

# Introducing biophotonics to first year undergraduates in science and non-science majors: Approaches and lessons learned

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## ABSTRACT

Engaging students in photonics can be challenging as the field appears lesser known compared to standard majors offered at US Colleges and Universities. At the University of California Davis we teach a well-received introductory biophotonics course that attracts 20-25 honors freshman students yearly. The 40-hour course attracts science, engineering, and humanities majors alike. The course is a basic interdisciplinary exploration of the intersection of biology, physics, medicine, optics and technology with light. In addition to an overview of biophotonics, class participants do hands-on experiments, practice peer-review, interact with biophotonics scientists, and carry out projects to communicate biophotonics to others.

**Keywords:** Biophotonics, Peer-review, Interdisciplinary Instruction, Education, Undergraduate

## 1. INTRODUCTION

The Center for Biophotonics Science and Technology (CBST)—a Science and Technology Center (STC) funded by the National Science Foundation (NSF)—advances research, development, and application of new optical/photonic tools and technology in medicine and the life sciences. The core mission of CBST Education and Outreach is to engage diverse audiences with the interdisciplinary science of biophotonics—the study of life with light. To accomplish our overall mission we have developed and implemented innovative programs that prepare and empower diverse participants to pursue STEM (Science, Technology, Engineering, Mathematics) knowledge and careers with an emphasis on biophotonics. CBST provides educational opportunities from middle school to graduate level learners and public events. We develop, help deliver, evaluate, and conduct research on our work to provide innovative and effective educational STEM experiences, products, and pathways for students, instructors and members of the educational research and outreach communities.

One program targeted specifically to undergraduates has involved the enhancement of existing undergraduate courses and the creation of new undergraduate courses at the University of California at Davis (4 new, 1 enhanced), University of Texas at San Antonio (1 new), and Central New Mexico Community College (2 new). At all of these institutions the enhanced courses have introduced a sizeable biophotonics component (1/4 or more of the course) with the new courses focused entirely on photonics as applied to biophotonics.

The purpose of this paper is to describe the longest lasting biophotonics course that has been taught at the University of California at Davis (UCD) yearly since 2004, IST8A: An Introduction to Biophotonics. Since its inception various components and approaches have been tried and improved to provide college freshmen at UC Davis an engaging and memorable introduction to the interdisciplinary field of biophotonics.

## 2. COURSE DESCRIPTION

The IST8A: An Introduction to Biophotonics course is an established course within the Integrated Studies Program at UC Davis. The Integrated Studies Honors Program (ISHP) at UCD 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 and tend to

maintain a higher grade point average. The ISHP provides a close-knit community to a total of 110-150 students. Typically, two-thirds 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 4-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. Students select their course offerings based on their interest in the topic as presented by course instructors in the quarter prior to the course offering. Typically in the IST8A course 25-35% of the students are declared science majors (primarily biology and chemistry), 25% engineers (primarily mechanical, and electrical), 15-30% humanities (english, political science, philosophy, economics, psychology, art,...), and the remainder undeclared.

The IST8A Introduction to Biophotonics Course is generally taught in the winter quarter, lasting a total of 10 weeks with four hours of weekly classroom interaction. All laboratory work is done in and around the classroom with the students supplying their own portable computers for the spectrophotometric experiments. All other materials, equipment, and software is supplied by the course instructors.

## 2.1 Course Topics

The course is meant to serve as an introduction and overview of the interdisciplinary field of biophotonics presented to students ranging from highly science-focused to those barely interested in science. Due to the broad range of interests and background knowledge the students bring to the course, the overall approach has evolved into one that begins with engaging students with biophotonics “gadgets” such as pulse oxymeters, infrared camera, thermal scanners, fluorescence mysteries and more, learning light basics, experiencing basic light and light/tissue interaction through experiments, reviewing basic molecular biology and cancer, and then delving into specific research examples covering uses of fluorescence, bioluminescence and advanced microscopy techniques. The course takes a “spiral” approach as topics are seen multiple times throughout the course and a central tenet of “practical biophotonics” elements is revisited on an ongoing basis (figure 1). For specific research discussions, scientists and medical doctors are brought in and coached prior to presenting in how to make their presentations accessible (more information in Section 3). The 2010 course syllabus, along with most of the discussion videos and pdf versions of the presentations are available online<sup>1</sup>.

