An Inquiry-based Course in Nano-photonics

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ABSTRACT

We developed a curriculum to introduce nanotechnology and photonics concepts to community college students enrolled in a program designed to attract and retain students in technology associate degree programs. Working with the Center for Research on Interface Structures and Phenomena, an NSF Materials Research Science and Engineering Center, and the PHOTON projects, funded by the Advanced Technological Education program of NSF, we developed hands-on, inquiry-based activities to address the course goals: improve critical thinking, introduce science and technology concepts common to technology programs and provide opportunity to practice math skills in context.

Keywords: photonics, nanotechnology, nano-photonics, education, community college, associate degree, inquiry

1. INTRODUCTION

Project TLC (Technology Learning Community) at Three Rivers Community College is a unique program funded by the Advanced Technological Education (ATE) program of the National Science Foundation (NSF). Unique to Three Rivers Community College, Project TLC seeks to enhance recruitment, retention and career placement of associate degree students in engineering technology programs by fostering a learning community of students, faculty, and student support specialists. Since 2006, the TLC project has sought to achieve the following goals:

- Improve the academic readiness of students entering engineering technology programs
- Create a learning community model for application in community college engineering technology programs
- Develop and test paired algebra and technology (PAT) interdisciplinary courses, one in mathematics and one an introduction to engineering technology
- Develop a project-based interdisciplinary capstone course (ICC) that includes all of the engineering technology programs.
- Raise student, faculty and counselor awareness of educational and career opportunities in technology fields, particularly for members of under-represented groups.

Project TLC recruits academically under-prepared high school seniors who may lack family support for the emotional and social challenges of college and offers support to foster self-confidence, and ultimately, to assure student success, as participants progress from the community college to either a four-year institution or the workplace. Project TLC students study together in classes taught by dedicated faculty that have been trained in TLC principles and methodology. Throughout the experience, students are mentored by a technology advisor to ensure they make full use of various support services offered by the college.

Students considered for the TLC program score marginally above or below the cutoff range for College Algebra and/or English Communications in the placement test given to all entering students at Three Rivers. Success in these two courses is critical for the first semester of most engineering technology programs. Students are chosen for the program based on teacher and guidance counselor recommendations and a personal interview with the TLC team. Once accepted, students receive a stipend to attend a rigorous summer institute during the month preceding their first semester at Three Rivers. Since community college students usually need to work to pay expenses, this allows them to concentrate on institute courses without the additional pressure of an outside job. Students are provided with intense instruction in English Communications and Mathematics (i.e. Introductory Algebra) and participate in team building and college

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Optics Education and Outreach, edited by G. Groot Gregory, Proc. of SPIE Vol. 7783,
77830M · © 2010 SPIE · CCC code: 0277-786X/10/$18 · doi: 10.1117/12.859955

orientation activities. Field trips to local companies allow them to see first-hand the types of careers that await with an associate degree in an engineering technology discipline.

During their initial fall semester, TLC students enroll as a group in a triad of courses: College Algebra, English Composition and Introduction to Engineering Technology. Faculty who teach these courses work together to ensure that ideas are introduced and reinforced across the triad. Introduction to Engineering Technology (TCN 101) seeks to improve critical thinking skills, introduce and reinforce science and technology concepts common to technology programs and provide an opportunity to practice math skills in context. Over the course of the TLC project, TCN 101 has used varied content to achieve its goals, including a spreadsheet applications course and course built around constructing and testing robots. In Fall 2009 the course was taught around the theme of photonics and nanotechnology (i.e. nano-photonics). In this paper we will provide details of course activities, a summary of the course evaluation by the TLC external evaluator and suggestions for continued improvement.

1.1 Collaboration with CRISP

The Center for Research on Interface Structures and Phenomena (CRISP) is an NSF-funded Materials Research Science and Engineering Center (MRSEC) established in 2005. The CRISP MRSEC is located at Yale University and is a joint venture of three institutions: Yale, Southern Connecticut State University (SCSU) and Brookhaven National Laboratory. The research mission of CRISP is to explore the composition, structure, properties and potential applications of a variety of materials. Since its inception, CRISP has focused on complex oxide materials primarily for electronic devices but has more recently broadened its research focus to include biological and optical materials. CRISP is multifaceted in its areas of materials research and education, developing and maintaining state-of-the-art specialized facilities for fabrication and synthesis, atomic-scale characterization as well as theory and computation. This is achieved with strong collaborations amongst university faculty, industry partners and national laboratories along with specialized-shared research facilities.

