NSF-ATE projects awarded to NEBHE since 1995 including *Project FOTEP*, *Project Photon* [16] and *Project Photon2* [17, 18], in which teachers and faculty from across the US were provided both classroom and web-based professional development in photonics technology, curriculum materials, custom laboratory kits with instructional videos, and access to a national network of photonics educators and industry mentors through a dedicated listserv, which continues to grow in membership. Professional organizations including SPIE and OSA were also instrumental in providing suggestions for potential industry and university partners.

Industry and university partners were asked to provide suggestions for specific photonics-related problems, appropriate for technician-level training, that had been solved by their technicians and engineers, and whose solutions had been documented. Criteria established for identifying a "good" problem included: (1) the problem must open-ended with more than one possible solution, (2) the problem should be ill-structured with insufficient information to facilitate inquiry, (3) the problem should be linked to introductory photonics concepts and principles, and (4) the problem should engage students' interest and motivate them to probe for deeper understanding of the concepts being introduced. After receiving numerous suggestions from companies and universities across the US, potential problem scenarios were evaluated by the Photon PBL project team to ensure that the core concepts addressed were appropriate for technician-level education and could be aligned with National Science and Technology Literacy Standards. After careful consideration, three problems were selected for development. A description of the problem and the associated partner organization is provided in Table 1.

Table 1 - Photon PBL Challenges 1-3

Partner Organization	Location	Description	Photonics Principles Reinforced
IPG Photonics Corporation (IPG)	Oxford, MA	*Fiber Laser Burn-in Testing* – Students are tasked with developing a safe, reliable and cost-effective method for testing high powered fiber lasers.	• Fiber optics • Laser power measurement • Laser safety • Laser beam collimation
Boston University Photonics Center (BU)	Boston, MA	*DNA Microarray Fabricator Analysis* – Students are tasked with determining the proper UV exposure level and optical power budget for a custom optical system that uses a digital light processing chip to fabricate DNA microarray chips.	• Radiometry • Photometry • Absorption spectra • Optical power budget • Optical system design
PhotoMachining, Inc. (PM)	Pelham, NH	*Laser Wire Stripping* – Students are tasked with determining a cost-effective method for laser stripping the polyimide coating from very small wires used in the medical device industry.	• CO2 & Excimer laser characteristics • Laser power measurement • Optical system design • Laser materials processing

3.2 Creating the PBL Challenges

One of the unique features of the Photon PBL challenges is the inclusion of context in the multimedia instructional materials. In developing each PBL Challenge, the Photon PBL project team visited each industry and university partner site for a two-day Challenge production meeting. On the first day of each visit, the Photon PBL project team presented the technical staff involved in the problem development at the partner organization an overview of the Photon PBL project and the basic principles of problem-based learning. This introduction was usually followed by a tour of the facility, which was captured using video recording equipment to be incorporated into the PBL Challenge to provide students with a "glimpse" into the actual real-world environment in which the problem was encountered and solved. On several occasions, the video footage was of sufficient quality to merit the development of additional video tutorials to supplement the PBL Challenges. Upon completion of the tour, the project team met with the scientists, engineers, and technicians to discuss specific details of the proposed problem and solution, and an agenda was developed for re-enacting the problem-solving process on day two.

On day two, technical staff from the partner organization was asked to provide a detailed description and re-enactment of how the problem was originally introduced (problem statement), brainstorming discussions on possible solutions (problem discussion), and a demonstration of the final problem solution (problem solution). The solution was presented first in order to reverse-engineer the original problem situation. Careful attention was paid to the specific requirements of the solution so that upon re-enacting the initial problem statement, important details and criteria were not overlooked. The presentation of the problem solution was video recorded for later transcription and many photographs were taken of the technical staff and equipment involved in the problem solution.

In producing the problem statement and problem discussions, partner organizations were asked to re-enact the original problem situation as it actually occurred. This involved recreating the initial problem statement and subsequent brainstorming discussions that took place, and capturing it all with both video and photographs. In the case of the IPG Photonics PBL Challenge, for example, during a Monday morning staff meeting an engineering manager tasks his technical team with developing a safe and cost-effective system for burn-in testing of a high powered fiber laser. The laser must be run at full power for 100 hours unattended, while key performance parameters are measured. While the manager describes the basic requirements for the system, the problem parameters are ill-defined and there are a number of questions that must be addressed before a solution can be developed.

