

Restarting a high school photonics program

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ABSTRACT

Following a severe drop in enrollment, one high school's photonics program was in jeopardy of being eliminated. Instead, the program was rejuvenated and expanded and now meets the needs of more students than ever. In this paper, we describe how various resources were combined to improve methods of instruction (specifically, through problem-based learning, or PBL), enhance classroom/real-world integration, and solidify the role this program plays within the school's larger science and technology curriculum (recently revised to meet new state guidelines). Instructor participation in the New England Board of Higher Education (NEBHE) PHOTON projects, funded by the National Science Foundation, was key.

Keywords: photonics, high school, problem-based learning, PBL, PHOTON, PHOTON PBL

1. INTRODUCTION

In this paper, we will trace the life cycle of the photonics program at Plainfield High School (PHS), a rural school of medium size in Plainfield, an old mill town of northeastern Connecticut, USA. During the program's middle stages, staff turnover resulted in a newly-hired teacher replacing the veteran teacher (and department head) that had originally started the program at PHS. The untimely departure of the prior teacher, a strong proponent of photonics at PHS and someone who was instrumental in creating an interest in teaching photonics throughout the region, almost meant the demise of the program. However, despite declining enrollment and not being part of the initial groundswell of support for photonics, the incoming teacher, one of the authors (BKB), was able to restart the program, drawing heavily on the various local, regional, and national resources available for support.

2. BACKGROUND (WHERE DID WE COME FROM?)

Several years ago, the physics teacher/science department coordinator at PHS was selected as one of the original high school teachers involved in Project PHOTON, an NSF-funded effort of the New England Board of Higher Education (NEBHE), for which one of the authors (JD) was Principal Investigator. In conjunction with that physics teacher's participation in the project, he established the photonics program at PHS, including setting up the course curriculum and acquiring a substantial amount of photonics equipment. Starting out with just the standard PHOTON Lab Kit, he also obtained additional lasers, optical breadboards, and other components, procured through funding available through the Tech Prep partnership between PHS and Three Rivers Community College (TRCC) in nearby Norwich, CT. Student enrollment varied, but had increased to at least 30 per year by 2005-06, his last year at PHS.

3. CURRENT STATE OF AFFAIRS (WHERE ARE WE NOW?)

3.1 Three years ago (2006-07)

In August 2006, I (BKB) was hired to replace the physics teacher at PHS. Although only certified at that point as a Technology Education (Tech Ed) teacher in Connecticut, my background as a career nuclear submarine officer coupled with the significant practice in applied physics I had acquired through engineering coursework and professional experience led to my selection as the most qualified candidate. I taught under the CT State Department of Education's (SDE) Durational Shortage Area Permit (DSAP) until I was able to satisfy the CT SDE educational requirements for full teacher certification in physics, which occurred in June 2007.

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Despite the successful track record that had been established for the PHS photonics program, and my exposure to photonics in the Navy, students in my first class did not seem to be prepared to learn photonics the way I was prepared to teach it. Students were unable to “do the math” that I thought they should and continually asked when they would get to “play with lasers.” Contributing to the difficulty was the fact that there was no formal written curriculum in place for the school’s photonics course, nor were any hard-copy textbooks or lesson plans available. (I have no idea what happened to any instructional materials my predecessor may have used, other than the lab equipment I found in the preparation room.) As an elective course, I gave the photonics course lower priority, since I was also struggling to teach integrated science, a new required course replacing earth science, to freshmen (also with no formal curriculum in place). The end result was a disappointing experience with photonics for both student and teacher alike.

Following that year (2006-07), enrollment in the photonics course dropped significantly. However, rather than admitting defeat and shelving the course in favor of more traditional science electives, I decided to take a multi-pronged approach to improving both the course content and my ability to deliver it in interesting and innovative ways. First of all, I needed to improve my knowledge of the subject material, which I had already begun, and continued to pursue in several ways. That first year, I signed up for free subscriptions to Laurin Publishing’s monthly magazines, *Photonics Spectra* and *Biophotonics Journal*, and read them cover to cover when they arrived. I also searched the internet for college optics and photonics class pages that had notes, slide shows, and/or textbooks available for download or online browsing. Whenever pertinent professional development opportunities arose, I made it a point to attend if possible, making it to a one-day workshop on “Light” offered by EASTCONN, the state-funded Regional Educational Service Center (RESC) that serves my school, and a 6.5-hour short course entitled “Introduction to Optics for Non-Optical Personnel” at the SPIE OPTICS EAST conference in Boston in November 2006. In a way, that conference served as a real eye-opener, exposing me for the first time to the extremely broad extent of the optics and photonics industry. Prior to that time, like most people outside the field, “photonics” was a strange new vocabulary term for me that was somehow related to working with light, primarily using lasers and fiber optics. Even though my brother is employed by a leading fiber optic manufacturer and service provider, and I myself had been responsible for the Navy’s operating manual for the new submarine non-penetrating periscope sensor system known as the “photonics mast,” I found that I had a very limited understanding of the myriad ways that photonics technology is applied throughout industry, research, manufacturing, and even within the military.