CRISP serves to nucleate the diverse and interdisciplinary efforts of research and education in the areas of materials science and nanotechnology. Materials science as a discipline studies the structure/property relationship of materials and encompasses many science fields such as physics, chemistry, biology, and engineering. Nanotechnology is an emergent discipline that has evolved from new knowledge of materials' properties in the nanometer regime (1 – 100nm, where 1 nm = 10^{-9} m). An integral part CRISP's educational mission is to enhance the quality and diversity of science education using materials science as a vehicle for enhancing the scientific literacy and knowledge of kindergarten through post-graduate level students as well as members of the community.

CRISP initiated a partnership with Project TLC in June of 2009 motivated by a common interest in enhanced recruitment and retention of groups traditionally underrepresented in science, technology, engineering and mathematics (STEM) fields. This emanated from the long-standing successful record of Three Rivers students transferring to SCSU to complete their Bachelor's degrees in physics. CRISP set out to collaborate with Project TLC in the development of interdisciplinary science resources based on common aspects of photonics, materials science and nanotechnology. CRISP has several years of experience with teacher professional development and K-12 outreach using materials science and nanotechnology concepts and applications to increase student interest in STEM fields.[1]

1.2 PHOTON PBL Challenges

TLC students have been accepted into one of Three Rivers associate degree programs in engineering technology, it may not be clear to students (or to their parents) how engineering technology differs from engineering or the common use of *technology* to mean *computers*. First and foremost, students need to learn what skills and attitudes will be required of them as working engineering technicians. From the TCN 101 syllabus:

> "Technicians are problem solvers – individuals who combine their technical knowledge with a set of problem-solving skills to tackle real-world issues across diverse settings. Working side-by-side with engineers and scientists, technicians are the "hands-on" side of an engineering team, responsible for designing experiments, building and troubleshooting prototypes, analyzing and interpreting data, and presenting experimental results to peers, supervisors and customers".[2]

Despite the nature of the work they will be called upon to perform on-the-job. Technicians in two-year associate degree programs are usually taught by the traditional instructor-centered method: lectures, cookbook laboratories and back of the chapter plug-in numerical problems. There is little in this instructional method to prepare students for the real world as an engineering technician. Students need to know what to do when the unexpected happens, that is, they need to develop the critical thinking skills needed to analyze problems and develop and test solutions.

The NSF/ATE supported PHOTON PBL (Problem-based Learning) project developed an instructional method to address the teaching of problem solving to engineering technology students, that is, to give students the tools they need to *know what to do when they don't know what to do*. PHOTON PBL created eight multimedia interdisciplinary *Challenges* in optics/photonics in collaboration with industry and research universities. The Challenges have been described in detail elsewhere;[3,4] what follows is a brief summary.

Each PHOTON PBL Challenge consists of five video segments: an overall introduction to set the context, an overview of the organization(s) that solved the problem, problem statement, brainstorming discussion and solution. The videos are created on-site, and the actors are the scientists, engineers and technicians who originally solved the problem. This format emphasizes that technical problems are solved by real people with careers similar to those the students are working toward. The discussion and solution videos are password protected to allow instructor flexibility when presenting the Challenges. Each video is accompanied by a link to additional resources relevant to the stage of problem solving.

Built into the Challenges is an innovative *Problem Solving Toolbox* that leads students through a four-stage problem-solving cycle:

- Problem Analysis – framing the problem and determining what constraints, if any, exist
- Independent research – self-directed learning to acquire the knowledge to solve the problem
- Brainstorming solutions – team meeting to discuss and rank possible solutions
- Solution testing – determining if the chosen solution meets the problem criteria

A *Whiteboard* with appropriate leading questions is linked to each stage of the cycle; this may be projected onto the classroom whiteboard for classroom use or printed out for smaller group work. Students are instructed to fill in as much of the Whiteboards as possible; skipping steps leads to incomplete solutions that may not address all problem parameters.

