Professional Development in Photonics: The Advanced Technology Education Projects of the New England Board of Education

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ABSTRACT

Since 1995, the New England Board of Education (NEBHE) has been providing curriculum and professional development as well as laboratory improvement in optics/photonics to middle school and high school teachers and college faculty across the United States. With funding from the National Science Foundation’s Advanced Technology Education program, NEBHE’s optics/photonics education projects have created a national network of educational and industry alliances resulting in opportunities in optics and photonics for students at participating schools and colleges. The cornerstone of NEBHE projects is collaboration among educational levels, career counselors and teachers/faculty, and industry and academia. In such a rich atmosphere of cooperation, participants have been encouraged to create their own regional projects and activities involving students from middle school through four-year universities. In this paper we will describe the evolution of teacher/faculty professional development from a traditional week-long summer workshop to a collaborative distance learning laboratory course based on adult learning principles and supported by a national network of industry mentors.

Keywords: Professional development, Curriculum, Laboratory improvement, Education, PHOTON, PHOTON2, Distance learning, Problem-based learning

1. INTRODUCTION

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. The New England Board of Higher Education (NEBHE) in Boston, Massachusetts was one of the first ATE grantees, with a project to prepare teachers to introduce fiber optic technology to secondary and postsecondary students in the six New England states. Twelve years and three ATE grants later, 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 as well as one European country (Figure 1).

Figure 1 - Locations of NEBHE NSF/ATE optics/photonics project participants.
1.1 The New England Board of Higher Education (NEBHE)

Founded in 1955 by the governors of the six New England states and approved by their state legislatures the same year, NEBHE promotes educational opportunities and services across the region by assisting in the development, implementation and assessment of sound educational programs and practices. Since 1995, through the programs discussed in this paper, NEBHE has been connecting educators and the photonics industry, first in New England and later, across the United States.

A key factor in the success of each of the programs described below is a strategic management model based on the idea that project faculty best spend their energy developing curricula and pedagogy, teaching, and being mentors to project participants. The day-to-day activities such as correspondence, report writing, organization of workshops, recruitment of teacher and industry participants, outreach and dissemination have been ably carried out by NEBHE staff. Including a principle investigator (PI) for project management has allowed the technical principle investigators to concentrate on what they do best and not be distracted by tasks that are not their area of expertise nor a good use of their time.

1.2 The NEBHE projects, 1995--present

Technology has changed at a rapid pace over the past decade, and the NEBHE NSF/ATE projects have also evolved to ensure that educators are able to remain current with the technology topics they are teaching as well as with the technology they are using to teach. In this paper, we will show the evolution of the projects we now refer to as “the PHOTON projects,” from 1995 to the present. (Figure 2) In each of the four projects, FOTEP, PHOTON, PHOTON2 and PHOTON PBL, we have tried to remain flexible and responsive to the needs of educators, retaining the best models of the past as we plan for the future.

Figure 2 - The optics/photonics Advanced Technology Education projects of the New England Board of Higher Education.

2. FIBER OPTIC TECHNOLOGY EDUCATION PROJECT (FOTEP)

The first of the NEBHE photonics-related ATE projects had as its goal to increase the number of secondary schools and colleges (primarily two-year community colleges) prepared to introduce fiber optics technology to their students. Over a period of 30 months, the principle investigators worked with teachers and faculty from more than 40 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.

2.1 Learning to teach fiber optics: Workshops, curriculum development, and lab equipment

In the fall of 1995 and spring of 1996, each FOTEP participant attended a two-day workshop at one of four regional locations throughout New England. These introductory workshops provided an overview of the fiber optic industry, applications of the technology and a hands-on introduction to fiber optic termination and testing. Each participant returned to their home institution with a binder of notes that could be immediately used in the classroom plus a fiber optic termination kit and a source and meter test kit to use for classroom demonstrations.

The introductory workshops were followed by two week-long summer workshops, at Wentworth Institute of Technology (1996) and Springfield Technical Community College (1997). Each workshop provided participants with additional curriculum materials, including more advanced theory and applications, and several hands-on laboratory activities that
teachers had the opportunity to practice during the workshop. Local fiber optics companies provided guest speakers and
tours of their facilities, and each participant received a custom designed xyz rotary stage to continue to build a fiber optic
laboratory at their home institution. The second summer workshop also featured reports by participants on the
considerable progress they had made introducing fiber optics into their own classes and programs.

