# The PBL Projects: Genesis and Evolution

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## ABSTRACT

In 1995, the PHOTON Projects began developing curriculum materials and providing teacher/faculty professional development for the "new" field of fiber optics. After three successful projects advancing photonics education, something was still missing– students could solve end-of-chapter problems and pass written tests, but companies reported graduates had poor problem solving and critical thinking skills and were missing the "soft skills" needed for the workplace. In 2006 we were funded by NSF-ATE for the first of four projects to address industry’s concerns - the Problem-Based Learning (PBL) Projects. We developed a comprehensive series of multimedia instructional modules, the PBL "Challenges", to teach problem-solving *at the same time* as content, requiring students to master the subject matter and also use critical thinking, communications, time management and other workplace skills. In this paper we present a retrospective of our more than 25 years advancing optics/photonics education, especially for technicians.

**Keywords:** Problem-based learning, optics education, photonics education, STEM, webinar, technician education, outreach

## 1. IN THE BEGINNING – THE PHOTON PROJECTS

In 1994, the National Science Foundation (NSF) awarded the first Advanced Technology Education (ATE) grants with the goal of improving technician education at two-year colleges and forming partnerships between academic institutions and industry. In 1995, the New England Board of Higher Education (NEBHE) in Boston, Massachusetts received its first of what would be seven NSF-ATE grants, a project to prepare teachers to introduce fiber optic technology to secondary and postsecondary students in the six New England states. (The seventh and final project was a grant to Springfield Technical Community College and completes this year.) The impact of these projects has grown in technical breadth and geographical extent to include all of photonics technology and teachers and faculty from Maine to Hawaii. Through our work with the optics/photonics societies Optica and SPIE, our impact has spread throughout the globe. The major impacts of the PHOTON projects is summarized below.[1]

### 1.1 FIBER OPTIC TECHNOLOGY EDUCATION PROJECT (FOTEP) 1995 – 1998

In FOTEP, the first of the NEBHE photonics-related ATE projects, we worked with teachers and faculty from more than 40 New England schools in a series of workshops, providing curriculum, materials, technical assistance and a unique opportunity to network with other educators and fiber optic industry personnel. The project developed a lab kit and set of instructional materials that were provided to each participating school to begin or enhance their own fiber optic courses and/or programs. Even more important, more than 60% of FOTEP faculty participants built contacts and partnerships with local fiber optics businesses. Strong collaboration between high school and college level instructors were begun that lasted long after the completion of the project.

### 1.2 PHOTON 2000 – 2003

By the end of the FOTEP Project, the importance of photonics technology was becoming increasingly evident, yet the number of technician education programs in the U.S. was not keeping pace with the demand. There were many obstacles to be overcome: the word “photonics” was mostly unknown to the public, there were few community colleges (where most technicians are educated) with faculty who could teach the core subject matter, and even if programs were to appear overnight they would have little appeal to incoming high school students (and their parents) who were completely unaware of the growing need for of photonics technicians.

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In Project PHOTON, the primary task was increasing the number of teachers who had the knowledge and skills to teach optics/photonics science and technology. Although NSF-ATE programs are focused on two-year colleges, the PHOTON team recognized that the pipeline of college students starts well before college admission, perhaps even before secondary school. For this reason, project PHOTON included middle and high school teachers as well as college faculty. This cross-grades collaboration resulted in the development of educational pathways in science education to help students achieve as they progressed through the educational system. Project PHOTON also included guidance counselors in the professional development workshops, company tours, and discussion sessions with industry representatives. Counselors gained new knowledge on available career options allowing them to provide outreach to students interested in math, science and technology careers.