A second feature of the PHOTON BPL Challenges is a method of scaffolding problem-solving skills using three levels of presentation. For novice problem solvers, the instructor may choose to work through a Challenge using the *Structured* method, leading the students through the Problem, Discussion and Solution videos as with a case study. More experienced students can be given more autonomy in what is known as a *Guided* format; this method may require several class periods and work outside of class as well. Finally, in an *Open-ended* format the instructor acts as a consultant and student teams must develop the solution to the problem on their own. Two PHOTON PBL Challenges were incorporated into the TCN 101 at the Structured and Guided level, and a third activity adapted the problem-solving Whiteboards to an experimental design problem.

2. COURSE GOALS AND ACTIVITIES

2.1 Goals

The overarching goal of TCN 101 Introduction to Engineering Technology is to introduce students to underlying concepts common to the technical fields served by Three Rivers Community College engineering technology programs. The course provides laboratory and field experiences to set a context for mathematical concepts and provide realistic technical problems on which to apply the math. The Fall 2009 implementation of TCN 101 employed hands-on inquiry-based activities, short presentations and problem-based learning Challenges to introduce and reinforce:

- Strategies for problem solving
- Observing and describing phenomena
- Evaluating and presenting results
- Scientific notation, the SI system and calculator use
- Presenting and evaluating data in graphical form
- Experiment design

Weekly communication among instructors throughout the semester insured that concepts would be reinforced in math and English classes whenever possible.

Because the students in the Fall 2009 course represented a diverse group of engineering technology majors, the TLC faculty and staff agreed that focusing on one Three Rivers technology program would be an unpopular choice with students whose technologies were not being addressed. (This may have been an issue in the Fall 2008 course that focused on robotics). On the other hand, including all technologies would involve arranging for many guest speakers and would result in a somewhat disjointed course. The decision was made to use nanotechnology as the vehicle for addressing the list of course objectives since it is interdisciplinary, not well known or understood by TLC students, and easily adapted to available photonics laboratory space. In addition, nanotechnology is an area of current interest and likely to be important in many technologies in the near future.

To learn about materials research and nanotechnology, the students, teachers and mentors visited CRISP research facilities at Yale and SCSU during the summer institute and fall semester. In August 2009, students visited the CRISP NanoCharacterization Facility at SCSU to learn about materials science and nanotechnology through hands-on demonstrations and a tour of the Facility to include electron microscopy and atomic force microscopy (AFM) instrumentation and specimen preparation (Figure 1). During their time at SCSU, student teams took photos and video of the instrumentation to later be incorporated into videos designed to explain nanotechnology to a seventh grade audience. A panel of seventh grade students judged the videos during the final week of the institute.

Figure 1. TLC students create liquid crystals during a visit to the CRISP NanoCharacterization Facility at SCSU.

2.2 Activities

Meeting once per week for a 3-hour session allowed projects to be efficiently completed in one class period. The format also made field trips possible, although only one was actually scheduled during class time. The students had several opportunities at other times during the semester for industry and university field trips including tours of Central Connecticut State University's College of Engineering and Technology and IPG Photonics.

The schedule of class activities is shown in Table 1. Each weekly class featured a specific optics or nanotechnology related topic, and in most cases the activities for each topic were completed in one week. The table also notes math concepts that were reinforced and additional science and or technology connections. English communication was stressed through weekly written assignments, some of which were coordinated with the English course instructor.

In the first meeting, students were introduced to a tool they would use throughout the semester: the concept map, a graphical tool used to organize knowledge and show relationships between concepts. Following the instructions provided in the PHOTON PBL materials, students were instructed to create a concept map describing a non-technical topic, the making of pasta. For this first attempt, six concepts were provided (sauce, pasta, boiling water, a good pot, salt, al dente) and students were required to add at least four concepts of their own. Pairs of concepts must be connected by a *proposition* in such a way that a sentence is created with the concepts at the beginning and end (Figure 2). Concept mapping a useful tool for organizing ideas and after some initial complaints students reported they were using them in other courses as well.