Another way for me to improve my teaching was to revamp my instructional approach. The advanced science methods course I took at the University of Connecticut (UConn) to fulfill my certification requirement in physics was specifically designed around the principle of teaching science by inquiry learning. Although this approach to teaching has long been practiced in the Tech Ed world (and was familiar to me from my teacher preparation program in that field), my own science education, some twenty-plus years in the past, had been more traditional, i.e., lecture/recitation, end-of-chapter problems, and cookbook-style labs. I never thought to apply the constructivist learning approach—so familiar in Tech Ed classes—to my new role as a teacher of science. Thus, my UConn experience brought me into the 21st century of science education.

Yet another adjustment I needed to make was related to my expectations of my students in terms of motivation, preparation, and ability to learn and understand the ideas related to the subject matter at hand, much of which was entirely foreign to many of them. Partly because of my experience with the submarine force, an elite group of sailors who have passed rigorous screening requirements prior to being admitted to that force, and partly because I came from another school district historically among the top performers in the state, I was used to dealing with young people who were highly motivated, sufficiently equipped through prior learning, and used to taking on and meeting challenging academic situations on a regular basis. The group of students I encountered here was an entirely different lot, and they required a different set of expectations. This was made evident when I was reading student responses on an entrance survey I gave my photonics students the first day of class. To the question, “What do you want to do after high school?” one wrote, “Get a nice job in a warehouse.” I was shocked. No college, no high-tech career with opportunity for advancement, no dream of excelling at something they really found interesting; nothing even remotely related to photonics technology – just a dead-end job at which to spend the next 40-plus years laboring – and not at all what I had expected to encounter. Yet, since it was my job to teach these students, I needed to figure out some way to do just that.

Fortunately, not long after the end of the first photonics class I taught, I received an invitation to participate in NEBHE’s PHOTON PBL project, a follow-on to the two previous NEBHE projects funded by the National Science Foundation’s Advanced Technology Education (NSF-ATE) program, PHOTON and PHOTON2. I applied and was accepted as one of eight high school teachers who, along with eight college instructors, were to receive a week’s training at a summer

workshop in the instructional strategy known as Problem-Based Learning (PBL), with the enthusiastic support of my department coordinator, building principal, and district administrators. All I had to do was find a community college instructor with whom to partner, and then pilot two “PBL Challenges” over the next two years. Finding the partner was the easy part; the other author (JD) had been Principal Investigator on the PHOTON project, and taught the online photonics class for the PHOTON2 project; additionally, her school (TRCC) had already been paired with PHS for Connecticut’s first-ever Tech Prep partnership for Photonics Engineering Technology.

The more difficult part of the PHOTON PBL commitment was being able to do the PBL Challenges. For starters, due to the drastic drop in enrollment in the photonics class for the coming school year (2007-08), the course was not going to be taught that year. However, I found out that it would be possible to incorporate the challenges into other courses I was teaching, such as physics, so I went ahead and attended the July 2007 workshop at Roger Williams University, in Bristol, RI. By the end of the first day, I was feeling both excited and frustrated. The excitement came from the realization that I was learning about a technique (PBL) almost *guaranteed* to improve student engagement and motivation for learning the material in my photonics class. However, my frustration was rising as each successive challenge was presented, not only because I was fearful that they too might exceed the capabilities of my students, but also since I was being pushed out of my own comfort zone, both in terms of my level of knowledge (or lack thereof) about the subject matter in question (e.g., parts of the textbook I never even got to in the first course) as well as the lack of direct control over my students and the path they would take to gain the required knowledge. (In retrospect, I now recognize that such discomfort was anticipated and expected by the project team leaders, and has since been addressed¹.) On the whole, however, I found the workshop very informative, the company of my fellow instructors most collegial, and the network of contacts I had formed extremely valuable. I left Rhode Island excited to be going back to school, very much looking forward to trying to implement some of what I had learned there.

