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Implementation and assessment of challenge-based instruction in a biomedical optics course

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Abstract

The domain of biophotonics/biomedical optics continues to increase in importance for many areas of Biomedical Engineering, Medicine, and the Life Sciences. Whatever the ultimate goal of the use of light in medicine and biology, the initial interaction and distribution of light within biological tissue is fundamental. Students at all levels have considerable difficulty with many of the concepts that govern light distribution in tissue. To address these conceptual difficulties, new paradigms in the learning sciences advocate approaches that actively engage the students in models of challenge-based learning.

The goals of this project were: 1) implementation of a challenge-based learning module, based on the laser treatment of a Port Wine Stain in an introductory course on Biomedical Optics, to teach the fundamental concepts of tissue optics; 2) assessment of the value of this module compared with two other modules (ablation and spectroscopy) that were not implemented in a challenge-based fashion. Our experimental design encompassed three instructors at two institutions teaching this material over the span of a year, with three different cohorts of students. We created an assessment instrument that consisted of 4 problems that probed the students' understanding as well as captured their ability to apply concepts to novel problems. Students were asked to complete these problems at the beginning (pre) and at the end (post) of the semester. Based on the learning goals of the course we created a scoring rubric that consisted of eleven categories, each with a five point scale. Students' answers to the questions (pre and post) were scored according to the rubric by three independent instructors who were blind to the identity of the students. In addition, data were collected using an observation system to quantify each student's level of engagement during class in the experimental (challenge-based) and control (non-challenge based) groups.

Analysis indicates 1) a higher level of student engagement during challenge-based instruction; and 2) statistically significant improvement in understanding between pre- and post assessment. This paper presents a full assessment-based analysis of the utility and benefits of the challenge-based learning approach in a bioengineering environment with a discussion of the broader implication to engineering education in general.

I. Introduction

Biomedical Optics is defined as ‘the use of light from the far-ultraviolet through the visible into the infrared for diagnostic, therapeutic and sensing applications in medicine and biology, and continues to increase in importance for many areas of Biomedical Engineering, Medicine, and the Life Sciences. Whether students pursue careers in Biomedical Engineering research centers, biomedical companies, or go on to the medical professions, they are almost certain to encounter optical technologies for diagnosis, sensing or therapy. It is expected that optical science and optical technology will be at the forefront of development of new enabling technologies and devices both in the basic science labs as well as in a clinical setting. Thus, several programs around the country, including ours, are actively working on course development in the area of Biomedical Optics. Typically courses in Biomedical Optics are aimed at upper level (senior) undergraduate students and first-year graduate students while a real need for continuing education has been identified as well. Interestingly, while numerous good reference books exist on this topic, there is no comprehensive textbook.

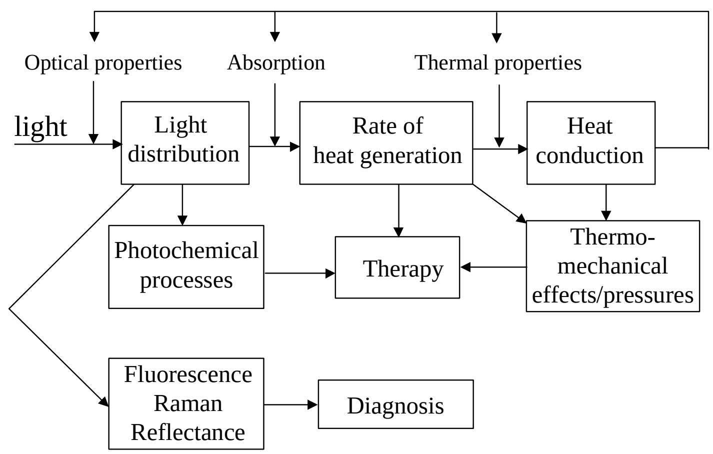

Figure 1: *Block diagram illustrating the interrelationships between optical properties and ensuing therapeutic, diagnostic and sensing applications.*

At the very core of all the interactions shown in figure 1 lies a thorough understanding of the interaction of light with biological matter governed by the wavelength dependent optical properties. The levels of absorption, scattering and scattering directionality determine where light goes and how much of it ends up at which location. Subsequent chemical, thermal or mechanical events determine the effect on tissue that can be therapeutic or diagnostic. Thus, the learning objectives of a course in biomedical optics are to 1) foster the students’ understanding of the role of laser properties (wavelength, irradiance, pulse duration) and tissue optical properties (absorption and scattering) on the light distribution in tissue and subsequent photochemical, photothermal or photomechanical events; 2) create an understanding that allows students to solve problems and design systems based on these properties and their effects on light-tissue interaction.