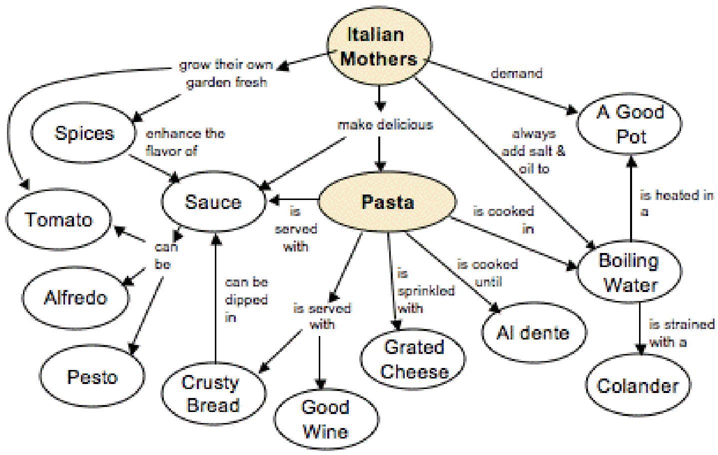

Figure 2. Concept map example from PHOTON PBL Teachers Guide, available at www.pblprojects.org.

The second session introduced the PHOTON PBL Whiteboards as a tool for problem solving. Students worked through the *Hiking 911* Challenge, determining the best technology for finding two hikers lost in rough, wooded terrain. The Challenge was developed with the assistance of the Pennsylvania State University Electro-Optic Center (EOC) and in solving the problem students learned about the electromagnetic spectrum, thermal imaging technology and the effect of pixel size and target distance on resolution. Students were shown the problem statement video (hikers are lost and the temperature is rapidly dropping) and then introduced to the Problem Analysis and Independent Research Whiteboards. Working together, the class listed what they knew about the problem, what they needed to learn to solve the problem, and where the required information might be found. They were then shown a video reenactment of EOC engineers in a brainstorming discussion of what technologies were available for use at EOC. Students then broke into small groups to discuss the available sensors, optics and unmanned aerial vehicles (UAV) and to brainstorm possible solutions. Reconvening in the classroom, each group informally shared their solution. After a discussion of student solutions, the EOC engineers' solution was shown to compare and contrast. Homework for this class was to write a summary technical report of the process by which the problem was solved, reinforcing the PBL method.

Pinhole camera construction allowed students to further explore concepts in imaging while also introducing MSDS, hazardous waste disposal (the chemical fixer contains silver), and some basic chemistry concepts. Math connections include similar triangles to predict the image size and calculating the optimum pinhole diameter. Students measured the pinholes using a USB microscope and needed to devise a method to calibrate the microscope and estimate the accuracy of their measurement. The cameras were constructed of oatmeal containers using black and white paper film and pinholes drilled into small pieces cut from soft drink cans. Students are often delighted that they are able to produce photographs from recycled trash.

How big is a nanometer? is an activity combining optics with ratio and proportion. Students used the diffraction pattern produced by taping a hair over the aperture of a laser pointer to determine the diameter of the hair (Figure 3). The problem they were then asked to solve was *If the outside corridor represents the diameter of the hair, how large is a nanometer?* Students needed to devise a way to measure the length of the corridor (160 m) using only a meter stick, and then set up the proportion to determine the length of a nanometer in this new scale. Students were astounded to learn that a nanometer would be not much larger than the crack between tiles (a few millimeters).

Several of the nanoscience activities and introductory presentations in the course were adapted from *NanoSense*, a nanotechnology curriculum developed for a target audience of high school students by SRI International and available at www.nanosense.org. The website provides complete background information, PowerPoint presentations, student handouts, quizzes and instructions for hands-on activities. After a brief presentation on how properties change at the nanoscale, students performed three of the eight activities from the *Unique Properties at the Nanoscale* unit: bubble self-assembly, ferrofluids, and surface area to volume effects. The ferrofluid activity was provided by the CRISP through its Education and Outreach website (http://www.southernct.edu/crisp) which offers materials science and nanotech curriculum materials and hands-on demonstrations. The surface-to-volume effects experiment was particularly well-received. Students broke effervescent antacid tablets into different size pieces, sealed them with water in film canisters, and waited to see which exploded first. This hands-on activity visually demonstrates the structure/property relationship of materials and how the nanoscale materials exhibit different properties from that of bulk materials, i.e. nanomaterials exhibit greater surface area. The activity was followed by calculations of surface area for varied shapes with the same volume.