In producing the problem discussion, technical staff members from the partner organization were asked to re-enact the brainstorming session(s) that took place in solving the problem. Given that the recording of the problem statement and problem discussion took place on the same day, technical staff members were asked to bring a change of clothing to create the impression that the problem was solved over a period of days or weeks. During the brainstorming session, key parameters needed to solve the problem were introduced and suggestions for alternative solutions presented and discussed. The purpose of the problem discussion is provide students additional information and "hints" toward possible solutions to guide their learning, but not to "give away the store." In the case of the IPG Photonics Challenge, the discussion revolved around key laser safety issues, the type of instrumentation required, and suggestions for cost-effective enclosures that could be used. This scaffolded approach is intended to alleviate anxiety in students who may have reached an impasse in solving the problem and also to model the brainstorming and teamwork skills commonly used in the real world. As in the problem statement, both video and photographs were used to record the re-enactment. The IPG Photonics Challenge is consistent with the requirements for a "good problem" in that it has more than one possible solution, is ill-structured with insufficient information to facilitate inquiry, is linked to introductory photonics concepts and principles, and given the potential real-world safety hazards could potentially engage students' interest and motivate them to probe for deeper understanding of the concepts being introduced.

Creating the actual multimedia PBL Challenge from the recorded video and photos proved to be quite challenging in and of itself. The original intent of the Photon PBL project was to use the actual video recordings of the industry and university partners' problem statement, problem discussion, and problem solution augmented with still photos and other media. This proved to be very difficult given the variations in audio quality, lighting and other factors. Fortunately, an alternative method was adapted from the "CaseFiles" project [9] at Nashville State Community College, in which still photographs dubbed with voice-overs were used to emulate video. By use of simple techniques such as panning and zooming, a realistic and effective video alternative was achieved that was much easier to edit and produce. Voice-overs were achieved by first transcribing the audio portion of the recorded problem statement, problem discussion and problem solution videos, editing and condensing them down into a 1-2 minute script, and using Photon PBL Project team members (and their families) to record the voices. These voice-overs, when combined with still photographs and other media using Adobe® Premiere Elements software, proved to be very effective in capturing the real-world context sometimes neglected in other PBL formats.

The first three Photon PBL challenges were originally developed using Microsoft® PowerPoint as a delivery platform. PowerPoint proved to be a simple yet effective means of delivering the Challenges in the classroom for field testing purposes and made it easy for teachers and faculty to modify "on the fly" if needed. The final versions of the PBL

Challenges, however, are currently being transformed to an html format for web delivery as a more cost-effective means of dissemination. By migrating the PBL Challenges to a web-based platform, password protection of the various components of the Challenge will be made available so that teachers can exercise control over what information can be accessed by students and at what point in the Challenge process. This feature will allow teachers to present the Challenges at different educational levels and at a pace consistent with student ability.

3.3 Professional Development and Field Testing

In July 2007, a 5-day summer workshop was conducted at Roger Williams University in Rhode Island for 30 high school math, science and technology teachers and engineering and technology faculty from sixteen two- and four-year institutions across the US including Hawaii. Recruitment for the workshop was accomplished through direct mailing, engineering and technology education list-serves, and soliciting participants from prior NEBHE NSF-ATE projects. Applicants were required to apply in teams of two or more institutions that included both high school and college-level teachers and faculty. The purpose for teaming high school and college-level educators was to facilitate collaboration between secondary and post-secondary education at the local level. This method, know as the "alliance model," was successfully used in both projects *Photon* and *Photon2* to generate many lasting relationships and articulation agreements between secondary and post-secondary institutions across the US. Another requirement of the application process was a commitment from the teachers to field test at least two of the challenges during the 2007-2008 academic year.

The focus of the 2007 summer workshop was to introduce teachers and faculty to the principles of PBL and for these educators to gain experience in the use of the initial three Photon PBL Challenges. Working together, workshop participants from different disciplines, education, and experience levels were teamed together to complete each of the three PBL Challenges. The first Challenge was introduced using the *Structured* approach; the second Challenge was introduced using the *Guided* approach and the third using the *Open-Ended* approach. This approach was used to model for teachers how the Challenges should be introduced to their own students. While the time frame for completing each of the Challenges was truncated due to the time limits of the workshop, evaluations of anonymous post-workshop surveys revealed that even though initially apprehensive about PBL, participants became more and more comfortable with the PBL method overall and were eager to begin implementing PBL in their own classrooms.