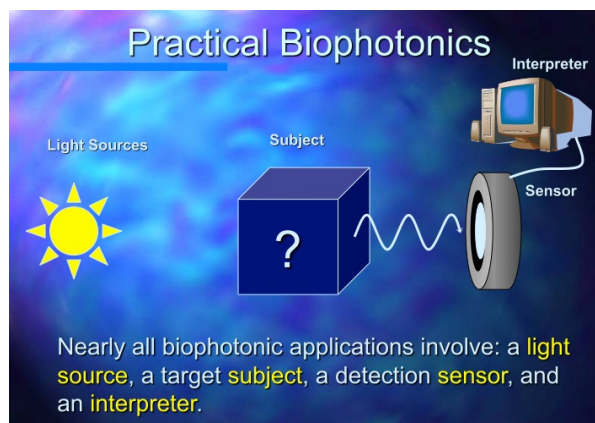


Figure 1. Practical biophotonics tenet presented as a central course element and revisited throughout the course when discussing experiments and approaches to addressing questions with biophotonics tools.

## 2.2 Grading Structure

The course strives to provide a balanced approach to grading that takes into account the varied learning styles present in such a diverse range of talented students pursuing a broad range of disciplines. Overall the course is graded in the following manner: Attendance (10%), Quizzes (15%), Presentations (25%), Laboratory reports (25%), and Final exam (25%). Points for attendance vary based on engagement in class discussions with approximately  $\frac{1}{4}$  of the class receiving maximum points due to highly engaged participation in discussion and only about 10% receiving the lowest scores, usually due multiple absences or lack of participation in class discussion. Quizzes are always 3-5 long answer questions designed to give near immediate feedback to the instructor as to areas of confusion/difficulty. Presentations and laboratory reports are described in greater depth in section 3 and constitute  $\frac{1}{2}$  of the course grade. The final exam is

structured with half of the points for 30-40 multiple choice questions and the rest for 12-14 long answer questions that include multiple questions on designing basic biophotonics experiments.

### 3. COURSE COMPONENTS

The course has evolved over the seven years of instruction to contain specific components that have ranked highly with students as engaging, informative, and challenging. Though no one component by itself is unique to science courses, the combination appears to work well for introducing the interdisciplinary field of biophotonics. These components are described below in detail.

#### 3.1 Science discussions with scientists at all levels

The entire course relies on interactions with scientists from the core instructor to the guest speakers. While this is standard for most science courses, the variety of people presenting and the approach taken with their presentations is less common. Among guest speakers are several graduate students, post-docs, junior researchers and senior researchers, often also including a medical doctor, industry researcher, and an undergraduate research panel. This range allows for the students to see the various levels of people engaged in biophotonics, hear their path into the field, and discuss their cutting edge research. Additionally, the core instructor acts as a moderator for the presentation/discussion often interrupting the speaker with questions the students may be uncomfortable asking due to fear of the basic nature of their questions.

The speakers are coached by the core instructor prior to their presentations and often share their talks ahead of time so that the core instructor can tailor the final talk and make sure the level will engage the students leaving them feeling challenged but not completely in the dark about the presentation content. On the class session following the presentations by external speakers, the core instructor will condense the material that was presented into one to two key slides with the main topics. This tends to help the students focus and see how the material fits into the overall course while easing their anxiety as to the amount and level of content they need to know.

#### 3.2 Hands-on experiences

Students often have a difficult time staying engaged in a new and interdisciplinary topic if they are solely talked to, no matter how well presented a topic may be. To help the students solidify their understanding, several hands-on experiences are interwoven into the course, two of which form the basis for the two laboratory reports. All equipment is brought in as needed into the classroom that contains larger tables fitting 2-3 students each. During the initial third of the course when students are learning the basic properties of light and light/matter/tissue interaction they have three key experiences:

1) Observing light properties with simple paper spectrometers – during this 70 minute experience students are given a pre-built paper-based spectrometer developed by NASA<sup>2</sup> to observe and discuss various light sources. An open-ended worksheet guides them to discuss what they know about light emitted from various sources. They are then given the spectrometers, which have rudimentary scales from 400-750nm, and asked to draw what they see upon observing various light sources directly or upon reflection. They observe incandescent light, the sky, fluorescent light, phosphorescence, red and green lasers, holiday lights, LEDs of various colors including white, glow sticks, and candlelight (see Figure 2 left image). The ensuing discussion gives them a sense of the spectral properties of various light sources, how the light is generated, and the range of energies they emit.