Table 1. Weekly activities for Introduction to Engineering Technology

Week	Topic	Activity	Math	Science/technology connections	Homework
1	What is Eng. Tech.? Concept Mapping	Concept mapping PBL pre survey			Concept map: how to make pasta
2	The Lost Hikers- PHOTON PBL Challenge	Problem solving cycle Using the PBL white boards to solve problems	Area Measuring angles	Infrared imaging Electromagnetic spectrum Resolution/ pixel size	Summary report and concept map
3	Pinhole camera	Make a pinhole camera: Measure pinhole with USB microscope Determine exposure time Develop photos in the darkroom	Similar triangles Trigonometry Using formulas	Chemistry of film development MSDS Hazardous waste Calibration	Lab report on pinhole camera with suggestions for improvement
4	How big is a nanometer?	Measure hair by diffraction	Powers of 10 Scientific notation Ratio/proportion	Diffraction; SI system	Lab report and SI conversion homework
5	Properties at the nanoscale	*Nanosense* activities: exploding canisters; bubble self assembly; ferrofluids	Surface area and volume	Magnetic materials Gas pressure	Lab report on activities
6	What is Energy?	Three energy activities: Energy of a bouncing ball Energy conservation Electrical energy	Using formulas with data	Energy conservation Energy and power	Home energy audit
7	Emission and absorption of light	Gas tubes/ spectrometers USB spectroscope and filter samples	Interpreting graphical data	Electromagnetic spectrum Calibration	Lab report on activities
8-9	Sunscreen Evaluation	How sunscreen works Sunscreen testing with UV beads (*Nanosense*)	Graphing data	Experiment design	Report on sunscreen test with suggestions for improvement
10	Clean Energy/Solar Cells	Solar Cell Basics Build and test a dye sensitized solar cell (*Nanosense*)	Graphing data	Motors/generators Measuring voltage and current	Lab report on solar cell
11	Water filtration	Need for clean water worldwide How water is filtered/treated Water filtration activity		Water chemistry Micro/nano filtration	Report on water filtration lab with suggestions for improvement
12	Trip to Yale Labs	Viewing surfaces at the nano scale			
13	Scanning Probe Microscopy	Model AFM	3D map from data	Resolution	Lab report on with suggestions for improvement
14	Infant Jaundice- a PHOTON PBL Challenge	Design a novel, portable and safe method to treat infant jaundice in the home		Causes of jaundice, Spectral absorption, Nanoparticle scattering	Research/group work on Challenge
15	Infant Jaundice	Presentations of solution Compare / contrast to organization's solution		Power point presentations	Summary report and concept map

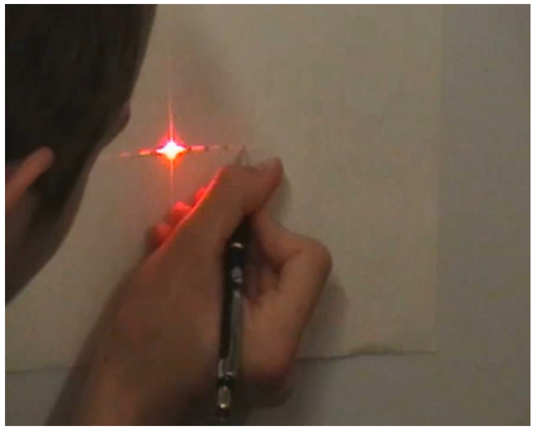

Figure 3. Measuring the diffraction pattern of a hair taped over the aperture of a laser pointer to determine the hair diameter.

Energy is an important topic in physics and technology, however it is not covered in the Three Rivers freshman physics course until after mid term. We decided to introduce the concept of energy through a set of hands-on activities including dropping table tennis balls to determine the energy loss on the first bounce, dropping the balls onto a motion sensor and comparing potential and kinetic energies, and heating water to compare heat energy to electrical energy. From the usual point of view of freshman physics, none of these "worked" because energy was lost in each experiment. However, the intent here was to have students think critically about what was really going on in each case and to speculate where the missing energy went. Homework for this week was a home energy audit, researching the typical energy use (and cost) for at least 15 home appliances, creating a plan for reducing energy consumption based on the research, and estimating the amount of money that could be saved by implementing the plan.

We intended to include two *NanoSense* activities that involve light and so preceded them with one class considering the origin of light. Inexpensive plastic spectroscopes were used to examine the spectra from several gas tubes (H, He, Hg) as well as incandescent and CFL bulbs, and then the same sources were studied with USB spectrometers. Students were asked to interpret the spectrometer graphs in terms of observed color and brightness. A prism spectrometer was also available for students to examine. Students were asked which instrument they thought was more accurate and nearly all felt the USB spectrometer must be a more accurate instrument because it is used with a computer. This led to a discussion of calibration; how does the computer know what wavelengths to display? How is this type of calibration different or more reliable than rotating a prism? Is it ever wise to just believe an instrument reading without question?