Drawing on current paradigms in the learning sciences, we have developed several modules based on the Legacy cycle in the context of a HPL (how people learn) framework [Bransford 2000]. This approach involves a sequence (generate ideas – multiple perspectives – research and revise – test your mettle – go public) that is formalized in the Legacy cycle. Emphasis is placed on continuous posing of questions to students as well as forcing students to formulate questions relevant to being able to solve the challenges posed to them. In this manner students will engage in problem-based educational activities that not only teach them subject specific content knowledge but help them develop into life-long learners and problems solvers.

The overall goals of this project were: 1) implementation of a challenge-based learning module, based on the laser treatment of a Port Wine Stain in an introductory course on Biomedical Optics, to teach the fundamental concepts of tissue optics; 2) assessment of the value of this module compared with two other modules (ablation and spectroscopy) that were not implemented in a challenge-based fashion.

II. Development and Implementation

The specific grand challenge used to teach the concept of tissue optics and selective absorption involves the laser treatment of a Port Wine Stain (PWS). The goal of laser treatment of this vascular malformation in the skin is to use laser energy targeted at the dermal vasculature and cause coagulation of blood and thus the vessel occlusion. The challenge is to target the blood and blood vessels selectively while avoiding significant heating to superficial layers of tissue that may absorb the laser light, in particular the melanin in the epidermis. While not the most common medical problem, laser treatment of PWS provides an effective vehicle to teach tissue optics and an elegant example of how optimal choices of laser parameters can accomplish the desired result (and how poor choices can cause adverse effects).

The grand challenge is broken up into smaller sub-challenges that consider questions such as: “What is the best wavelength to treat a PWS?”, “What is the optimal laser irradiance to treat a PWS?”, and “How long a laser pulse should one use to treat a PWS with an optimal cosmetic result?”. The PWS learning module was developed and used first at Vanderbilt University in the Spring of 2002 in a class with 16 students (14 seniors and 2 juniors). During the first week of class the grand challenge was presented to the students and their initial intuition was documented. About 1/3 into the semester, the challenge was revisited and the PWS module was presented. The module was delivered in class and was incrementally posted on the course website. Activities were presented throughout the module as assignments out of class and discussions in class. The research-and-revise phase consisted of lectures, exposure to audiovisual clips of interviews with experts, in class demos, and homework assignments, some of which involved use of an interactive simulation of light distribution in tissue (Monte Carlo simulation) [Jansen 2001]. For example, a homework assignment required students to determine what a chromophore is and what chromophores are present in skin. Following up on this, students were asked to determine the optical properties (scattering coefficient and absorption coefficient) of the most important chromophores in skin. A third activity involved simulating light distribution in skin using the Monte Carlo program at different wavelengths.

III. Assessment and Evaluation

An extensive assessment protocol was developed to assess student learning and to determine if the educational objectives were being met. Specifically the efficacy of the Challenge-based (HPL) approach was contrasted to a conventional lecture delivery (non-HPL). Our experimental design encompassed three instructors at two institutions teaching this material over the span of a year, with three different cohorts of students (see figure 2).