The purpose of the field testing was to evaluate the efficacy of the PBL Challenges with regard to students' knowledge, skills and attitudes and to provide recommendations for implementation strategies to be used in the subsequent development of a Photon PBL "Teacher's Guide to Problem-Based Learning" to be developed in year three of the project. Prior to the 2007/2008 field testing, a BlackBoard website was established as a portal for participant communication and resource sharing. On the website, a discussion board was set up in which participants were asked to respond to a series of four questions regarding field testing. The intent of the discussion board was to collect valuable data regarding the various implementation strategies used in different programs and at different levels, and to provide a forum for the exchange of ideas regarding PBL as well as photonics and other related topics. The field testing questions were as follows:

1. Which PBL Challenge did you field test and how was it presented? (Structured, Guided or Open-ended?)
2. Describe how the challenge was introduced in your class. For example, was the PBL Challenge presented as a supplemental activity in a traditional lecture course or was PBL the primary mode of instruction? How much time was allocated? What resources did the students have available to them? Did students work in teams? What was your role? How did you structure the student activities? Did the students solve the problem and present their solutions?
3. How did your students react to the PBL instructional method? Were they more engaged in the learning process? Was the experience stressful or enjoyable? Did students appear more or less motivated to learn using the PBL format? Did students feel they learned more or less using the PBL format?
4. What specific recommendations (if any) can you make to help us improve the next five PBL Challenges?

Responses from three representative teachers were selected and are presented in Table 2. While anecdotal, the overall response from students and faculty was very positive. Some suggestions were made with regard to adding additional resources for both students and instructors, which are currently being incorporated into the first three Challenges as well as the five new Challenges under development.

Table 2 – Sample Responses from Field Testing Questions

Field Test Question	**Response**
Teacher 1	**Profile:** Lead instructor of a two-year Associate Degree program in Laser and Photonics Technology at a community college in the southeast U.S.
Question 1	• PM (second-year students, open-ended) • BU (same second-year students, open-ended)
Question 2	Both PM and BU: Challenges introduced (PM first, BU second) as a supplemental activity in two classes: Photonics Applications and Photonics Fundamentals (both are required of all laser and photonics students). In each case, students were presented with the challenge and given seven hours to solve it, without help from their instructor. For resources, students were given a CD with the challenge, except for the solution, and internet access. Students worked in two teams of two and one team of three. Each team of students developed, documented and presented a solution for the challenge. Each solution was somewhat different.
Question 3	PM: "The reaction by all of the students to this PBL Challenge was that they loved it! In fact, they look forward to the next two." Comments included: • "It was nice because you could hear the perspective from the customer, the company and the engineers." • "The video made it more exciting because it made you feel like you were in a real world environment, with many people working on a common goal." • "Having the video and scripts made it easier to understand the question." • "It was good that you could think outside the box for a solution, without having to have only one way to solve it." • "Teams could work individually and come up with different solutions without being wrong." • "Enjoyed collaborating with teammates, which made it feel like you were working with fellow coworkers on a real problem." • "Like it because it was a real-life based problem and it was something new that had to be researched and problem-solved to develop a solution." • "The students were very engaged in the learning process; using problem solving skills, teamwork, and research to develop analyze the problem and develop solutions." • "The students did not seem to be stressed, but rather in fact enjoyed this learning approach a lot." • "The students believe that they learned a great deal more by solving a real world problem, than just by listening to a lecture, or just reading about it." BU: "The reaction by all of the students to the BU PBL Challenge was again, extremely positive! All agreed that they would love to see them a lot more frequently. Comments were very similar as with the first PBL challenge"
Question 4	PM: • Students suggested the addition of more specific information about the problem and the expectations for the solution in future PBL Challenges (i.e., it would have been helpful to have a requirements document from the customer). BU: • Students said that the BU challenge was fine as is. They really enjoyed it. All of them also enjoyed listening to and studying the solution by the BU team.