During the academic year after each of the summer workshops, the principal investigators and senior personnel provided
technical assistance to the participants. Experience has shown that while workshop attendance is important for
professional development, implementation of new curriculum requires a support system. Often, educators return to their
classrooms and the demands of teaching and the introduction of new material takes a back seat to other concerns.
FOTEP personnel were proactive in staying in contact with participants by providing technical assistance that included
consultations by phone and by email, visits by the PIs to participants’ institutions and visits by participants and their
students to PIs’ home institutions. In addition, the project manager sent out many communications and newsletters
describing participants’ activities in order to maintain a high level of interest and support.

While faculty are often eager to begin new courses or programs, implementation is sometimes stymied by a reluctant
school administration, particularly if the new curriculum involves a laboratory. To ensure a strong commitment from
both faculty and administration, each institution was required to make a $2000 equipment match in order to acquire
$4000 worth of laboratory equipment. Although applicants to the project were not turned down if they were unable to
definitely commit matching funds from their institution, those with an institutional commitment were in a stronger
position to be accepted. In the end, only one school was unable to make the required match; the participant, with the
assistance of the FOTEP team, secured the match from a local fiber optics company.

2.2 FOTEP outcomes: New courses, new programs, new industry connections

The strong combination of institutional and technical support resulted in an 88 percent retention rate for participants in
FOTEP, and the participants who stayed with the project actively promoted fiber optic education in their home
institutions. Prior to the start of FOTEP, 58 percent of the participating schools and colleges offered no instruction in
fiber optic technology. Over the course of the project, the number of fiber optic units taught by participants grew from
six to twenty-six, and the number of courses in fiber optics increased from three to seven. In addition, the participant
from Three Rivers Community College initially proposed a new course, and was encouraged by the college
administration to start a new two-year associate degree program, which was developed with the input and support of an
industry advisory committee and approved by the state of Connecticut in 1997.

FOTEP participants created one-year fiber related certificates, such as Line Worker Technology (Maine), and others
offered non-credit workshops to technicians and managers in local fiber optic companies or to Tech Prep teachers at
local high schools (Figure 3). At some FOTEP schools, students installed fiber optic cable on their campus or assumed
responsibility for the school’s data services system. Overall, the number of students exposed to fiber optic instruction at
FOTEP participating institutions exceeded 4200 for the 30-month grant period.

![Figure 3 – FOTEP Senior Personnel Elias Awad conducts a fiber optic workshop attended by high school Tech Prep
instructors at Three Rivers Community College.](image)
FOTEP participants also collaborated with local fiber optic industry, which donated supplies and equipment, delivered classroom presentations, served on program advisory committees and hosted site visits to their companies. By the end of the grant in 1998, 60 percent of FOTEP participants had been in contact with industry and many of the relationships begun in FOTEP continue to this day.

2.3 FOTEP innovations

When FOTEP funding ended in 1998, the PI team focused their energies on the creation of the National Center for Telecommunications Technology (NCTT), located on the campus of Springfield Technical Community College. Many of the FOTEP participants continued to be active in the National Center for Telecommunications Technology where NEBHE played a key role in the Centers’ administration. The FOTEP PI team, however, believed that the energy and enthusiasm of the project’s participants could and should be maintained through professional development in the broader area of optics/photonics. In the development of PHOTON, the second optics-related project proposal to NSF/ATE, several key aspects and innovative features of FOTEP would be preserved.

- Professional development would stress secondary/postsecondary collaboration. Although the original intent of FOTEP was to have separate workshops for high school and college teachers, the two groups were joined since the participants requested to work together. In addition, bringing the two levels together encouraged collaboration and eventual articulation agreements between secondary and postsecondary programs.
- Collaboration with industry would be central to the new project’s success. FOTEP included an industry PI, as well as industry mentors, speakers, and plant tours for participants.
- Pro-active technical support by the project staff would be essential to the successful implementation of PHOTON curriculum.

3. PHOTON: CURRICULUM DEVELOPMENT, TEACHER ENHANCEMENT AND LABORATORY DEVELOPMENT IN NEW ENGLAND

As the 20th century came to an end, it was clear that applications of optics/photonics were rapidly growing in importance, creating an increasing need for optics/photonics technicians beyond the fiber optic industry. Project PHOTON was funded by NSF/ATE to address a critical shortage of technicians in the New England photonics industry. The specific goal of the project was to increase the number of middle, secondary and postsecondary institutions in New England with programs and laboratory resources to prepare students for work in the photonics industry.

3.1 Regional alliances of multiple education levels

PHOTON addressed the issue of photonics education on a number of fronts. Of primary importance was increasing the number of teachers who had the knowledge and skills to teach photonics technology. Although ATE programs are focused on two-year colleges, PHOTON 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. The collaboration of middle school, high school, and college educators resulted in the development of curriculum ladders that connected to and built on each other.