3.2 Two years ago (2007-08)

Once school started, in August 2007, my photonics class got pushed to the back burner, since I was not teaching it at all that year, and my number one task in addition to the classes that I did teach was to prepare a teaching portfolio for submission to the CT SDE as part of the evaluation procedures for beginning teachers (the Beginning Educator Support and Training Program, BEST). Needless to say, getting that career milestone completed satisfactorily was weighing heavily on my mind for almost that entire school year. Additionally, the school now had a new principal, and we were also beginning preparations for our ten-year re-accreditation process, so there were other challenges I needed to meet as well. But always in the back of my mind was the burning question of how could I better teach my photonics course the next time around (wondering, as well, if there was even going to *be* a next time).



Fig. 1 PHS students make and decorate laser-engraved Christmas ornaments at TRCC

One of the professional contacts that resulted from my participation in the first PHOTON PBL workshop was not someone who attended, but rather a person who was referred to me by another participant. Nancy Magnani, who works for EASTCONN, our local RESC, had just started a new inter-district grant program called “Expanding Horizons.” Due to us not running a photonics class and my time commitment to my BEST portfolio, I had to limit our participation that year, but still was excited to have found another source of information (for myself and my students) and to be able to build a working relationship with Ms. Magnani. As it turned out, I took members of both of my physics classes to visit the photonics labs and classrooms at TRCC in December 2007, where they met and interacted with students from two

other high schools as well as Professor Donnelly and her staff and students. They also got to see some of the equipment used in the photonics industry, including a laser engraver (with which one group of students designed and manufactured their own simple products, such as Christmas tree ornaments). Another group experimented with various optical signal paths to transmit audio signals through space via laser. On the bus ride home that afternoon, the kids could not stop talking about “how cool everything was!” I shamelessly used this opportunity to plug my photonics class for the following year, since there were a number of students who would still be in school then, and it would be a great way for them to learn more about what they had just experienced at Three Rivers. Some also let me borrow their decorations to show to the freshmen in my integrated science class; they would be eligible to take photonics after completing biology the coming year.

Another opportunity to market photonics to the student body, or at least a good portion of it, occurred at about that same time. Each year, our guidance department holds an assembly for the junior class during which representatives from two local community colleges deliver presentations on the College Career Pathways (CCP) program (formerly Tech Prep), whereby students who take a certain sequence of courses in high school can also earn college credit at no cost to the individual. One of the sequences that satisfies this program involves my photonics course, which is articulated with TRCC’s Laser and Fiber Optic Technology program. Again using several contacts from the summer workshop, including my roommate from the campus dorm, I put together an informative slide show and presentation to give the students a better idea of what photonics is all about. (Part of the problem, I believe, is that the term “photonics” has not yet become one that most people are familiar with; TRCC actually went so far as to rename their AS degree program from “Photonics Engineering Technology” to “Laser and Fiber Optic Technology” as a means to overcome this unfamiliarity. Everyone has heard of lasers and fiber optics, but few outside the industry know what photonics is.) Describing the various fields in which photonics technology is applied, explaining some of the interesting labs we could do, emphasizing the opportunity for free college credits, and tossing out some job opportunities and salary figures, I got the attention of more than a handful of students. I actually had to cut my presentation short due to time constraints, but had several come up to talk to me afterwards. It was beginning to look like we might need to teach photonics again after all!

A couple of months later, in the spring semester, I was once again invited to the PHOTON PBL summer workshop, to be held at Boston University this time. With twice as much experience as a science teacher this time around, and being one of the veteran participants (or as Judy Donnelly likes to say, part of the “senior class”), I was much more comfortable with both the subject matter and the teaching strategies involved. There were a handful of my “classmates” from the previous summer, most of whom I got to know much better this year, as well as a whole new crop of “freshmen” (or new participants). It was great to hear about some of the successes other teachers had had running the PBL Challenges at their schools, and instructive to learn how they had fared as challenges of their own had sprung up. It was also an opportunity to strengthen professional relationships with both the participants and the PBL leadership team, not to mention the fantastic facilities and cutting edge research going on all around us: we were fortunate to be hosted by the BU Photonics Center, an impressive state-of-the-art facility right in the heart of one of the research Mecca’s of the world (Boston). One afternoon, we even took a “field trip” across the Charles River to see holograms from the Massachusetts Institute of Technology Museum holography collection—the world’s largest. All told, it was a wonderful experience, and again I left feeling pumped up about teaching photonics at PHS.