Returning to the *NanoSense* curriculum, students were introduced to absorption by sunscreens with organic UV chemicals or inorganic particulates. The emphasis of the sunscreen unit is the cosmetic improvement when nanoparticle-based sunscreens are used. In our case, students were asked to design an experiment to test sunscreen efficacy, in particular, to compare sunscreen SPF ratings using the available materials: UV bead testers and either sunlight or UV LED flashlights. The UV bead testers were made by melting the beads in an oven to flatten them, then gluing the flattened beads onto craft sticks.

The first week was spent on experiment design. Using a modified PHOTON PBL Whiteboard, students were asked:

- Clearly state the problem you are trying to solve.
- What do you already know about the problem?
- What do you still need to learn?
- How will you go about learning what you need to know?
- What ideas do you have for a solution?
- Which of these ideas seems the most promising?
- How will you know if you've succeeded in solving the problem?

The following week, the experiments were performed and analyzed. Students learned that the procedures they devised did not necessarily take into account how SPF factor is measured and what it means. UV beads are sensitive from 300 – 360 nm, and so do not test the full UV-B range where sunscreen SPF is measured (280 – 320 nm). Students who chose to use the UV flashlights were surprised to learn that they are fairly monochromatic at 395 nm, beyond the maximum sensitivity of the beads and outside of the range where SPF factor applies. Students were asked to devise a better means of testing both UVA and UVB protection of sunscreens, and to write instructions specifying the instrumentation and method they would use.

The third *NanoSense* unit, *Clean Energy*, introduced solar cells. After viewing an adaptation of the excellent *NanoSense* presentation on how solar cells work, students used materials provided by CRISP to construct dye-sensitized solar cells (DSSC) using raspberry juice for the electron source (dye) and iodine as the electrolyte. The DSSC kit is available from the Institute for Chemical Education, University of Wisconsin at Madison (http://ice.chem.wisc.edu/). Unfortunately, the cells were not successful and no current was measured. However, since the goal of the course is to practice critical thinking skills, the failure of the exercise provided an opportunity to determine *why* the experiment did not work. Our assumption is that the TiO_2 coating on the glass plates was not uniform, with high spots causing short circuiting of the cell current.

The final *NanoSense*, *The Water Crisis*, concerns nanofiltration. The online materials include an excellent introduction to the chemistry and properties of water and information on worldwide use of water. This unit was of particular interest to the civil and environmental engineering technology students in the class. CRISP supplied kits for comparing non-woven paper ultrafilters to NanoCeram® filters consisting of a multilevel woven membrane with nanoparticles embedded into the layers of membranes. The filter comparison was based upon completeness of filtration as measured by a change in color of the filtered dye and the relative amount of pressure needed to push the water through each filter.

After completing the *NanoSense* units, CRISP arranged a tour of research facilities at Yale shared by both CRISP and YINQE (Yale Institute for Nanoscience and Quantum Engineering) [5]. These labs are among the CRISP signature facilities for research and much of the instrumentation is home-built and world-renowned. A Yale Post-doctoral Fellow showed students atomic scale fabrication and characterization instrumentation such as ultra-high vacuum (UHV) chambers coupled with microscopy and spectroscopy instrumentation and a non-contact (NC) AFM (Figure 4). The NC-AFM generates high-resolution data (picometer (pm) distance resolutions and piconewton force resolutions; 1 pm = 10^{-12} m). This was an eye-opening experience; most of the TLC students had never been to a university campus, in fact, before making the trip none could explain how a university differed from a small community college.

Figure 4. Yale Post-doctoral Fellow speaking to the TLC students about ultra-high vacuum (UHV) instrumentation used to study sample surfaces for materials processing and chemical catalysis.

Following the Yale field trip, students completed the nanotechnology activities of the course with scanning probe microscopy model activity provided by CRISP. Their instructions were to improve the activity for a high school audience. The objective of this lab is to probe the contents of a small box with a wooden skewer and from the position and height data create a model of what is inside the box. Students used inexpensive 3D graphing software to plot their data and nearly every student remarked that the *x-y* position resolution of the boxes provided was insufficient. Another common suggestion was to use a smaller metal probe mounted so that it remained perpendicular to the box surface during measurement. Students were required to write their own instruction set for use of their improved experiment.