Building on the success of Project FOTEP, the PHOTON project enrolled teachers from 39 New England middle and high schools, and community colleges. A lab kit was provided to each participating school consisting of industry-quality as well as educational components to perform 25 laboratory experiments in basic & applied optics. At the same time, a series of 13 "Explorations in Optics" was developed based in part on demonstrations participants shared during PHOTON workshops. The Explorations document is now available in pdf book form on the pblprojects.org web site. Over the years it has been expanded to include eighteen easy-to-perform experiments with simple materials, fifteen of these were videorecorded by theater and communications students at Eastern CT State University with funding through a grant from Optica. These videos can be found on the PBL Projects YouTube channel.[2] The Explorations formed the basis of outreach workshops for over 10 years for students from elementary school through senior citizen groups and at conferences around the world.

Finally, the PHOTON Project helped create strong bonds among high schools, community colleges and local industry leading to joint activities such as field trips, internships, and job opportunities. One important component of maintaining these relationships was an industry-mentored email listserv that is still active today.

### 1.3 THE PHOTON2 PROJECT (2003-2006)

The third project in the PHOTON Projects series expanded the New England-based project and created a network of photonics educators and industry personnel across the U.S. Participants from eight geographics regions were required to apply to participate as a “regional alliance” of a community college, one or more area high schools, and local industry. Alliances between local high schools and colleges enabled seamless integration between their STEM curricula and the addition of local industry ensured that what was being taught was relevant to eventual employment of students.

PHOTON2 developed and implemented a web-based professional development course, “Introduction to Photonics” that relied heavily on the kit developed by the PHOTON project to illustrate concepts being taught with hands-on experiments. Because of the complexity of the kit, and to foster community among PIs and educators, members of the PI team visited each of the eight regional alliances for a mini-workshop to explain the project and demonstrate the kit before the online course began. The PIs also created a series of 26 lab videos using the lab kit; these can be found on the PBL Projects YouTube channel. Notes from the PHOTON professional development workshops were edited into book form for use in the course. First self-published online by lulu.com, the textbook is now available in a second edition published by Photonics Media of Pittsfield, MA.[3]

The close relationship with the photonics industry developed through regional alliances was utilized to create local, paid summer internships during 2005 and 2006 for both teachers and guidance counselors. The project completed with a capstone “Showcase” workshop in summer 2006 held in collaboration with SPIE at the Optics and Photonics conference in San Diego. Teachers had the opportunity to display their photonics teaching experiences at the conference exhibition an to hear first-hand from industry attendees how important their work is.

## 2. THE PBL PROJECTS

At the end of PHOTON2, our participants were offering several new photonics-related programs and many new courses. Students seemed to be learning the appropriate technical material and skills, but feedback from industry was that graduates often had poor problem solving and critical thinking skills, were lacking communication skills and were missing the "soft skills" needed for the workplace. As one manager said, “We don’t have time for technicians who keep asking what they should do next.” In 2006 we were funded by NSF-ATE for the first of what would be four projects to address industry’s concerns- the Problem-Based Learning (PBL) Projects. At the time, classroom chalk-and-talk was the norm in STEM education, especially in the education of photonics technicians. We developed a comprehensive process, the PBL "Challenges", to teach problem-solving at the same time as content, requiring students to master the subject matter and also use critical thinking, communications, time management, teamwork and other workplace skills. Of course, this radically different type of instruction also required providing educators with the tools they need to be successful with PBL in the classroom.

### 2.1 PHOTON PBL – LEARNING TO CREATE PBL CHALLENGES

Our first PBL project was a learning experience for the PI team as well as for our project participants. Although we began with several ideas for turning real-world industry problems into "Challenges", or case studies, the actual final form took trial and error. In the end we developed a successful process that remained essentially unchanged over the next three PBL projects.

Relying on the large network of companies from the PHOTON projects, we worked with industry and research universities to define problems that could be transformed into a Challenge. Problems suitable for Challenges:

- do not have readily available solutions on the internet
- are open-ended with several possible solutions
- are ill-structured to challenge students and promote inquiry
- are interdisciplinary, requiring collaboration and teamwork
- address several topics normally covered by the course in question
- have ideally been solved by "experts" so that students can compare and contrast their solutions to the expert solution and so novice teachers would feel comfortable knowing there is a documented solution