3.3 Last year (2008-09)

As the start of the new school year (2008-09) approached, I began to look for new ways to increase student interest and awareness of some of the exciting things they can do related to science. One I had been considering ever since I was first hired was an astronomy club. Although I have always been interested in space exploration (growing up near Houston in the 1960’s may have had something to do with that), I had never taken a course in astronomy, nor had I even pursued becoming an amateur astronomer. However, my son *did* have a telescope, and I had been subscribing to *Astronomy* magazine since coming to teach in Plainfield, so I discussed it with my department coordinator and decided to approach the principal with a proposal to start a club. Besides, 2009 had been designated as the “International Year of the Telescope,” marking the 400th anniversary of Galileo turning the telescope toward the heavens and beginning astronomy as we know it, so this was all the more reason to get the club up and running at this point in time. He was all for it, and even told me he could probably come up with a little bit of financial support if he looked at the budget the right way. I was thrilled, but more than a little nervous since I had little experience to go on. However, as I stated in my proposal and told the group that showed up for our first meeting, I would be learning along with them, and having fun while we all explored the exciting world that begins just beyond our home planet’s atmosphere. Besides, I was aware of several

students who already knew quite a bit about the field, having taught integrated science to some when they were freshmen two years ago (my first year here). As expected, one of them became our club president.

Since photonics was only scheduled for the second semester, the astronomy club was the group of choice to support EASTCONN's Expanding Horizons program during the first term, and the timing could not have been better. We had only been meeting for about a month when Nancy Magnani approached me about having club members help out with the groups of 5th graders she was bringing together at the UCONN campus to learn about basic optics and make simple telescopes of their own. Three or four elementary schools were involved, with around 75 students total, so there were not enough adults to go around. My young astronomers were thrilled to lend a hand, so Judy Donnelly and Nancy came to one of our club meetings and taught us what we needed to know to teach the 5th graders. The week before the winter holiday break, we all converged on the Bishop Center at UCONN and made even younger astronomers out of the 10- and 11-year-olds from across the state. As one of my kids said on the way home, when I asked what he had learned that day, "Fifth-graders have a *lot* of energy!"

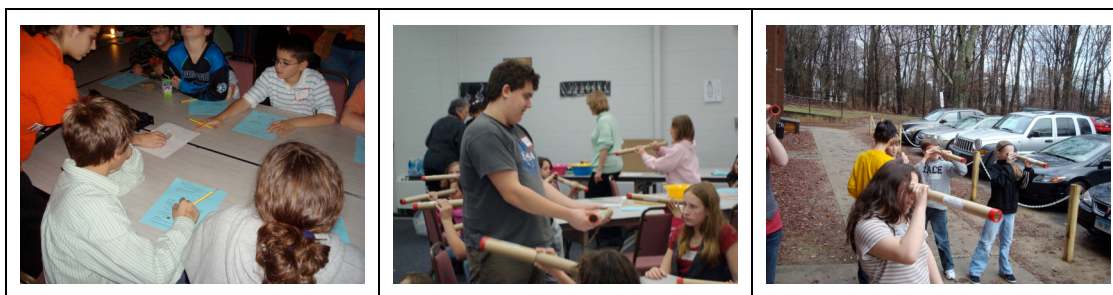


Fig. 2 PHS astronomy club helping EASTCONN 5th graders at UCONN

In the astronomy club, we had students from all four grades at the high school, some of whom were in one or another of my classes first semester, some whom I had taught in previous years, and some who were brand new faces. All were interested in astronomy, and as I explained how photonics applies to that field, they became fans of photonics as well. Several were already signed up for my spring course, but some went and had their schedules changed so they could add it in favor of some other elective that no longer seemed as exciting. "I may need to run *another* section!" I thought to myself happily.

Once spring term rolled around, the newly-structured photonics class began. Originally only a single quarter in length (equivalent to a half-year course under the traditional schedule, but we had been on a four-by-four block schedule since moving to a new building in August 2005, the year before I arrived), it was difficult to cover all the material I had wanted. Additionally, students had difficulty scheduling all the classes for the CCP pathway necessary to gain them college credit. To help rectify this, the photonics course was expanded to a full semester (now a full science credit, instead of a half-credit as before), additionally pulling in material from the physical science curriculum that they had had to take in a separate class before. This meant that one less course (but still the same number of credits) was now needed to meet the CCP requirement, giving students and guidance counselors more flexibility in scheduling courses.

Another change to the course involved giving the students a textbook of their own. The first time I had taught photonics, *Light: Introduction to Optics and Photonics*², the textbook Judy Donnelly and Nick Massa put together for the original PHOTON program, was still in draft form. I downloaded a copy for myself, and made some excerpts for my students, but they did not have a copy they could consider their very own. That, I felt, was another detriment to their success that time around. By this time, the book had been published and we purchased enough copies for an entire class. (To save money, we only ordered two hardbound volumes; the students used spiral-bound, black-and-white copies, and I printed color pages only when necessary on our school's one good color printer. In retrospect, that may have been false economy, because the front covers have come loose or off entirely on about half the copies; I am still looking for a better solution.)

