III.

The Spectrum of Courses offered by the Center for Biophotonics Science and Technology (CBST)

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Abstract: The National Science Foundation (NSF) funded Center for Biophotonics Science and Technology CBST) provides a number of short to full-length courses on the subject of biophotonics. A middle school summer camp and various versions of multi-year high school courses are currently in progress. Two courses define a Biophotonics Option within the Photonics Technology Degree Program at the Central New Mexico Community College. CBST also collaborates with the Integrated Studies Honors Program (ISHP) at UC Davis to provide an introductory course to some of the top students in the freshman class. Advanced undergraduate and graduate courses are provided at UC Davis and sister institutions within CBST.

1. Introduction

The Education and Human Resources Program of the Center for Biophotonics Science and Technology (CBST) is committed to the goal of increasing the quality and quantity of science education experiences available to a diverse population of students, educators, and the public. We are accomplishing this by developing and implementing an innovative program that establishes pathways to careers in the emerging field of biophotonics. Applications of biophotonics range from using light to image or selectively treat tumors, to sequencing DNA and identifying single biomolecules within cells.[1] The CBST educational program is a comprehensive educational package that links *"the learning years to the earning years."*

The inauguration of the Science and Technology Center (STC) program at the National Science Foundation in 1987 represented a fundamental shift in scientific funding policy in the United States,[2] viz., a move from individual principal investigators to large, multi-investigator, multi-institutional centers. Well established by 2002, the STC program added six new centers, including CBST for which the University of California, Davis was the lead campus. Partner institutions included Lawrence Livermore National Laboratory, UC Berkeley, UC San Francisco, Alabama A&M University, Stanford University, University of Texas at San Antonio, Fisk University and Mills College. Roughly 100 researchers, including physical scientists, life scientists, physicians and engineers, are collaborating in this rapidly developing area of research.

CBST is now in its fifth year of operation. Science and Technology Centers have typically operated for a ten-year period. Although the earliest STC's have now finished their NSF funding cycles, many have been institutionalized as permanent research centers. There are currently 17 STC's funded by NSF. A benefit of the community of STC's is networking and collaboration among different centers. The Center for Adaptive Optics, started in 2000 and headquartered at the University of California, Santa Cruz, has been an especially useful collaboration for CBST. Similarly, the annual meeting of the NSF Research Center Educators Network (NRCEN), a gathering of educational specialists from the various STC's and similar NSF-funded centers such as Engineering Research Centers (ERC) and Materials Research Science and Engineering Centers (MRSEC), is a highly effective forum for sharing best practices for educational programs.

CBST currently provides educational opportunities from a middle school summer camp to advanced graduate courses. Pre-college courses tend to provide a stimulating access to the sciences (evenly balanced between the physical and

biological sciences) while undergraduate courses provide a general introduction to the field of biophotonics and graduate courses give advanced training in specific topics within the field.

2. Pre-College Programs

A 20-hour summer program for middle school children will be taught for the second time in summer 2007 in collaboration with the California State University, Sacramento (CSUS) Academic Talent Search program. The 2006 program was oversubscribed and there have been requests to run multiple 20 student sessions in summer 2007. Materials used for this group are based on our previously tested high school activites.

The High School Biophotonics Research Academy is a high school enrichment program that challenges students' ideas about careers in science and demonstrates the relevance of biophotonics in medicine, industry, and research. This program engages students in inquiry-oriented activities and research projects. The curriculum is steered by emerging conceptual models of biophotonics, emphasizes information technology, scientific inquiry, and biology/physics/chemistry concepts through studying the applied field of biophotonics. Program designs include (1) after-school programs, (2) in-school elective courses, and (3) integration as a module or unit in an existing course.

Fig. 1. High School Biophotonics Research Academy students touring the Center for Biophotonics Science and Technology at the University of California Medical Center.

During the first year, the students (1) engage in inquiry-oriented activities, (2) work in small research teams to design a systematic biophotonics investigation, (3) are introduced to industry and research opportunities through field-study trips and interactions with CBST research scientists. The year culminates with a research symposium and a publication of the students' research reports. Students who successfully complete the first year may be offered an opportunity to continue their study for a second year during which they will continue their research and compare a competitive biophotonics

science fair project. They may also apply for internships as available.