A key feature of PHOTON was adapted from a previous NEBHE grant, AQUA, that provided professional development in aquaculture to teachers throughout New England. In order to be accepted into the program, schools needed to apply as “regional educational alliances” consisting of at least one high school and one college, plus a middle school if possible. These educational alliances enhanced opportunities for articulation and sustainability by bringing together educators from middle, secondary and postsecondary institutions in the same professional development activities. The alliances were successful at sharing knowledge and resources, strengthening connections with industry partners, and solving a variety of implementation problems. Educational alliances that were able to create formal articulation agreements were most successful at designing comprehensive, multi-level programs.

The inclusion of career and guidance counselors along with faculty in professional development workshops was a unique feature of Project PHOTON. Counselors, who have great influence over student decision making, were equipped with new knowledge for outreach to students interested in math, science and technology careers. Working together with teachers and industry representatives (in some cases, for the very first time) counselors gained important information and resources to help them work with students to make the link between education and the many potential career opportunities in the emerging field of photonics.
3.2 Industry collaboration

The development of collaborative alliances between schools and the photonics industry was a strong component of project PHOTON. As in project FOTEP, PHOTON had an industry co-PI who assisted the project team in making connections with potential industry partners. Collaboration with photonics companies resulted in field trips and internships for students, donation of industry-quality materials for student use, and the development of advanced courses taught on industry sites.

Beyond industry partnerships, Project PHOTON participants engaged with professional associations that helped them gain access to a professional photonics community to enhance their own professional development and to recruit new teachers and faculty from the industry. Partnership with SPIE (the International Society for Optical Engineering) and OSA (the Optical Society of America) bolstered the sustainability of the project by building commitment to collaborative activities and a learning supply chain focus that brought industry requirements and educational resources together.

3.3 Project PHOTON activities

Approximately sixty schools (a total of 120 teachers and counselors) were selected from seventy applications to take part in one of two two-day introductory workshops held in November of 2000. The first day of each workshop was held at an industry location, Zygo, Inc. in Connecticut and Lucent in Massachusetts, and included both teachers and career/guidance counselors. Industry professionals presented an overview of the photonics industry, the types of careers available, and what kind of education is needed for different job categories. On the second day of the workshop, a nearby college (Three Rivers Community College in CT and UMass Lowell in MA) hosted the teachers only for inexpensive, hands-on activities that could be brought directly into their classrooms. Participants were also given time and resources to establish professional contacts in their state that would lead in the future to alliances among middle, secondary and postsecondary institutions.

The introductory workshop gave the participants the opportunity to learn more about photonics as well as their expected commitment to Project PHOTON, both in terms of time and financial resources. Participants were expected to connect with fellow participants from nearby schools to form regional alliances and then develop a joint application to participate in the activities of the remainder of the project.

Thirty-nine schools were accepted to participate in the one-week in-depth summer workshop in 2001, designed to prepare teachers to introduce optics/photonics instruction into the classroom. Hosted by Springfield Technical Community College in Springfield, MA, the workshop included lectures and demonstrations by the PHOTON PI team covering topics usually addressed in a first “introduction to photonics” course. Hands-on laboratory exercises were performed each afternoon by groups of middle school, high school and college teachers working together (Figure 4).

Figure 4 – Middle school, high school and college instructors worked together during project PHOTON

The summer workshop was also designed to meet the special needs of guidance/career counselors by including a special joint session with teachers on work-based learning opportunities, internships, and other ways to partner with industry to
bring “real world” experiences and information into the classroom. A special session for counselors only included practical information on infusing career development into academics, engaging students in technical careers, and marketing photonics to administrators and parents. Counselors were later joined by teachers for an industry field trip to JDS Uniphase in Bloomfield, CT, for many, an eye-opening view of a modern manufacturing facility.

During the academic year following the summer workshop, the PHOTON PI team provided one-on-one, web-based and on-site technical assistance. As in project FOTEP, this strategy was designed to assist participating educators to implement photonics instructional materials into existing programs and develop laboratory exercises for hands-on activities. Teachers field-tested the PHOTON materials, providing feedback from their classroom experiences that was incorporated into the curriculum.

With the assistance of volunteers from the New England Chapter of the Optical Society of America (NE-OSA), a mentored e-mail listserv was created, hosted first by the Rhode Island Department of Education and later by NEBHE. The listserv allows easy access to technical and curriculum advice from both industry mentors and other teacher participants. Now, with more than 100 subscribers, the listserv still hosts lively discussions on everything from what’s new in fiber optic teaching materials to how to set up laser experiments in the classroom to handling unruly students.