Probably the most significant change to the course was the addition of the PBL Challenges. We did two of them, one about midway through the course, and the other in the last month. Students enjoyed them, although because they were so very different than anything they had done before, they were quite uncomfortable being left so much on their own to figure out what they needed to learn about. I, too, was uncomfortable, as I had been when first exposed almost two years prior at the first summer workshop in Rhode Island. However, at least this time I knew that feeling was coming, and was to be expected, both in myself and in my students. They really did enjoy learning that way. Most learned at least as much as I had hoped they would, and several went significantly beyond my goals. They were quite surprised, and justifiably proud of themselves, when almost every group came up with a solution that was close (or, in one case, identical) to the “university lab solution.” Not only did they master the material, they also figured out (a) how to go about learning something on their own, and (b) that they were capable of performing on a par with college students in a dedicated photonics program. Their self confidence shot through the roof! (To make sure they really did “get it,” I added questions to the final exam relating back to the challenges they did, and the results were impressive; if they had done the challenge, they knew how to answer the exam questions.) That, to me, shows the success of the PBL approach; add me to the list of “believers” (and I will be sure to add PBL to all my classes now). I know they enjoyed the challenges, too; I gave them the choice about whether to do the second one or some more traditional project, and the vote was unanimous. PBL is here to stay, at least for this science teacher.

Draft Photon PBL Challenges

PHOTON PBL (Problem-Based Learning)

A Photonics Curriculum and Professional Development Project
funded by the Advanced Technology Education program of the National Science Foundation

Problem Based Learning (PBL) is an educational method that engages students in inquiry based "real world" problem solving. It has been used extensively in medical education since the early 1970s. While already adopted in other fields including business, law and education, it is only beginning to emerge in engineering and technology education as an alternative to the traditional lecture-based approach. The project's goal is to create teaching materials using this student-centered problem-solving method to teach photonics and optics. For further information and additional photonics instructional materials, contact Fenna Hanes.

Challenges

- **Blinded by the Light** - What dangers does a pilot face when an aircraft is targeted by a laser pointer?
- **Stripping with Light, fantastic!** - PhotoMachining, Inc. needs to develop a process for stripping the coating from 50 micron wire
- **DNA Microarray Fabrication** - Boston University graduate students need to determine the best starting exposure time for a DNA microarray fabricator
- **High Power Laser Burn-In Test** - IPG Photonics needs a way to run 100-hour unattended burn-in tests on a 2-kw laser.
- **Shining Light on Infant Jaundice** - Partners Photodigm, Drexel and SMU ask, "Can technology provide a safe and effective portable home treatment for newborn jaundice?"
- **Watt's my Light?** - The package says a 26 watt fluorescent has the same light output as a 100 watt incandescent. Can Cal Poly Pomona students verify this statement?
- **Of Mice and Penn** - Can optics provide a non-contact measurement method as part of a UPenn McKay Orthopaedic Research Lab project to study the healing of tendons?
- **Hiking 911** - Two boys are lost in deep woods in rough terrain. Penn State Electro Optics Center (EOC) needs to recommend the best technology to locate them.

P H O T O N I C S

Fig. 3 Screenshot of PHOTON PBL Challenges website

[Note: For more on PHOTON PBL and Problem-Based Learning in general, see the brief description at the end of this paper and the more complete report in reference [1], from which that description has been taken in its entirety.]

Other differences between this course and last include the three field trips we made through the Expanding Horizons program. Twice, we went to TRCC for *Laser Camp* (also funded by SPIE and the CT Regional Center for Next Generation Manufacturing). The first time, right at the beginning of the spring semester, we learned about polarization of light and made “polarized art” projects with paper, tape, and sheets of polarizer film during one half of the visit, which we did with one other high school. The other half was spent learning about, then building and using, pinhole photography “cameras” made out of oatmeal boxes. I know this was a success, too; when we got back to school, I sent students back to their last block class and then headed to the office to brief the principal. On the way, I peered into the

library media center and saw one student who had gone there instead of his class, so I stopped in to redirect him. I had to bite my tongue, however, because he was not just goofing off, as I had suspected; instead, he was showing his friends his pinhole photo. I overheard one girl say, “That is so cool! I’m going to google that right now and learn how to make one myself!” Nothing like a little free publicity. Plus, a teacher’s favorite words in the whole wide world have to be “I want to learn...”!