2) Observing spectral properties of light sources with fiber-optics based spectrophotometers – during this 100 minute experience the students repeat the experience outlined in (1) above except this time they do their observations with a fiberoptic based spectrophotometer. They learn how to use the basics elements of the software (acquisitions time, mode, display, simple noise reduction) and the spectrophotometer to obtain spectra that have 1nm resolution and then relate the data they obtain back to what they saw based on the simple spectrometer. In a later laboratory experiment they learn more advanced aspects of the tool and software.

3) Laser light diffraction – Prior to this experience students are given a handout and checklist that discuss what the components of a laboratory report should be plus they are given information on what makes an effective graph and/or table. During this 80 minute experience the students measure laser diffraction patterns from the hair of each of the 3-4 members of their group with both red and green lasers. The students are given minimal direction and need to figure out what is important information for them to collect for their laboratory report focusing on the use of laser light to measure

small thicknesses. They hopefully do their measurements multiple times and collect and analyze their data for the laboratory experiment #1 (See figure 2 right image).

As the course progresses they have multiple hands-on experiences during the fieldtrip described below in Section 3.4.

Lastly, at the start of the last third of the course the students have 110 minutes to measure the light reflecting, absorbing, and fluorescing properties of various forms of plant matter including green and brown leaves, another color of leaf, flower petals, woody stems, and green stems to determine what they can discover spectroscopically about the pigments that are present in various part of plants in different stages of their lifecycle. Often students will come back and request to borrow the instrumentation so they can obtain additional spectra outside of classtime. Students routinely obtain excellent evidence for chlorophyll confirmed through absorption, reflection and fluorescence (though it can take them several attempts to master obtaining strong signals over the noise). Some also “discover” additional plant pigments and most learn about taking reference spectra and using subtraction to see the “signal”. Surprisingly many of the students report this laboratory as the first time they have had to interact with data consisting of thousands of points, had to deal with “noise”, and had to come up with their own procedures.

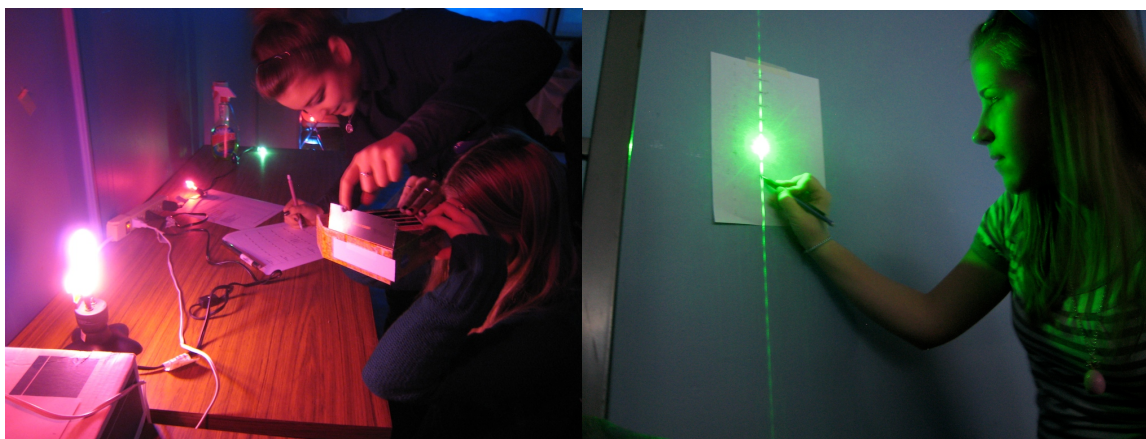


Figure 2. Left image shows students observing the spectral qualities of a “pink” fluorescent light using a paper NASA spectrometer<sup>2</sup>. Right image shows a student measuring her hair diffraction pattern using a green laser.