A final “Spring Showcase” was held in May, 2002 to allow participants to share their implementation of the PHOTON curriculum. Sixteen schools, including three community colleges, twelve high schools and one middle school, exhibited posters demonstrating how they used their PHOTON materials in their classrooms. Several members of the PHOTON industry advisory board as well as industry project mentors attended the workshop. NEBHE was pleased to be able to distribute to participating schools $50,000 worth of lasers and optical components and mounts that had been donated to the project by Melles Griot, a vendor that provided components to the PHOTON lab kit (See Figure 5).

Based on requests from many PHOTON teachers and faculty for one more workshop on advanced topics, the PHOTON instructional team designed and held a final Advanced Topics Workshop in November, 2002. The one-day workshop program held at Springfield Technical Community College included two hands-on laboratory sessions on optical image processing and holography. Participants tried their hands at aligning spatial filters and using a 4f optical data processor to remove unwanted lines and dots from photographic slides and created reflection holograms to take home.

3.4 PHOTON curriculum materials development

Although the PHOTON team originally intended to produce only a set of notes to accompany workshop lectures, the development of curriculum materials quickly became a focus of the project. In large part, this was due to participant dissatisfaction with commercially available materials at an appropriate educational level. The original workshop notes were first revised into eight optics “modules” at the request of participants, who wished to use them in their own classrooms. Later, again with encouragement from PHOTON participants, the modules were expanded, resulting in a ten-chapter textbook. During project PHOTON2, five additional chapters were added, and the text has been renamed LIGHT—Introduction to Optics and Photonics. Three of the applications chapters, Imaging, Manufacturing Precision Optics, and Biophotonics, were written by industry experts who served as mentors to the PHOTON projects. Table 1 shows the textbook Table of Contents.

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Table 1 – Table of Contents for the PHOTON textbook LIGHT—Introduction to Optics and Photonics, written during the PHOTON projects by PIs Donnelly and Massa.

In order to increase the usefulness of the text, end of chapter conceptual questions and numerical problems were written for nearly all of the chapters. A separate teachers’ manual includes complete worked-out solutions to the problems. The
book is written at the algebra/trigonometry level, suitable for community college and upper level high school students. To ensure technical accuracy and readability, the text has been edited several times by numerous technical and non-technical readers, including college students. It is anticipated that the text will be available both electronically and in book form in Fall, 2007.

As in FOTEP, hands-on activities were central to project PHOTON. In order to enable participants to bring laboratory experiences to their own classrooms, a laboratory kit was developed, blending industry quality equipment with standard physics lab supplies. This unique custom kit was not only more flexible than the traditional “science lab” variety, but it also featured equipment that students might see, for example, on an industry field trip, making their school hands-on experience more like that in the “real world.” (Figure 5) Since teachers were unfamiliar with this type of equipment, an important part of the summer workshop was familiarization with the lab kit through hands-on practice with the experiments their students would perform in the classroom.

Twenty laboratory experiments in basic and applied optics were written and thoroughly field-tested and edited by participants and their students, as well as by a college student intern. (The number of experiments was later expanded to twenty-five.) Half of the $3000 cost of the kit was paid for by the PHOTON grant; the remaining $1500 was matched by the schools. As in FOTEP, this matching fund requirement was used to ensure administrative support for photonics education at participating institutions. Again, schools unable to find funding were assisted in locating a source of matching funds if they otherwise showed a strong commitment to the project.

Finally, the presence of middle school participants was the impetus for developing a set of PHOTON Explorations, simple demonstrations and hands-on activities using inexpensive materials and supplies. Many of the fourteen experiments were demonstrated by PHOTON participants during one of the PHOTON workshops as their “favorite optics activity.” All the demonstrations have been field-tested by students of PHOTON middle school teachers, and some have been used in various outreach activities. Recently, for example, the PHOTON Explorations formed the core activities of a hands-on teacher professional development workshop as well as yearly “optics days” attended by 150 fifth grade students in eastern Connecticut. The PHOTON Explorations are available for download from the NEBHE web site, www.nebhe.org.

Figure 5 – The PHOTON laboratory kit, 2001. The later version kit (PHOTON2) was modified based on teacher feedback. The revised kit is no longer packed in the bright yellow cases, and a few components were added or changed.