The next time at Three Rivers, all four of the participating schools were there at the same time (so we got a group photo). This time, so many kids were involved that we had to have six activities going at once, of which each student got to do three (a logistical nightmare, had not Judy had the forethought to have them put in their requests ahead of time, then prepare a master schedule giving everyone at least their number one choice). Judy, her staff, her students (and SPIE student chapter members), and EASTCONN staff all were kept busy, while we teachers moved back and forth among the commotion (amazingly minor, for all that activity), snapping photographs and listening to dialogue. Everyone had fun, learned something, met someone new, and got something to take home for “show-and-tell.” I even picked up a telescope that TRCC was discarding that Judy had offered to pass on to our astronomy club.



Fig. 4 Expanding Horizons: Plainfield students with others at TRCC *Laser Camp 2009*

Finally, and probably the highlight of the year, was our third field trip, this time not to a place where they teach about photonics. No, this time we were headed to where it is actually put to use, making products (and earning a profit for shareholders, *and a paycheck for photonics techs!*). We rode halfway across the state to Farmington, CT, home of the U.S. headquarters of TRUMPF, Inc. In their own words, “TRUMPF is the largest manufacturer of fabricating machinery in the United States and a world market leader in lasers used for industrial production technology”³. After a brief introduction to the Germany-based international parent company, TRUMPF GmbH +Co. KG., we were briefed on some of the equipment and design services they provide to customers worldwide, then got to see several laser-powered machine tools in action. They were impressive: large, complicated, even noisy at times, but amazingly clean, fast, and precise. Next, we split into groups and toured their laser production and test building and their fabrication and packaging plant. We even got to see their own machines being used to make more of the same machines which would ultimately be delivered to customers to make whatever it is that their customers make. It was quite an amazing process, to say the least, and an eye-opener for both me and my students—a real insight into the world of modern manufacturing. I was also extremely pleased to hear our tour guide, a production supervisor, explaining to my students that some of the main qualities people need to succeed there (or anywhere) are the ability to work in groups with other people and the ability to teach oneself what one needs to know; qualities we teachers and schools have been telling students for years, and

attempting to build within them. It was regarded by the students with much more authenticity, coming from the mouth of a potential employer instead of just another teacher “who’s *supposed* to say that to us.”

Other things I have done to improve our photonics program include:

- Increased math/science rigor of course (not just “playing with lasers” anymore).
- Created several chapters’ worth of test questions in popular test-generator software program (ExamView), drawing mostly on chapter review questions and problems in NEBHE *Light* text (Donnelly/Massa). Makes it much quicker/easier to prepare and grade quizzes and tests, leaving more time to plan and prepare for lessons and other activities.
- Obtained additional equipment and materials:
 - Received “Supplemental Lab Kit” provided by NEBHE to expand capabilities from original PHOTON Lab Kit.
 - Purchased six laser pointers using CCP (formerly Tech Prep) funding.
 - Obtained class set of “Terrific Telescopes” through grant offered by Optical Society of America (OSA) (same as those used by 5th graders at UCONN, when astronomy club helped out).
 - Collected and displayed photonics, physics, and astronomy posters from number of sources.
 - Obtained exam or online copies of textbooks from CORD, SPIE, BYU, and others.
- Increased visibility of photonics program within and outside of school:
 - Participated in PHOTON PBL project (both summer seminars).
 - Newspaper article about photonics and PBL ran in local newspaper after first PHOTON PBL press release.
 - Article posted in all science classrooms following publication.

4. FUTURE PLANS (WHERE ARE WE GOING?)

So, is our photonics program back on track? It is and it is not. It is in much better shape than it was two years ago (when we could not run the course due to insufficient enrollment). But there is still much work to be done. Here, in no particular order, are some of the things we have yet to do:

- Improve mathematical readiness of incoming photonics students (or, to be quite honest, incoming students to *all* our science classes).
- Help our photonics students to see connection between math as an abstract manipulation of numbers and its application as a tool or language by which to express relationships between physical objects, processes, and amounts.
- Attract, motivate, and engage students of varying backgrounds and abilities and keep them interested in our photonics course, science and its application in general, and follow-on opportunities in the workforce, military, or further education.
- Improve our students’ understanding of scientific ways of viewing the physical world around them and investigating questions and solving problems with which they and their generation will be faced (improving their scientific literacy).
- Demonstrate through tangible means (artifacts and activities) our photonics program’s direct and efficient support of our school’s published mission statement and developing vision (especially in light of our upcoming re-accreditation).