### 3.3 Peer-reviewed laboratory reports

A written component in an introductory science course is important both to improving students’ abilities to communicate science as well as begin to be “indoctrinated” into the field and the “language” used in science, especially if they never choose another science course. Initially the course asked for a term paper on a biophotonics topic. While the students were quite comfortable with this type of assignment and often turned in what appeared to be well written reports expected in an English course they did not really have a science experience. In an effort to give students a more challenging and science-focused experience the extensive laboratory report in the format of a scientific paper was introduced. To further enhance the experience, a peer-review component was added to the first report. Peer review is an established scientific practice that few freshman students, especially those that are not science-focused, ever experience and can help with general science literacy. Initially it was hoped to use Peer-Calibrated Review (CPR)<sup>3</sup> originally developed for larger chemistry courses and utilized in some biology classrooms. While the online nature of the system simplifies multiple aspects of peer-review, it was found not sufficient for reviewing laboratory reports in which there was text, formatting, images, tables and more to comment on. A general approach where each laboratory report was copied and anonymously reviewed by three randomly chosen students from the course plus the instructor proved to work well. Each student then received 4 reviews, 3 from peers and one from the instructor. The students were then given one week to incorporate the feedback and turn in the final report. Their score on the report was the average of the score given by the instructor on the initial and final reports as well as a score for their depth of reviews of the three reports of their peers (see Figure 3). The vast majority of students saw increases in their final score with a large percentage incorporating the comments of their peers almost entirely. A second laboratory report was assigned but the peer-review process not undertaken due to time constraints.

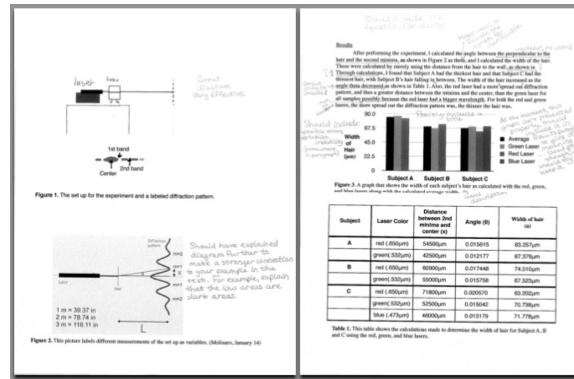


Figure 3. Two pages from an example laboratory report on laser hair diffraction. Note the multiple comments in the margins from a peer reviewer.

### 3.4 Fieldtrip

To get a sense of the real research happening in biophotonics laboratories, each year we bring the entire class of 20-25 students for a 2 hour fieldtrip to the main Center for Biophotonics facilities in Sacramento, CA. During this visit to the laboratories, the class is divided into two groups with one group visiting the laboratories as the other interacts with biophotonics “gadgets” and uses a research grade microscope to image objects of their choosing. At the midpoint of their visit the two groups interchange to experience the other component.

In the laboratory portion the students visit three different laboratories each set up with advanced instrumentation including laser trapping/Raman setups for cancer cell identification, multiple CARS imaging setups, and one of the world’s highest resolution optical microscopes that last year imaged the passing of HIV viruses from infected to non-infected cells<sup>4,5</sup>. Each of these instruments is explained and discussed with graduate students and post-doctoral fellows that helped develop the instruments and use them in their daily work.

In the interactive demonstration portion the students interact with biophotonics “gadgets” in multiple stations that have been setup to feature elements mentioned in the course including: thermal imaging, fluorescence in everyday objects and common tissues, pulse oxymetry, near-infrared fat monitoring, and various forms of microscopy (brightfield, darkfield, phase, polarized, and fluorescence). The students image an object that they brought for the specific purpose of visualizing under a microscope. Objects have included razor blades, tea, hot cocoa mix, cork, gum, foam and many other objects that they are curious about. The various images are then made available to the students online and a poster is created (see Figure 4).