3.5 PHOTON Impact and Outcomes

In 2002, teachers and counselors were asked about implementation of PHOTON materials in their classrooms. With nearly three quarters of participants responding, it was reported that over 3600 middle school, high school and college students had been exposed to photonics through the project PHOTON materials since the start of the project. New industry partnerships were reported by three community colleges, including donations of equipment, co-op job opportunities, industry scholarships for students, and industry participation on college advisory committees. Fourteen high schools also had forged new relationships with neighboring photonics companies, resulting in part time jobs for
students, participation by industry on school advisory boards, and plant tours. In addition, new collaborations between high schools and community colleges and also between teachers and counselors resulted from participation in PHOTON, leading to dozens of activities such as field trips, job shadowing, photonics activities at career days, and professional development in photonics for teachers who were not PHOTON participants.

Project PHOTON met and exceeded its goals by successfully supporting the development of school-based photonics education programs and collaborations across the New England region. The alliance partnerships that developed as a result of Project PHOTON continue to flourish and work collaboratively to build strong comprehensive programs in their geographical areas. In many cases, PHOTON partner schools have reached out to include new schools in their alliance. As with FOTEP, several features of project PHOTON model were identified as crucial to the accomplishment of the project goals. These are the features that would be replicated on a national level in PHOTON2.

- To build an effective photonics education continuum that gains student interest and prepares them for careers in photonics, alliances must work at multiple education levels. The collaboration of middle school, high school, and college personnel resulted in increased understanding of the problems and opportunities faced by each, and fostered a spirit of cooperation. Regional alliances support program sustainability by creating articulation agreements and connecting to local industry partners.

- In today’s high tech world, high school and college students are thinking about post-graduation employment and continuing education options as an important factor guiding their choice of courses and programs. Project PHOTON successfully engaged guidance counselors and provided them with information and resources that helped them work with students to make the link between education and career ladders in photonics.

- High quality and flexible curriculum materials are essential to photonics courses and programs. While the development of a field-tested textbook, laboratory kit, lab manual and Explorations were not an explicit goal of the program, due to the lack of other commercially available materials they were important to the success of the project.

4. PHOTON2: WEB-BASED COLLABORATIVE LEARNING FOR TEACHERS

At the end of the PHOTON project in 2003, dozens of new courses and programs in fiber optics, optics or photonics had been initiated in the six New England states and thousands of students had been impacted by the FOTEP and PHOTON projects. Encouraged by NSF to bring the PHOTON curriculum to a wider audience, NEBHE applied for NSF/ATE funding to create a web-based adaptation of the successful PHOTON model. The goals of PHOTON2 were to increase the number of high school teachers and college faculty across the United States prepared to teach photonics at their own institutions, and to develop and evaluate a web-based model of hands-on professional development for teachers. To assist with the design of the course and to conduct research on the effectiveness of the online course, researchers from the University of Connecticut’s (UConn) Neag School of Education joined the PI team.

4.1 Forming PHOTON2 alliances across the nation

Participant selection for a nationwide project presented unique challenges. In addition to contacting college presidents and deans and previous PHOTON participants in New England, recruitment also occurred through professional societies, SPIE, OSA, and LIA, the American Association of Engineering Education (ASEE) listserv, minority focused organizations, the NSF ATE listserv and a list of EET department chairs and program coordinators assembled through an extensive Internet search. Industry contacts and PHOTON advisory board members also assisted with recruitment.

As in PHOTON, PHOTON2 project applicants were asked to form regional alliances, with a career/guidance counselor as well as a teacher/faculty member from each alliance institution, and each institution was required to make a dollar match for the PHOTON2 lab equipment. In some cases, especially outside of New England, the concepts of regional alliance (and dollar matching) needed clarification before the applications could be submitted. The first institutions accepted into the program in the spring of 2004 were designated “Cohort 1”; a second cohort was recruited during the Fall of 2004 while Cohort 1 was engaged in the online course.

Participants in PHOTON2 were from 38 institutions, in states from Maine to Hawaii. Regional alliances were formed in New England (two alliances, one in each cohort), Pennsylvania, northern Alabama and Tennessee, central California, southern California, Arizona, Hawaii, and Texas. Before the start of each online course, the PHOTON2 PI team traveled to each regional alliance to meet with participants at one of the participating alliance institutions. The initial workshop
agenda included an introduction to photonics technology, clarification of the grant and course expectations, and an introduction to the PHOTON2 lab kit. Based on PHOTON participant recommendations, the kit was modified slightly from the PHOTON kit. The kit was assembled by Lumenflow, a Michigan based photonics design, development and manufacturing firm. An industry field trip was conducted at each alliance location, beginning the connection between the educators and their local photonics industry.