How do we plan to achieve these objectives?

- Continue addressing rising students regarding content and application of photonics course. Check with guidance department about doing this earlier than junior year. Additional opportunities to market course may arise through our forthcoming Freshman Academy and our newly-implemented Student Advisory programs. Perhaps address students at our sending middle schools.
- Advertise our expectations, needs, activities, and successes through school and local media outlets.
- Design and build something substantial for other students to see, using photonics technology. One idea is scrolling light sign for announcements and other information of interest to student body, placed near school entrance or in cafeteria or gymnasium.
- Continue CCP partnership with TRCC and Expanding Horizons partnership with EASTCONN, TRCC, and other high schools in our region.
- Incorporate additional PBL Challenges and other interesting projects into photonics curriculum (and other science courses as well).
 - Consider devising our own challenges, using PHOTON PBL set as template, especially if we do these with our partner schools. (Perhaps a little friendly competition would be in order.)
 - Conduct professional development workshop for peers (science department and others) on PBL
- While continuing to present content knowledge via PBL Challenges, place greater emphasis on universality of problem-solving approach that it fosters. Show how it applies in:
 - Other science courses
 - Math and Tech Ed courses
 - College courses
 - “Real-world” scenarios
 - “Life” scenarios
- Take additional field trips to places in “real world” where students can see photonics technology in action. Possibilities include:
 - U.S. Coast Guard Museum, on grounds of U.S. Coast Guard Academy, New London, CT – lighthouse optics (lenses/prisms)
 - Submarine Force Library and Museum, Groton, CT – periscopes (World War II vintage) with attendant optics, Historic Ship (ex-USS) NAUTILUS (SSN-751)
 - Submarine Base New London, Groton, CT (including operational submarines and training facilities) – periscopes, photonics masts, radio/radar/electronic surveillance systems, fiber optics, other non-visual uses of electromagnetic spectrum
 - Naval Undersea Warfare Center (NUWC), Newport, RI – many same systems as at sub base, but with access to scientists, engineers, and technicians who design and implement these as well as future systems
 - Kollmorgen Electro-Optical, Northampton, MA – designer and builder of submarine periscope systems worldwide, now including “optronic” systems involving wide array of optical and electronic sensors
- Work with school’s career center to invite guest speakers from above sites and others and to arrange job-shadowing opportunities for photonics students.
- Continue developing and expanding astronomy club, with additional activities.

- Consider starting photonics club, perhaps combined with astronomy club (an “astro-photonics club?”) and/or becoming student chapter of SPIE.
- Continue modifying and adjusting photonics curriculum and content delivery to more closely match interests, needs, and abilities of students, while keeping attuned to needs of outside organizations (such as college and industry) for specific skills and abilities of program graduates.
- Look for ways to integrate photonics course with other science courses, math and Tech Ed courses, and ultimately with interdisciplinary projects across entire spectrum of PHS course offerings.
 - One Tech Ed teacher has already approached me about possibility of having students in his program and mine investigate (and hopefully obtain) solar energy system to help reduce school’s dependence on traditional sources of energy. This may also involve Environmental Science class and/or club, among others.
 - A math teacher wants to teach his algebra students to solve problems that involve the physical quantities they will actually encounter in science classes (such as physics and photonics). In turn, they will apply geometry and trigonometry (in addition to algebra) in both these classes.
- Formalize curriculum, but keep it flexible and responsive to needs of each particular class of students.
- Introduce and incorporate use of school-wide rubrics for applicable photonics assignments and assessments, providing consistent “story” to our students as compared to what they get in other, more traditional classes.
- Work toward more “authentic assessments” and away from traditional written chapter and unit quizzes and tests.
- Do more hands-on activities and less “book learning.” We have fairly sophisticated set of lab equipment but have not made much use of it yet, primarily because I am not familiar enough to be comfortable teaching students how to use it. I am also somewhat fearful it will get damaged due to negligent or intentional mishandling.

5. CONCLUSION

Although it is unlikely that Plainfield High School is the only traditional high school (i.e., not a vocational, technical, or magnet school) with a photonics program, we are certainly in the minority. At present I am not aware of any other regular high schools offering a one-credit course in photonics as a science elective. We are the first high school in Connecticut, and I believe still the only one, to have a College Career Pathway partnership with a local college that leads to an associate’s degree in Laser and Fiber Optic Technology (with Three Rivers Community College). With this foundation in place, it was both shocking and disappointing to go from full classes to no classes over the course of one year (my first attempt to teach the course). It would have been quite the shame to let our program silently slip away.