Table 2 Continued – Sample Responses from Field Testing Questions

Field Test Question	**Response**

Teacher 2	**Profile:** Community college technology instructor from the northeast U.S.
Question 1	• PM (College Physics II and Electro-optics Communications classes, open-ended for both) • BU (College Physics II class, open-ended at first, changed to structured approach mid-challenge)
Question 2	Both PM and BU: The Challenges were delivered as two-part laboratories conducted over four-hour long class sessions. The first lab was used to introduce students to the problem, and then let them explore the background information and develop ideas to meet the needs of the problem statement. During the idea development stage, students tended to form teams or work individually according to the overlap between their ideas and those of other students. During the second lab session, students converged on their final designs and presented these to the class using PowerPoint, whiteboard, and hand-waving visuals.
Question 3	PM: “The PBL format was a welcome change from the tightly structured program. The level of enjoyment shown by the students was demonstrated by the quality of the work that they prepared for the second class session. They were all active participants in the development and presentation of their designs.” BU: “The PBL method worked very well for most students. A few were a bit shy at getting too involved with the module and never quite got the level of excitement that I was looking for. The PM module was more motivating in that it was more intuitive, the solution had the moral (KISS), and they knew they were going on a field trip to PM the next week. The BU module was a little tougher to get off the ground. It is more complex with a lot of distracters which kept them from gaining critical mass. The toolkit document helped to get them oriented and on track, but the enthusiasm was much less than that of the PM module.”
Question 4	PM: • “The PM challenge is well balanced between the resource materials and the problem definition. For instructors who have limited experience with laser machining, it might be difficult to appreciate the value of different problem approaches students may devise. It’s important to remember that the published solution is not the only solution!” • “KISS! The more intuitive the problem, the quicker the students will adopt the problem as their own.” • “How about some distance field trips? Use someone with a camera to follow [PM President or staff member] around as he/she describes the latest goings-on at PM. The students linked to the presentation can ask questions of [him/her] during the tour. With today's technology, it seems that we should be able to find a way to transport photons instead of people to bring the PM experience to distant classes.”
Teacher 3	**Profile:** High school physics teacher from Slatina, Romania.
Question 1	• PM (17- and 18-year-olds enrolled in “Physics by Experiments,” a school-based curriculum course, structured) • IPG (17- and 18-year-olds, guided)
Question 2	Both PM and IPG: Students worked in teams to determine “What do we know?”, “What do we need to know?” and “What should we do?” in order to develop an exact statement of the problem (i.e., they used the “White Boards” located in the Problem-Solving Toolbox of the Challenge). This process required repeating. Students filled in a Scientific Notebook and discussed questions with PBL team members and PM personnel through online forums. A Science Club was created to continue PBL as an ongoing activity.

Table 2 Continued – Sample Responses from Field Testing Questions

Field Test Question	Response

Question 3	PM: "At first, they found the PBL difficult, but in the end, a girl asked me, 'When will we solve another PBL Challenge?' I said 'Next year (2008),' and the reply was, 'Good, because now we know how to deal with that kind of problems.' At the beginning my students said 'It's interesting, but why us?' I said, 'Because you are more intelligent than other students of mine!' 'Oh, it's the first time when a teacher pays us such a compliment!' After starting the Challenge, they ask me all the time 'Teacher, what have we to do next, what have we to do next?' I said, 'I don't know! It's your work! You must do what you think is right!' You must be patient with us because Romanian students are not familiar with team work. We have a lot to do!" IPG: "In the end, there were active students who asked a lot of questions, responded, made drawings, had ideas and, on the other hand, there were passive students who did not contribute with anything. We also had a lot of fun, because some students from the outer circle thought that they are a kind of jury. I said that they only observe and I will be the evaluator of all participants. After the seminar, many of them gave me new or improved drawings of their device."
Question 4	PM: "I think that questioning an expert and discussing with a directly involved person from PM Inc., is the best opportunity for my pupils to understand that they are researchers looking for a solution to a real-world problem. … My students will be very happy. I think this a good idea to increase their enthusiasm and motivation."