Figure 6 - Co-PIs Judith Donnelly and Nicholas Massa (second from right) work with participants from the Dallas, TX area alliance on the use of the PHOTON2 kit at a regional workshop.

4.2 The PHOTON2 online course

In order to form an online community of learners, PHOTON2 enlisted the aid of adult education specialists from the UConn's Neag School of Education. The development of the web course was guided by the principles that adult learning must be:

- active, including hands-on experiences, reflection, practice and feedback to fully engage learners in constructing a knowledge base
- continuous, with enough hours over a long enough time span to allow for problem solving and processing of material
- coherent, that is, linked to genuine problems.

The three-credit Introduction to Photonics course was delivered via the WebCT platform through Three Rivers Community College, a member of Connecticut's Distance Learning Consortium. The resources developed in the PHOTON project were central to the course, which used the textbook, lab kit and lab manual as well as some of the Explorations. Since participants were at a great distance from the instructors, and recognizing the complexity of the lab kit, the instructors created video segments illustrating the set up, performance and data analysis for each of the 25 lab experiments. Equipment questions that arose during the course were also quickly answered by posting photos to the course web site.

In the first offering of the course (Fall 2004) to Cohort 1, the structure was similar to the online introductory optics course taught previously at Three Rivers to traditional college students. Photonics topics were introduced through text readings, web-based interactive applets, and hands-on lab activities using the PHOTON2 lab kit. Participants worked both individually and collaboratively with alliance members to complete assignments. Threaded discussion and real-time online chat were used to allow participants work with their alliance members and to ask questions or make comments to the instructor. Participants were given specific assignments that included self-tests, quizzes, and several reflective journal entries spaced throughout the semester. A final curriculum project was required of each participant, outlining the planned implementation of the course material in the instructor’s own classroom.

It quickly became apparent that participants were conversing mostly with the instructor, if at all, and efforts to encourage communication among participants were not particularly successful. Therefore, in the semester break between the Cohort 1 and Cohort 2 courses, with the assistance of the UConn education specialists the course structure was
completely redesigned to foster a more collaborative learning environment to encourage increased student engagement. The introductory workshops for the Cohort 2 alliances were also changed to more clearly delineate expectations for the course. Although the members of the regional alliances had met in person at the introductory workshops, teachers in different geographical areas were still strangers to each other. To allow participants to introduce themselves to the larger group and engage in a period of informal socialization, the course web site was opened for one week before the start date for the course. Teachers had the opportunity to log onto the site and were encouraged to post to the threaded discussion including where they were from, why they were participating in the project, their educational background and any other information they wanted to share such as hobbies or family information.

For the Cohort 2 version of Introduction to Photonics, the scope of photonics topics to be covered during the semester was reduced to allow more time for reflection on teaching and learning. The topics that were retained were those judged “most likely to be taught in my classroom” by the participants in Cohort 1. Reducing the number of technical topics allowed teachers to spend more time on the remaining core concepts, leading to deeper understanding, which in turn would increase the likelihood that the material would be taught in their own classrooms.

The most important change in the course was the shift from an “instructor centered” course to a “learner centered” course, with the instructors acting as facilitators rather than leaders. Each of the photonics instructional modules was rewritten to begin with an open-ended application problem, to be answered through the activities of the module. After a few days of individual study, including readings, computational problems, web-applets and tutorials, and hands on experiments participants entered into discussions with their regional alliance partners to collaboratively solve the application problem. The module ended with a report out to the entire class. During the module, the content expert instructor acted as “coach”, reading the discussions, answering questions when asked, prodding reluctant participants, and holding online office hours, but not leading the class in any particular direction.

Each optics lesson, referred to as “Learning Photonics”, was followed by a two-week “Teaching Photonics” discussion, led by the UConn education specialists (Figure 7). Participants were asked to reflect on what they learned, how they learned it, the best strategies for approaching the material, and how to teach the material in their own classrooms. Participants also kept private journals as part of the online course where they could post messages visible to the instructors only or report and reflect on their progress in the course.

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<td>LEARNING PHOTONICS</td>
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<td><em>Introduction to Laser Physics</em></td>
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<td>TEACHING PHOTONICS</td>
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Figure 7- The PHOTON2 web-based course was redesigned for Cohort 2, to allow time for reflection on teaching and learning after each photonics module.
4.3 Online course findings

Analysis of the research data for the two PHOTON2 online course offerings plus interviews with the participants yielded some specific recommendations for a successful hands-on professional development course for educators

- Sufficient time should be spent at the beginning of a course to allow participants to socialize and become comfortable with each other and with the learning environment.
- Educators are very busy, and often unable to maintain a high level of course activity over a full semester. Offer shorter length courses with some “down time” between sessions with ongoing technical support and mentoring.
- Clarify expectations before the course begins, including an estimate of how much time is expected of participants and what types of activities they will be expected to take part in.
- Provide explicit guidelines for writing thoughtful discussion postings, which will encourage critical thinking.
- Include video or video conferencing where possible both to clarify concepts and to provide a human element.
- Identify at-risk participants who lack the self-regulation skills needed to participate in an online course, and provide them with additional support to plan, monitor and evaluate their learning strategies.