Not being one to give up easily, especially when I perceive something valuable is at stake, I set my mind on restarting our photonics program and have been occupied almost non-stop over the past two years doing just that. We extended and expanded the course, obtained textbooks, equipment, and other materials, launched a marketing campaign, and revised our whole approach to teaching the course. Key to the entire process has been the substantial (almost monumental) support we have received from outside our school system.

Far and away, our largest benefactor has been the New England Board of Higher Education. Through the three NSF-funded PHOTON projects that NEBHE has sponsored, PHS staff and students have received equipment, teaching materials, professional development, and access to a wide array of other resources and materials. This is followed closely, but on a more regional scale, by the EASTCONN “Expanding Horizons” grant program, providing field trips and other activities that students participate in firsthand. Our partnership with Three Rivers Community College, through both the Tech Prep/College Career Pathways program and their joint participation in the NEBHE and EASTCONN programs along with us, has been instrumental, if not critical, to our success and, at times, to our very survival. Finally, the photonics industry and the professional societies surrounding and supporting that industry have also played a key role. Without the dedicated effort and support of all of these organizations, and especially the individual people within

them who allow them to function so well, the photonics program at Plainfield High School would long have since ceased to exist. They have our utmost, heartfelt thanks.

6. PROBLEM-BASED LEARNING AND PHOTON PBL

[The following description is from Massa, et al. (reference [1]). See original paper for illustrations/original references.]

Problem-based learning is an instructional method that challenges students to “learn how to learn” by collaboratively solving genuine real-world problems. PBL is based on the constructivist model of learning, whose major tenets are (1) learning and understanding are directly related to the environment or context in which learning occurs, (2) cognitive conflict or “puzzlement” is the stimulus for learning and determines the organization and nature of what is learned, and (3) social environment is primary in providing alternative views and additional information against which we can test the viability of our understanding and comprehension. Research shows that compared to traditional lecture-based instruction, PBL improves student understanding and retention of ideas, critical thinking, communication and problem-solving skills, as well as the ability of students to adapt their learning to new situations – the cornerstone of lifelong learning.

PBL teaches students the process of solving real-world, open-ended problems that may have a number of possible solutions. The pedagogical framework for the PHOTON PBL project is guided by Barrows’ Model originally developed at McMaster University in Canada for use in medical school education and subsequently adopted widely by medical, business, education, and engineering schools around the world. The Barrows Model involves a recursive problem-solving process that begins with a problem scenario presented in the context in which it is to be solved. Student teams work collaboratively in analyzing the problem by identifying relevant facts and learning issues, activating prior knowledge, generating hypotheses, reflecting on their beliefs about the problem, and generating learning objectives needed to solve the problem. This phase is followed by a period of self-directed learning whereby each student engages in learning specific content identified as relevant in the initial problem analysis phase. During this phase, the instructor serves as a consultant, guiding the student as they seek out required resources and providing additional information as needed, thus shifting the responsibility for learning onto the student. By shifting the responsibility for learning onto students and providing scaffolds for learning, students are more likely to develop the self-directed learning skills needed to successfully engage in lifelong learning. Upon completion of the self-directed learning phase, students reconvene to assess and evaluate their problem solution based on their new understanding of the problem, and reformulate solutions if needed. This process...may repeat itself several times in the process of solving a single problem. Student evaluation in PBL may take one of several forms, from a final patient diagnosis in medical education, to the generation and presentation of a formal proposal including cost/benefit analysis and/or feasibility analysis in an engineering education application. In either case, the final problem solution takes the form of what would be most appropriate in that particular context.

While PBL has been used extensively in medical education since the early 1970’s and has been widely adopted in other fields including business, law, and education, it is only beginning to emerge as an alternative to the traditional lecture-based approach to engineering and technology education. For example, Nashville State Technical College has adopted PBL in its two-year engineering technology program through its NSF-funded CaseFiles® project. Four-year engineering institutions such as University of Buffalo, University of Delaware, Worcester Polytechnic Institute, and several others have also adopted PBL in selected engineering courses, reporting increases in problem-solving skills, critical thinking, retention, and motivation for learning. Given the practical nature of photonics technology education where students must learn to apply their knowledge in solving complex, real-world problems, PBL appears well-suited for educating technicians capable of addressing the ever-changing needs of today’s technological and multicultural society.¹

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PHOTON PBL

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OSA FOUNDATION

The OSA Foundation is a charitable organization dedicated to supporting programs that advance youth science education, provide optics education and resources to underserved populations, provide career and professional development resources and support awards & honors that recognize technical and business excellence.

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