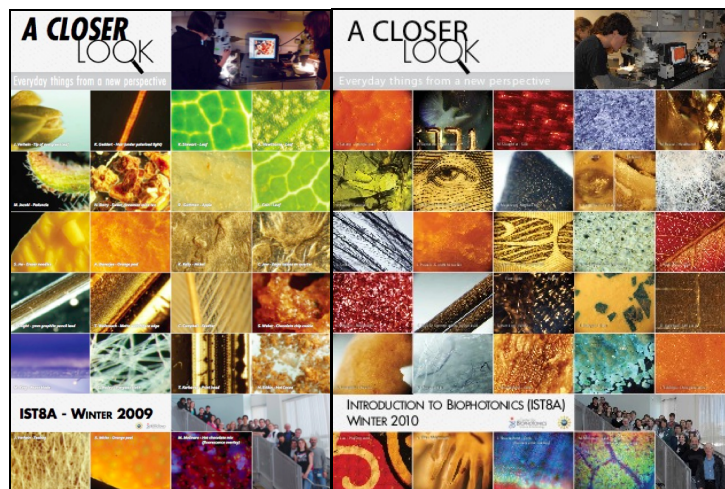


Figure 4. Student microscopy images collated into posters created for the 2009 (left) and 2010 (right) classes.



### 3.5 Public Presentations

As a final element of the course, all students are required to make some sort of group presentation that helps others learn about biophotonics. Being able to communicate science concepts to others often helps students clarify and solidify their own understanding. Over the years the following forms of presentations have surfaced:

1) Presentation to a middle school audience – every year two or three groups of 4 students have chosen to spend 50 minutes in an inner city school presenting biophotonics concepts through some form of Powerpoint presentation plus interactive demonstrations or stations. Every year we are asked to bring more students to present at these schools. For many of the IST8A students this is their first exposure trying to teach someone else science.

2) Presentation to a general college or public audience – groups of students set up a table in a public area, whether on a college campus or at the local Farmer’s Market, and present basic biophotonics tools and ideas to members of the public.

3) Video presentation – usually every year one group chooses to make some sort of multimedia presentation. This has led to some very interesting videos over the years with the most memorable being: interviews with persons on the street about what they think biophotonics is, the biophotonics dating game, basics of light puppet show for elementary kids, and the Photon Phoebe cartoon<sup>6</sup>.

Every year, I as the instructor, have learned something new in terms of how to engage members of the public in biophotonics through the creative efforts of the varied groups of IST8A students.

## 4. COURSE ASSESSMENT AND EVALUATION

IST8A has evolved over the last seven years primarily based on student performance and feedback. We have relied on the students overall generic course evaluations, their pre/post changes in a Biophotonics Concepts Inventory (BPC)<sup>7</sup> created in-house with the help of the biophotonics research community, and specific student feedback on course components. Below the data from the 2009 and 2010 iterations of the course are presented as they reflect the evolved version of the course that is described in this paper.

### 4.1 Course Evaluations

A generic form is mandated for all courses taught at UCD. 15 questions ask the student to rate a specific statement on a Likert scale that varies from a value of 5 for “strongly agree”, to 3 for “undecided” to 1 for “strongly disagree.” Two key questions, and values are presented in Table 1 below.

Table 1. Basic statistics on 2009 and 2010 student reported values for two questions given as part of their university course evaluation for the IST8A course on biophotonics.

Question	Year	Mean	S.D.	n
“I see relationships among course topics”	2009	4.5	0.7	22
	2010	4.8	0.4	24
“Overall this is a good course”	2009	4.0	0.9	22
	2010	4.3	0.5	24

### 4.2 Biophotonics Concepts Inventory (BPC)

This tool assesses basic concepts that are key to biophotonics via conceptual, highly visual questions that are multiple choice in nature but emphasize conceptual understanding rather than memorizable facts. The tool was created by having CBST educators and scientists identify key concepts underlying biophotonics, jointly develop items, test the items with multiple student and professional audiences with the process iterated multiple times over three years to arrive at the current instrument<sup>7</sup>. The resulting instrument, although still in development, has proven to be a relatively trustworthy and useful tool for evaluating students’ conceptual understanding. The full description of its development and validity of the 14 items is discussed elsewhere<sup>7</sup>. As seen in Table 2, the IST8A course was a significant intervention in increasing

the basic biophotonics concept knowledge of the students. The significant differences in post versus pre test scores and the large effect size confirm that the course caused this large positive difference.

Table 2. Paired samples t-test values and effect size for 2009 and 2010 IST8A classes pre/post Biophotonics Concept Inventory results. Numbers presented as means can be converted to a % correct value by multiplying by 100.