Guided by these findings, the PHOTON2 online course was offered a third time in the spring of 2007 to approximately 20 high school teachers and college faculty. The course was team taught by a PHOTON2 PI and a PHOTON2 participant who had taken the Cohort 1 course. Beginning with a week of introductions and socialization, the course lasted only ten weeks, including a final wrap-up summary by the instructors. Participants were from Hawaii in the west to Romania in the east, a twelve-hour time zone difference. Nonetheless, many lively discussions took place during the twice-weekly office hours, resulting in increased collaboration among participants. Since not all participants had access to a PHOTON2 laboratory kit, the hands-on activities included low-cost versions doable with common materials and the OSA Optics Discovery Kit. The instructors encouraged participants to compare methods and results and to consider which type of equipment would be best in their own classrooms.

4.4 Industry involvement: Externships and the Final Showcase

The online course successfully introduced optics/photonics principles to the teachers and faculty who had begun their participation in PHOTON2 at an introductory workshop. The third phase of the project, faculty and counselor internships at photonics companies, followed in 2005 and 2006. A common industry complaint is that students understand theory but not how to apply theory in a practical environment. Educator internships are an ideal way to bring the “real world” into the classroom, and they were a key component of PHOTON2.

During the summer of 2005, twenty-four PHOTON2 teachers and six counselors participated in one- to two-week paid internships (funded by the grant). Eighteen employers, including photonics companies in telecommunications, high-tech manufacturing, military contractors and research universities provided internship sites (Figure 7). Since some participants had not been able to do an internship in 2005 and/or some wished to do another internship, in 2006 nine PHOTON2 instructors and one career counselor completed an internship with either the same or a new internship host.

Figure 7- Two Tucson, AZ area guidance counselors and a community college faculty member completed an educator internship at NP Photonics manufacturing facility in Tucson.
Most of the internships were similar to job shadowing, with interns pairing up with one or more employees and observing their job functions. A few participants arranged for extended internships that allowed for more in-depth experiences. Internships not only provided “real world” experience that educators brought back to their classroom, they also led to long-term relationships between teachers and companies. In the majority of the faculty-industry partnerships, the faculty intern was continuing to collaborate with the host industry representative well beyond the paid internship experience provided by the PHOTON2 project. Host companies were reaching out to educators and their institutions by providing guest speakers, tours, student internships, scholarships, donations of equipment, job opportunities for graduates of the respective programs as well as participating in advisory committees and boards for the participating educational institutions.

Although it may seem that teachers gain most of the benefit from an educator internship, all the industry hosts were highly satisfied with the faculty and counselor interns and the externship experience. Industry hosts also reported that the financial support provided to the teachers and/or counselors by the PHOTON2 NSF funds was essential to the success of the externships as the host companies would not have been able to provide funding to support the participating educators. The participating industry hosts responded unanimously that they would consider participating in future faculty and counselor internship experiences.

The final phase of PHOTON2 was participants’ development of curriculum materials and classroom implementation. In August 2006, twenty PHOTON2 instructors and counselors from across the U.S. met at the SPIE Annual Meeting in San Diego to share with each other and with meeting attendees how they implemented what they learned in PHOTON2 (Figure 9). Participants listened to a variety of speakers on topics from nanotechnology to SPIE student chapters and met with industry representatives at the conference exhibition. Following the emphasis on applications that is the hallmark of all the PHOTON projects, the Showcase included a speaker on the topic of nanotechnology and a field trip to the Palomar Observatory.

Participants presented their implementation of the PHOTON2 curriculum materials at a special poster session held during the conference exhibition. Among the projects on display were:

- An interdisciplinary photonics course was developed for students at a technical high school in Connecticut.
- An Introduction to Photonics course developed by a community college in Connecticut. Instructors also incorporated ideas and demos from PHOTON2 in the teaching of Physics courses, and revised the Manufacturing Engineering Technology with courses in laser manufacturing.
- A two-day seminar/workshop on photonics for local high school science teachers and community college professors offered by four-year university in California. An optical communications course was also developed using PHOTON2 materials extensively.
- New instructional material incorporated into the chemistry, photonics, physics and honors physics curriculum at a comprehensive high school in Connecticut. Senior students in the physics and photonics courses made presentations and demonstrated laboratory experiments to younger students in a variety of science courses.
• Implementation of PHOTON2 curriculum into an existing fiber optics curriculum at a community college in Tennessee.