The Program is a collaborative effort among CBST, Center High School in Antelope, California, Mills College (a women's college in Oakland), East Oakland Community High School, Sacramento High School (a St. Hope Academy school), the UC Davis Cancer Center, the UC Davis Medical Center, Capitol Center MESA, the Edward Teller Educational Center, the Lawrence Hall of Science, and local industries indicating an interest in partnering with the project.

Four modules constitute the completed 200+ hour curriculum draft. During 2005-2006 the Research Academy model was implemented as an after school program at Center High School, and as a year-round elective course at East Oakland Community High School. Seventy percent of student participants in these programs came from underrepresented groups (25 out of 36). Eight second-year students participated as "Research Associates" in the Academy; two competed in the Junior Science and Humanities Symposium; six students competed in the Sacramento Regional Science and Engineering Fair (winning first and second place in the team science event); three also competed in the California State Science Fair; six plan to pursue STEM fields. Four Undergraduate Mentors (three from underrepresented groups) supported these academy programs. High School Research Academy in Biophotonics presentations were given at various national science education meetings. Evaluation outcomes indicate (1) significant changes in students' understanding of the processes, skills and values of science; (2) significant change in students' understanding of the discipline of biophotonics; (3) changes in students' course choices for math/science (increase in AP course choices); and (4) change in students' interests in pursuing STEM-related majors and careers.

Fig. 2. Two High School Biophotonics Research Academy students displaying the results of their research project.

3. Community College Program

For the job market in the United States, a serious undersupply of workers is projected for jobs requiring an associate degree or equivalent advanced training (Table 1).[3] A similar shortfall has been specifically identified for photonics technicians (Table 2). From its inception, CBST has included in its educational mission the training of a technician workforce for the field of biophotonics. In exploring potential partner institutions for CBST, it became clear that one of the most mature photonics technician training programs in the USA is that at the Central New Mexico (CNM) Community College in Albuquerque, New Mexico. The administration and staff at CNM saw significant benefits from including a biophotonics option in the Photonics Technology degree program in order to enhance the career options for their graduates.

Table 1: The Workforce Gap*

Where 9th Graders Are Headed	*versus*	Where the Jobs Are
28% will enter a 4-year college		20% require a 4-year college degree
32% will enter an associate degree program or advanced training		**65% require an associate degree or advanced training**
10% will lack the skills needed for employment		15% require minimum skills for employment
30% will drop out of the system before completing high school		

* Richard W. Judy and Carol D'Amico, *Workforce 2020: Work and Workers in the 21st Century*, Hudson Institute, Indianapolis, IN, 1997.

Table 2: Estimated Demand for Photonics Technicians*

Estimated demand for technicians in 2005	52,200
Number of technicians in 2000	19,900
Post-secondary technician graduates 2000 – 2005	8,000
Net shortfall in 2005	**24,300**

* Center for High-Technology Materials, University of New Mexico.

A Biophotonics Option was developed within the long-established Photonics Technology degree program at CNM within two years. Representatives of CBST and CNM first met to discuss areas of mutual interest in October 2003 at the Education and Training in Optics and Photonics (ETOP) Conference in Tucson, Arizona. A formal Letter-of-Intent was signed between the two groups in February 2004 by Dennis Matthews, Director of CBST and Don Goodwin, Dean of the Technologies Department at CNM. The Letter-of-Intent included an agreement that CBST and CNM would cooperate to assess the demand for technicians in the biophotonics field, comparable to the estimate shown in Table 2 but specifically focusing on biophotonics. In addition, CNM agreed to develop biophotonics courses appropriate for a Biophotonics Option with support from the resources and personnel of CBST.