Year	PRE (Mean)	POST (Mean)	p value	Effect size	n
2009	0.62	0.79	< 0.001	> 0.8	20
2010	0.75	0.91	< 0.001	> 0.8	24

### 4.3 Anonymous Student Feedback

At the end of the course students were given the opportunity to provide open-ended feedback on all primary course elements as well as the course overall. When asked what the students liked most about the class, each of the following statements, in one form or another, were made by at least 25% of the students in the 2009 and 2010 IST8A courses:

- The wide range of topics/material covered.
- Learning about cutting edge science and discoveries and the interesting/current research applications.
- The applicability of much of the course material, the current technologies, and how they work
- The variety of topics covered and the depth to which they are covered.
- The interactive demonstrations/activities and hands on examples/models of biophotonics and tools, especially the spectrophotometer.
- Exposure to all the developing ideas at a level a non-science major can understand.

When asked if the course had affected the students' career intentions, about 1/3 of the students responded that the class did not change their intentions, 1/3 said the course reaffirmed their career intentions, and the remaining third said the course made them think of additional options/ways to go in their career. One history major commented that the laboratory experiences made them want to pursue a statistics minor, and several intended science majors discussed wanting to minor in education after enjoying the experiences of interacting with the middle school students and/or members of the public.

## 5. LESSONS LEARNED AND FUTURE PLANS

Reflecting upon seven years of teaching the interdisciplinary introduction to biophotonics course a few key principles/lessons learned have arisen including:

1. Focus on the key concepts. An introductory, or survey course aimed at science and non-science majors alike can quickly become overwhelming to both audiences if too much or too little content is discussed. The science majors may appreciate delving deeply into specific science questions but the non-science majors will quickly disengage from the course if they do not perceive enough "value" or variety in what is covered. Keeping everyone engaged is extremely challenging but keeping it as the primary goal for the instructor forces classtime to be carefully spread between basic to advanced topics with clear learning expectations frequently enumerated to ensure that the non-science majors focus on what they can and do understand rather than what they do not understand.
2. Provide a wide range of learning experiences. Some students are more auditory, some visual, some tactical and virtually all appreciate a mix of all three. By allowing for lecture, ample discussion, hands-on experimentation, written work, and creative expression through projects to teach others, we've observed that the vast majority of students appreciate the variety and often find multiple elements of the course to their liking.
3. Focus on the basics as they apply to the cutting edge. I have yet to meet a student that does not appreciate learning a seemingly complex scientific principle or approach by understanding the basic concepts and how they apply to the more complex picture. By involving scientists who present the latest results in their field in a comprehensible manner, whether due to the presenter's skills and/or the core instructor's coaching, questioning, or pre and post-presentation support,

students often leave feeling like they have peered into the cutting edge of science and medicine and understand most of what they heard.

4. Use real instrumentation whenever possible. Students have remarked every year that working with the fiberoptic spectrophotometers on fairly open-ended experiments is a real highlight of the course. They enjoy the technology and generally appreciate the capabilities. All the other biophotonics “gadgets” are also to their liking and much preferred to very simple or virtual versions of instrumentation.

5. Provide individual and group work components. Interdisciplinary science, almost by definition involves teams of people working together, each contributing to a larger problem or question. An interdisciplinary course should be no different! By creating opportunities for individual and group work, students are exposed to the realities, both positive and negative, of interdisciplinary science. Group work comes in the laboratory and public presentation components with the rest of the course being of a more individual nature.

And lastly, (6) Never underestimate where your non-science majors end up and what they may do with their course experience. During the Spring of 2009 I had the pleasure of representing our campus at a presentation of National Science Foundation funded research on Capitol Hill. Part of the experience involved visiting California Senators and Representatives to discuss our efforts in biophotonics. Lo and behold in one of the offices I was greeted by one of my former students from 2005! The student had been an English major who had taken my course as a freshman and was now a Congressional aide for a California Representative to the US Congress. She fondly remembered the course and could still accurately describe biophotonics and the types of research possible through the use of biophotonics! New interdisciplinary science fields seem to be proliferating at an ever-increasing rate and a science literate public is essential for the active participation in and promotion of science. Introductory courses that bring students together students with varied interests and backgrounds and help them advance their appreciation and knowledge of new scientific disciplines and approaches are critical to our continued successful contributions in science.

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