In July 2008, a second 5-day professional development workshop will be held at Boston University Photonics Center. Funding for this second summer workshop was not originally part of the Photon PBL project budget, but an overwhelmingly positive response from the 2007 summer workshop and subsequent conference presentations of the Photon PBL project has led to numerous requests for a second summer workshop with returning participants as well as a new cohort of participants interested in learning more about PBL. To accommodate this request, additional funding was requested by NEBHE and granted by the National Science Foundation. Additional financial support from SPIE and OSA will be used to fund participation of faculty from outside the US. Table 3 provides a description of the five new PBL Challenges to be presented during the 2008 summer workshop.

4. RESEARCH AGENDA

While PBL has been used successfully in the medical profession since the 1970s with great acclaim, little is known about the efficacy of PBL in technician education. A review of the literature on PBL identified a number of studies conducted to validate the efficacy of PBL in engineering education with researchers reporting mixed results. In a meta-analysis conducted by researchers at Middlesex University [19] that included 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 effectiveness of PBL. The researchers concluded that while PBL appears to be a promising alternative to traditional lecture-based methods of instruction in engineering and technology education, more research is needed to assess its efficacy.

To address the need for more research on PBL in technology education, the PHOTON PBL project will work in partnership with researchers from the University of Connecticut NEAG School of Education to conduct quantitative and qualitative research on the effectiveness of PBL as compared to traditional lecture-based methods with regard to learning outcomes, problem-solving and critical thinking skills, adaptive expertise, metacognitive development, self-efficacy, and motivation. Researchers will also examine the extent to which specific professional development activities contribute to changes in teaching practices (i.e., transfer of training) among participating faculty. Research results will be submitted to peer-reviewed journals for publication and disseminated through conference presentations.

Table 3 - Photon PBL Challenges 4-8

Partner Organization	**Location**	**Description**	**Photonics Principles Reinforced**

Photodyne, Inc & Drexel University	Dallas, TX & Philadelphia, PA	*Portable Infant Jaundice Treatment* – Students are tasked with developing a safe, portable and cost-effective method for treating infant jaundice.	• Opto-electronics • Fiber optics • Diffraction • Radiometry & photometry • Laser safety
University of Pennsylvania McKay Orthopaedic Research Lab	Philadelphia, PA	*Non-Contact Measurement of Biological Tissue* – Students are tasked with developing a laser-based method for measuring the cross-sectional area of mouse tendons used in orthopedic research.	• Laser-based displacement measurement • Radiometry & Photometry • Light detection • Reflectance measurement • Optical system design
California State Polytechnic Institute (CalPoly)	Pomona, CA	*Testing Light Bulb Efficiency* – Students are tasked with developing a cost-effective method for comparing the total light output and efficiency of standard vs. high efficiency fluorescent bulbs.	• Optical system design • Radiometry & Photometry • Light detection • Reflectance measurement • Optical system design
Penn State University Electro-Optics Center	Kittanning, PA	*Finding a Lost Hiker* - Students are tasked with determining the appropriate IR imaging technology to use for locating a lost hiker under adverse weather conditions.	• IR imaging • Optical resolution • Detector technology • Radiometry & Photometry • Optical system performance
Rayval, Inc. (Tentative)	Long Island City, NY	*Holographic Optical Elements* – Students are tasked with developing a holographic recording set-up for producing holographic optical elements for commercial applications.	• Holography • Diffraction • Optical system design • Imaging

5. CONCLUSION

In this paper we reported on the progress of the NSF-ATE Photon PBL project, a three-year National Science Foundation Advanced Technological Education (NSF-ATE) project aimed at developing, in partnership with photonics industry and university partners, a comprehensive series of multimedia PBL instructional materials and training for photonics technology educators from across the US and abroad. The project is currently completing its second year. In year two of the project, three multimedia PBL Challenges were field tested by 15 high school and colleges to gauge the effectiveness of the Challenges with regard to student learning outcomes and reactions in tradition math, science and technology classrooms. Anecdotal evidence suggests that the PBL Challenges were a welcome change from traditional didactic methods as indicated by responses from both students and teachers, which were very positive. Suggestions for improvement made by both teachers and students are currently being incorporated into five new Challenges that will be presented to teachers and faculty in a five-day Photon PBL Professional Development Workshop to be held in July 2008 at Boston University Photonic Center. Field Testing of the eight Challenges will continue during the 2008-2009 academic year and research will be conducted on the efficacy of the Photon PBL Challenges in photonics technology education.

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