• Integration of the study of lasers and photonics into a high school Principles of Technology course in New Hampshire to introduce the students to present applications as well as future trends that will influence manufacturing and the quality of life.

• Development of a dynamic activity-based optical communications/networking program at a community college in New Hampshire. The new program has proven effectiveness based on student performance.

• Incorporating photonics principles into courses in electronics, physics and technical science at a high school in Hawaii.

5. PHOTON PBL (PROBLEM BASED LEARNING)

By the conclusion of PHOTON2, a complete set of curriculum materials had been developed suitable for a one- or two-semester course at the junior/senior high school or college level, including a fifteen chapter textbook with a problem solution manual, a laboratory kit (available from Lumenflow) with instructions for twenty-five field-tested lab experiments, a supplemental lab kit to increase the number of students serviced by the lab kit (also from Lumenflow), a set of videos of each of the labs being set up and performed, and fourteen inexpensive Explorations. Although the optics/photonics content is thoroughly covered, what is missing is the development of critical thinking, communication and problem solving skills. To address these vital competencies, NSF funded NEBHE in 2006 to develop eight industry-driven problem based learning (PBL) challenges.

PBL is an instructional method that challenges students to collaboratively solve “real world” problems. In order to provide the material for the challenges, the PHOTON PBL team recruited eight companies from PHOTON and PHOTON2 supporters and mentors, PHOTON2 internship sites, and leads from advisory board members and SPIE and OSA. Companies ranged from laser machining and telecommunications to lighting and research universities. Industry representatives were invited to a workshop in January 2007 where they were introduced to the philosophy and method of PBL. Workshop participants engaged in a brainstorming session on problem solving. They also discussed how different companies approach a problem and what techniques are used to define and frame the problem, identify resources needed to solve the problem, and then test efficacy of the solution. Each company provided an outline of a problem they had solved, along with a brief description of their solution.

The PBL team created three draft multimedia photonics PBL challenges in the spring and summer of 2007 using video and still photography combined with audio voiceovers. The challenges were designed so that they could be presented on one of three levels, providing appropriate support depending on problem-solving skills of the students:

• **Structured challenge** - For novice problem solvers, this level presents the problem statement, the company employees’ discussion of the problem and the company solution as a case study.

• **Guided challenge** - Beginning problem solvers view the problem statement and brainstorm to determine what is being asked and what they need to know to solve the problem. They then view the company discussion session video and use the additional clues to develop their own solution, which they can compare and contrast to the company’s solution.

• **Open-ended challenge** - Experienced problem solvers see only the problem statement and are then responsible for finding the resources needed to form their own solution.

In July 2007, twenty-three PHOTON PBL participants from across the United States were introduced to the problem based learning philosophy and the three draft challenges developed by the PBL team. They were joined by three senior staff members from the Regional Center for Next Generation Manufacturing, a Connecticut ATE regional center working on laser manufacturing curriculum. High school and college instructors were given the opportunity to work on the challenges, presented at one of the three levels. (Figure 10) Additional information was provided on implementation of challenges, including problem solving and assessment strategies, and participants engaged in a wide-ranging discussion of implementation issues.
Each participant will pilot test one or more of the draft challenges over the coming year, and the resultant feedback will form the basis of a teachers’ guide to using the challenges, as well as inform the revision of the current challenges and the development of new challenges. Five additional PBL challenges are planned for development in the 2007-2008 academic year.

6. CONCLUSION

Since 1995, the New England Board of Higher Education has successfully managed four National Science Foundation Advanced Technology Education grants for teacher professional development, laboratory improvement, and curriculum development in optics/photonics. Classroom-tested products include a fifteen chapter introductory textbook with teacher problem solution manual, an industry-quality laboratory equipment kit, a laboratory manual with twenty-five experiments and a set of fourteen low-cost Explorations. More important, a community of optics/photonics educators and industry mentors and professional societies has been created that stretches from Maine to Hawaii and also includes Romania. This diverse group of high school teachers and college faculty along with their industry mentors continues to stay in contact through an active email listserv.

REFERENCES

**ACKNOWLEDGEMENTS**

*Fiber Optic Technology Education Project*

*Project PHOTON: A Curriculum Development, Teacher Enhancement and Laboratory Development Project*
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