Various exchange visits between representatives of CBST and CNM were carried out through the remainder of 2004, culminating with the design of both the Biophotonics Option and specific courses for that option. A press event announcing the collaboration between CBST and TVI was held in Albuquerque, New Mexico in October 2004 and the first, prototype course on "biophotonics" was offered at CNM beginning in January 2005. In February 2005, Dr. Marco Molinaro, Chief Educational Officer of CBST, met with this class to discuss internship opportunities (Fig. 3).[4] The core of the Biophotonics Options is the courses PHOT 227L (Introduction to Biophotonics) and PHOT 228L (Biophotonics Applications) that students can select from the list of electives in the Photonics Technology Degree Program. The successful implementation of the Biophotonics Option within the Photonics Technology Degree Program was reported at the October 2005 ETOP Conference in Marseilles, France.[5]

CBST is now exploring the possibility of replicating the CNM courses at a Northern California community college. A greater effort, however, is focused on recruiting science and engineering community college students from Northern California to UC Davis and our sister four-year campuses within CBST.

Figure 3: Discussion of internship opportunities at the Center for Biophotonics Science and Technology (CBST) with the "Introduction to Biophotonics" class at the Central New Mexico Community College (CNM). Dr. Marco Molinaro, Chief Educational Officer for CBST is fourth from the right.[4]

3. Freshman Honors Course

The Integrated Studies Honors Program (ISHP) at UC Davis is the oldest residential living/learning program in the University of California system, having been started in 1969. A steady increase in selectivity has led to the program being a cornerstone of campus efforts to recruit freshmen of exceptional talent. The traditional program goals are to provide excellent, personalized teaching; to integrate course offerings in the humanities, social sciences, and natural sciences; and to create a small residential community. These high achieving freshmen generally continue to be high achievers throughout their career at UCD. They graduate at a much faster pace than the general population. Also, one should note that the gpa at graduation for UCD students averages near 3.10. For the ISHP students, the average gpa at graduation is typically between 3.5 and 3.7. A significant fraction of each class (typically about 25%) graduates with a gpa above 3.90. The ISHP provides a close-knit community to a total of 114 students, the number available in the relatively new Bryan Miller Hall in the Segundo dormitory complex. Typically, a majority of the ISHP students receive Regents Scholarships, the most prestigious scholarships provided by the campus.

Each quarter, each ISHP freshman selects one of five different four-unit courses under the general label of IST 8. Each IST 8 class has been pre-approved for General Education credit and is in the area of science/engineering (IST 8A), humanities (IST 8B), or social sciences (IST 8C). Each IST 8 class is capped at 25 students.

The course, IST 8A (Shedding Light on Life), was patterned after the research themes of CBST along with the background needed to comprehend a broad definition of biophotonics. The course represents a general introduction to light, lasers, biology basics, and light/tissue interactions. Applications to diagnostics (tags), bioimaging, and therapies are illustrated, along with discussions of genes, cancer, and bionanophotonics. To engage the students, several experiential hands-on sessions are provided including student group research projects involving spectroscopy of living matter and light/tissue interactions.

The individual topics within the course are referenced to the introductory textbook on biophotonics by Paras Prasad.[1] As the Prasad text is targeted to a more advanced audience, the lectures are intended to be self contained, with the outside reading in Prasad most beneficial for biological science and other science/engineering majors. All lectures are prepared as PowerPoint presentations and archived, video and Powerpoint, for convenient access by the students. Guest speakers from within the CBST community of scientific researchers are carefully selected as those who give effective introductory lectures. The IST 8A instructors work with the guest speakers to ensure that PowerPoint presentations for their talks are also archived.

The students in the class have access to a large body of archived material from the Education Program of CBST, as well as the PowerPoint lectures from their instructors and guest speakers. The archived material is especially useful to the students as they prepare a required term paper worth 25% of their course grade. All of the archived material on the Education site of the CBST web site is available to other interested educators (http://cbst.ucdavis.edu).

As noted earlier, the annual meeting of the NSF Research Center Educators Network (NRCEN), a gathering of educational specialists from the various STC's and similar NSF-funded centers is a highly effective forum for sharing best practices for educational programs. In that forum, we became aware that an Engineering Research Center at the University of Illinois has a similar course to IST 8A for honors students interested in the theme of their center (earthquakes).

Of special note about IST 8A is the fact that about half of the students are non-science majors taking the course as a General Education elective, while the other half are science and engineering majors taking the course because of their specific interest in the topic of biophotonics.