The final activity of the course was a PHOTON PBL Challenge, *Shining Light on Infant Jaundice,* completed in the Guided format. During the first session, students were shown the video introduction explaining the problem of infant jaundice and the problem statement video: Develop a safe, effective and portable home treatment for infant jaundice. Teams of four or five students worked together to fill out the Problem Analysis whiteboard. They were allowed to work in the optics labs, which are equipped with Internet access, or to go to the library, computer labs or hallway lounges to complete this part of the Challenge. After two hours, the class reconvened and students were shown the discussion video, the reenactment of a brainstorming session at Drexel University by the engineers and scientists who solved the problem. For the remainder of the class period, students continued to fill out the Whiteboards as they researched and discussed the problem. The following week, each group presented their solution to the class using PowerPoint. Since it was the last class of the semester, a pizza lunch was served and the PBL faculty and staff team was invited to hear the presentations. After peer review of the class solutions, the organization's solution video was shown. Interesting, and in keeping with the course theme, their solution was a blanket embedded with blue LEDs that used nanoparticle scattering to create uniform illumination.

3. COURSE EVALUATION

The 2009-2010 formative evaluation by the Project TLC external evaluator that pertains to this course is based on written student satisfaction surveys, a student focus group and faculty interviews. In general, students enjoyed the course and viewed the experience as positive. The diversity of student majors led to a few minor negative comments regarding some topics; students in non-manufacturing related careers (e.g. Civil Engineering Technology, Construction Management) would have preferred more activities from their discipline. Students did, however, appear to enjoy the problem-based learning activities and found the PBL method to be helpful in other classes. They also enjoyed field trips to high-tech companies and university labs, which provide them with valuable insight into their career choices. Typical negative and positive student comments were:

- "I'm a construction management major – Intro to Technology course was geared to manufacturing and mechanical technology. It would be nice if there was some construction technology and nuclear taught in the course."
- "PBL was enjoyable. Whiteboards helped us organize our thoughts. It was very helpful. Concept mapping was interesting and showed you how things come together. The problem solving process we learned was valuable. Using it now in circuits, statics, and physics. It's more of a mental process. The PBL Infant Jaundice Challenge was enjoyable. Solar cell activity was also good. PBL forced us to step out of our comfort zones and learn in different ways."

It is important to note that the students did not choose to enroll in this course; nonetheless, most found it interesting and enjoyable and understood that nanotechnology would in the future be important in nearly all of their chosen technologies. Although the course topics may need to be expanded for the particular audience of Project TLC students, the course as it was taught in Fall 2009 should be very successful as an Introduction to Nanotechnology course. Tentative plans are to offer such a course as a science or technology elective in Fall 2011.

4. CONCLUSION

We have developed an interdisciplinary, inquiry-based introduction to nano-photonics course suitable for advanced high school or community college students. Emphasis on problem solving and critical thinking skills throughout the course resulted in improvement in those areas. Although the course was not ideally suited to the particular audience of mixed-discipline students who were required to enroll, it will serve as an excellent elective choice for non-majors in the future.

5. ACKNOWLEDGEMENTS

TLC (Technology Learning Community) funded in part by the Advanced Technological Education program of the National Science Foundation (ATE #ATE 0603404) Principal Investigator, Anthony Benoit, Co-Principal Investigators Linda Tremer, Christine Hammond, Jodi Calvert, Three Rivers Community College.

CRISP MRSEC (research and educational programs) is supported by the National Science Foundation (MRSEC DMR05-20495). Use of CRISP Shared Facilities is also acknowledged. Education Director, Christine Broadbridge; Education & Outreach Coordinator, Jacquelynn Garofano. Website: www.crisp.yale.edu

PHOTON PBL funded in part by the Advanced Technological Education program of the National Science Foundation (ATE #ATE 0603143) Principal Investigator, Fenna Hanes (Project Manager), New England Board of Higher Education; Co-Principal Investigators Judith Donnelly, Three Rivers Community College; Nicholas Massa Springfield Technical Community College. Website: www.pblprojects.org

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