Once we had a partner organization and a problem, we met at the organization's location and asked the engineers, scientists and technicians involved in solving the problem to reenact the discovery of the problem (e.g. discussion at a meeting or a request from a customer), a brainstorming session where the group discussed possible solutions, and the organization's final solution to the problem

We videorecorded the organization's discussions to be used as the basis for a final script, and took hundreds of still photos of the team at work, illustrating good work behaviors such as appropriate dress, teamwork and note-taking. Each Challenge consists of five parts each comprising a video and related resources:

1. Introduction – This sets the Challenge in a context familiar to students, for example, the sensors one might find at home for a Challenge about photonic sensor design.
2. Organization Overview – We create an introduction to the organization that solved the problem, as both a thank-you to the organization and a reminder to students that the problem is from real life, not contrived.
3. Problem Statement – A reenactment of the team learning of the problem to be solved.
4. Discussion – This password protected video shows the team discussing pros and cons of possible solutions. This section is revealed to students once they have made an initial attempt at defining and framing the problem.
5. Organization's solution – This section is also password protected to be shown only after students have presented their own team solutions for peer review.

In addition, we created a detailed (password protected) site with resources for teachers including detailed technical background on the problem, tips for assessment in PBL, and information on how other teachers at various educational levels implemented the Challenge in their own classroom.

PHOTON PBL created Challenges with eight different partner organizations (companies and research universities) in various topics in photonics science and technology ranging from laser safety to determining light requirements of a DNA microarray. Secondary and post-secondary teachers from more than 20 New England institutions attended workshops to learn about the PBL method and how to field test the Challenges in their own classrooms. Their feedback provided the Implementation Stories included in the teacher resources of each Challenge. Research we conducted on the efficacy of PBL in engineering technician education encouraged us to apply for additional PBL funding from NSF-ATE.[4]

### 2.2.1 Implementing the problem-solving cycle with Whiteboards

Critical thinking and problem solving do not "come naturally" to students; they are skills that can and should be taught and reinforced with practice. After brainstorming with a group of a dozen engineers from the New England photonics industry we devised the "Whiteboards", a teaching device that would introduce the steps of the problem-solving cycle (Figure 1) and require students to follow them as they worked to solve a Challenge. The Whiteboards have been modified over the course of the four PBL projects but the essential structure remains the same.

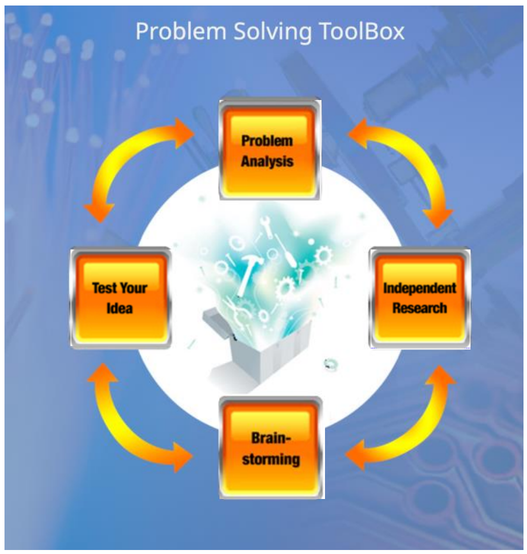


Figure 1. The problem-solving cycle

The Whiteboards tool breaks each of the four main cycle sections into a number of logical steps beginning with the most important, "Clearly state the problem you are trying to solve." The difficulty students have with this seemingly simple step indicates its necessity in beginning to find a problem solution. Problem analysis also asks students to describe the criteria for a successful solution. Then, in the "Test your solution" step they once again write the criteria and show how their solution addresses each one. Between analyzing the problem and testing the solution students are asked to determine what they need to learn, divide up the learning tasks among teammates, and determine a timeline for completion – tasks that are usually handled by the instructor when the syllabus indicates "do these end of chapter problems by next Tuesday." Affirmation that the Whiteboards are a useful tool is reinforced each time students request a copy because they have a "project to complete in another course," which happens quite often.