The ISHP students are selected on purely academic standards and are not a particularly diverse group. Nonetheless, the IST 8A class has attracted a large number of female students (as high as 67 % in one recent class). Furthermore, the students have been active ambassadors for CBST, with several groups going out to the predominantly Hispanic Douglass Middle School in Woodland, California (ten miles north of Davis) and presenting introductory biophotonics concepts to seventh and eighth grade science students. CBST educators provide the IST 8A students with an introduction to learning theories and teaching techniques prior to the classroom visits. Groups of students have also

presented to the general UC Davis student body and at community colleges with highly diverse student bodies in the Sacramento area.

Fig. 4. IST8A students with middle school science teacher (on the left) after a presentation to her class.

4. Other Undergraduate Courses

In Spring of 2007, a one-unit seminar was offered within the Integrated Studies Honors Program for the first time as a follow up to the IST8A course described in section 3. The goal of this seminar was to engage some of the brightest freshman students at UC Davis in the development of tutorials and narrative elements for the CBST-led website BiophotonicsWorld.org. The seminar involved mostly students who had not taken IST8A and focused on creating public-friendly information on biophotonics for use on BiophotonicsWorld and elsewhere. The course was divided into two parts: 1) enhancing the twenty IST8A topical papers from the previous quarter by clarifying terms and making them accessible to the public and 2) creating a biophotonics primer in print and for the web.

A one-unit freshman seminar course open to the general campus population on the theme of "biophotonics" was taught for the fourth time in the Fall of 2006. The course introduced students to research in biophotonics and supplied some basic understanding of the underlying science. The course also introduced students to CBST and the opportunities for undergraduate interactions with the educators and researchers there. Several researchers from CBST presented their work. Students that participated were required to write two one-page papers on these presentations. In addition, the students were required to 'interview' a researcher connected with CBST and give a class presentation on their research

as well as write a short paper on that topic. Several students from prior offerings of this course have successfully applied to the CBST summer internship program. The seminar will continue to be taught yearly. CBST scientists from the Department of Applied Science are involved in the teaching of EAD 172, a three-unit course on "Optical Methods for Biological Research." The course is an elective within the Optical Science and Engineering major and serves as an excellent opportunity to expose these students to research opportunities within CBST.

5. Graduate Courses

CBST scientists are also involved in the teaching of EAD271, a graduate course on "Optical Methods in Biophysics" and the graduate level version of the EAD 172 course described in section 4. The course is also cross-listed as Biophysics 271 for students in the Biophysics Graduate Group. The course also serves as a portal to the Designated Emphasis in Biophotonics (a minor for graduate students majoring in a related field such as Biophysics, Biomedical Engineering, or Applied Science). Students in the Designated Emphasis in Biophotonics also participate in the joint seminar series Biophotonics 290/Biophysics 290 that provides 30 seminars per academic year.

CBST Director Dennis Matthews and Associate Director for Science/Education Integration Frank Chuang, MD, Ph.D., lead a course EAD 289 entitled "Special Topics in Biophotonics." The course is cross-listed as Biomedical Engineering 289. The course is available to all graduate students from the various CBST-affiliated institutions. The goal is to introduce new graduate students to the depth and diversity of current biophotonics research being conducted through CBST, as well as recruit new graduate students to CBST. This course focuses on familiarizing students with the fundamental principles, new tools and techniques that make-up the growing field of biophotonics. Through a combination of lectures, discussions, hands-on lab tours and research assignments, students learn about biophotonics in much greater detail. As five institutions (UCD, UCLA, University of Nevada-Reno, University of Toronto, and the Lawrence Livermore National Laboratory [LLNL]) were involved as participants and provided co-teachers, televideo was extensively utilized. Copies of lectures are available on the http://cbst.ucdavis.edu website. Streamed video of the lectures is also available.

Fig. 5. CBST Director Dennis Matthews lecturing in the graduate course, EAD289 on "Special Topics in Biophotonics."

Finally, Professor Anup Sharma of Alabama A&M has developed a new course on "Nanophotonics." This three-unit physics course (PHY692) serves to introduce his students to the new field of nanophotonics and covers topics such as quantum-confined materials, nanocomposites, nanolithography, and nanobiophotonics. The initial offering in Spring 2007 has enrolled 12 graduate students, with several expected to engage in biophotonics research.

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