### 2.2.1 Assessing PBL - Our tools

For many engineering technology instructors, assigning a grade to a long term team project that involves oral and written communication is daunting. To help make the process manageable we developed assessment tools available in every Challenge in the Teacher Resources section. Our process is four-pronged (Figure 2) and includes Content Knowledge (traditional homework and quizzes), Conceptual Knowledge (visual tool to show how concepts in the Challenge are interrelated), Problem-Solving Ability (a guided report describing the thought processes used to solve the problem) and teamwork. The assessment strategies employed were derived from over 30 years of research by major universities and is detailed in several of our publications available on the PBL Projects website.[5,6]

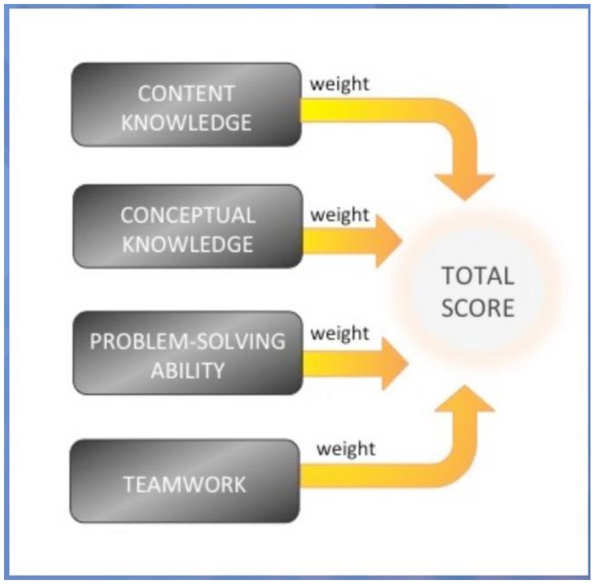


Figure 2. Assessing student learning in PBL

### 2.3 STEM AND ADVANCED MANUFACTURING PBL PROJECTS

Problem-Based Learning for Sustainable Technologies (STEM PBL) built on the PHOTON PBL Projects by creating a 15-week online professional development course, "Principles and Applications of PBL", allowing us to recruit a pool of teachers nationwide. Six Challenges were created with partner organizations on topics from sustainable technologies that would appeal to students, such as sustainable agriculture and lighting. Results of research conducted during this project showed that overall, photonics technology students reacted positively to the PBL method of instruction.[7] Students reported an increase in intrinsic motivation as a result of the real-world nature of the problems. Moreover, results showed that the more students interacted with PBL, the more their confidence and critical thinking skills improved as well as their ability to plan, monitor, and evaluate their own learning and performance. Results also indicated that students learned with practice to work collaboratively and productively in teams.

During STEM PBL we convened a team of four middle school teachers and asked them to work through our Challenges to learn how they were constructed and to determine how the Challenges could best be adapted to middle school-level students. The group was able to develop a set of adaptations to make the Challenges and their resources accessible to younger students and those requiring adaptations. These Grade Level Adaptations are available to teachers in the Teacher Resource section of each Challenge.

We returned to New England for Advanced Manufacturing PBL, creating six new Challenges field tested by secondary and post-secondary teachers throughout the region. New to this project was the inclusion in professional development activities of teacher education faculty who would influence the next generation of STEM teachers. In collaboration with Central CT State University, we developed new instructional materials for STEM teacher education programs that serve both pre- and in-service educators. Research conducted on pre-service and in-service technology educators showed overall gains in motivation, self-efficacy, critical thinking and metacognitive self-regulation.[8] Finally, we developed a template for teachers to create their own Challenges with local business and industry that would be of specific interest to the region. Many of these are on the pblprojects.org web site along with the Challenges developed by the projects.

## 3. THE CURRENT PROJECT – PBL IN ADVANCED PHOTONICS MANUFACTURING

The current project, PBL for Advanced Photonics Manufacturing is developing additional Challenges with the assistance of companies and universities such as IPG Photonics, Coherent and Convergent and the Massachusetts Institute of Technology.

The overarching goal of the project is to increase the pipeline of photonics technicians prepared with the knowledge and skills needed to sustain and grow the advanced photonics manufacturing industry in the Northeast through student engagement with real-world industry problems drawn from the advanced photonics manufacturing industry. Special emphasis was placed on the development of PBL Challenges in the area of silicon photonic integrated circuits (PICs) to support the work of the MIT's AIM Photonics Academy. MIT's AIM Photonics Academy is the education, workforce development, and road mapping arm of AIM Photonics, one of 14 public-private manufacturing innovation institutes launched as part of the 2014 Revitalize American Manufacturing Innovation Act.[9]

To date, five of the eight proposed PBL Challenges have been developed. Three of these challenges were developed in partnership with companies including IPG Photonics, Coherent Laser, and Convergent Photonics in the areas of fiber laser welding, active fiber testing, and active fiber absorption testing. Project personnel also worked closely with researchers from MIT to develop two PBL Challenge dealing with photonic integrated circuit sensors and evanescent-wave coupling to PIC chips. These PBL Challenges are currently available on the PBL Projects website. In addition, older PBL Challenges that had become dated were updated to reflect recent technological advancements.

In early 2020, the COVID-19 pandemic shutdown of the project's college, university, and industry partners posed a major obstacle not only to the development of the eight PBL Challenges, but also the planned professional development workshops and outreach activities. The pandemic forced the project to postpone its 2020 in-person summer workshop for 24 STEM educators from around the U.S. for one year. Because many of our project participants had little or no formal background in optics, photonics or problem-based learning methodology, and to keep the educators engaged in the project, we created a 5-part live webinar series hosted by Optica as part of the We Are On series. Topics included geometric & wave optics, fiber optics, laser fundamentals, and problem-based learning methodology. These five webinars were well attended not only by our project participants, but also STEM educators from around the globe. Recordings of the webinars can be found by searching Optica's video library or direct links from the PBL Projects web site.[10]

In March 2020, discussions with Optica led to the development of a series of online family-friendly hands-on workshops that would prove useful to parents looking for simple science activities for their children whose schools were closed during the pandemic. Eight webinars were delivered over the course of the year, all based on the Dumpster Optics lessons that were an outgrowth of the Explorations in Optics. Aimed at ten- to twelve-year old students, the lessons can be done at home with simple easy-to-find materials. The international audience included participants of all ages from more than 325 households in nearly 50 countries.[11] Participants were invited to join in the experiments at home and send along their photos for small prizes awarded by Optica. The recorded webinars are in the Optica video library (search for Exploring Optics at Home) and also linked to the PBL Projects web site.[11]

In summer 2021, still hampered by the COVID-19 pandemic lockdown, we were again unable to offer a live face-to-face professional development PBL workshop to introduce our participants to the new Challenges. As an alternative, we decided to offer the four-day workshop virtually via Zoom®. The workshop was attended not only by 14 participants from the U.S., but also four additional educators from Mexico, Italy, and Romania. Educators who participated and field tested the PBL Challenges in their classrooms during the fall 2021 and spring 2022 semesters were invited to display and disseminate the results of their classroom field-testing to other educators and industry representatives in the Exhibition Hall of the 2022 Annual SPIE Optics and Photonics conference in San Diego, CA.

Now in our second one-year no-cost extension, the project is finalizing the five new PBL Challenges and looking for additional opportunities to disseminate them through partnerships with NSF-ATE Centers and other related projects that will build upon our instructional materials and resources moving forward. All of our materials developed during the PHOTON and PBL Projects will remain available at no cost on our own website hosted by the New England Board of Higher Education.

## 4. CONCLUSION

For more than 25 years, the seven NSF-ATE supported projects comprising the PHOTON and PBL Projects have brought together an international group of educators from middle school through university along with local industry partners to improve STEM education through curriculum development, lab improvement and teacher professional development. All of the resources developed by the projects, including resources for teaching optics/photonics from fifth grade through college and more than 20 problem-based learning Challenges are available at no cost on the web site www.pblprojects.org.

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