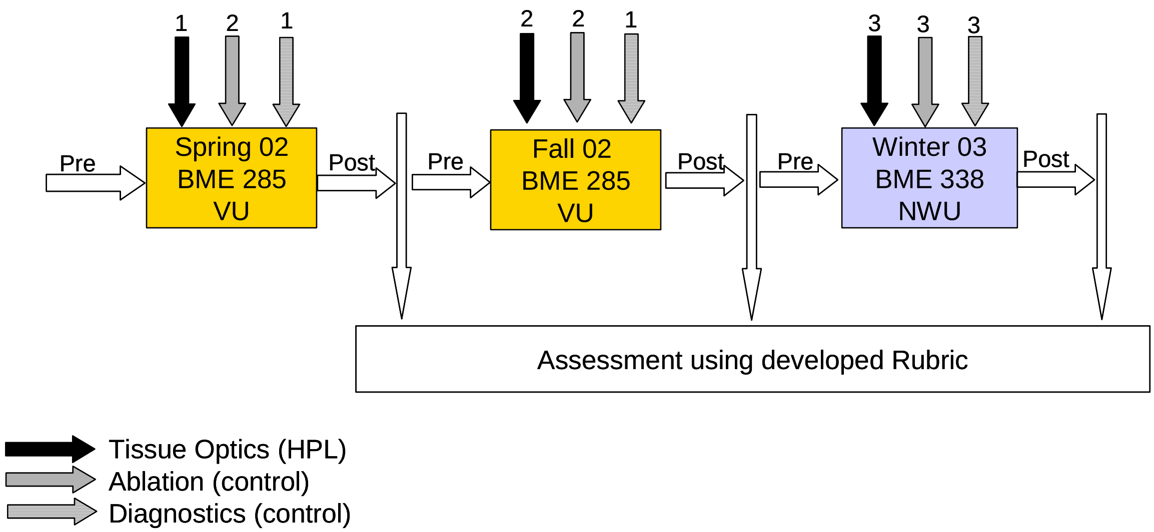

Figure 2. *Assessment design. Three modules: Tissue Optics (PWS) (HPL), Ablation (non-HPL) and Diagnostics (non-HPL) are taught each semester. At VU the Tissue Optics module was taught by two different instructors in subsequent semester while the Ablation module was taught by instructor 1 in both semester and the Diagnostic module will be taught by instructor 2 in both semesters. At NWU all three modules were taught by instructor 3.*

We created an assessment instrument that consisted of 4 problems that probed the students' understanding as well as captured their ability to apply concepts to novel problems. Students were asked to complete these problems at the beginning (pre) and at the end (post) of the semester. The first of these assessment questions is shown in figure 3.

Based on the learning goals of the course we created a scoring rubric that consisted of eleven categories with a five point scale. Students' answers to the questions (pre and post) were scored according to the rubric by three independent instructors who were blind to the identity of the students. The scoring rubric is presented in figure 4.

In addition, data were collected using an observation system (VOS) to quantify each student's level of engagement during class in the experimental (challenge-based) and control (non-challenge based) groups. A detailed description of this system can be found elsewhere [Harris 2002].

1) After graduating from Vanderbilt you are offered a fantastic job with this small start-up biotech company. They want you to test an ablation system with great potential. This tabletop laser system, which emits every possible wavelength at every possible pulse duration with as much power as you could ever want, was developed with money from NASA and thus the first test will be in space. On lift off there is a problem, you black out and awaken as the shuttle shakes upon atmospheric re-entry. Strangely, as you look out the window, the planet does not look like earth and your wristwatch is saying it is 2102 (ah the joys of time travel). You land miraculously. The inhabitants praise you and bring you to their leader, who explains that his tribe is dying from a skin condition. You determine that you can cure them by removing only the ~300 μm thick lesions with the laser.

a) Tell me the steps that you will take to use the laser to remove the skin lesions but not harm the underlying structures. Note that the optical properties of these aliens may not be the same as that of earth-based life forms.

b) Discuss the factors that are involved in this procedure. This could include biological issues, experimental issues, and any other technical or practical issues you feel are important.

c) Identify the information you would like to have in order to be most effective in solving this problem.

***Figure 3**. Example of Assessment Question.*

Rubric Design:

A1. Student explicitly states the general goals of treatment and design specifications (boundary conditions) that need to be met.
A2. Student gives implicit evidence of understanding of the general goals of treatment and design specifications (boundary conditions) that need to be met.
B. Student defines general approach of to use light/laser radiation to remove tissue.
C. Student identifies and discusses need for strong absorption or preferential absorption of laser radiation in target tissue
D. Student identifies and discusses need to know optical properties of tissue.
E. Student describes and discusses methods to determine /measure optical properties of tissue.
F. Student identifies need to consider pulse duration and discusses pulse duration in context of minimizing collateral thermal / mechanical damage.
G. Student identifies need to consider pulse repetition rate and discusses pulse repetition rate in context of thermal diffusion (thermal damage) and practicality (time of treatment).
H. Student identifies and discusses beam delivery strategies.
I. Student identifies and considers biological effects.
J. Student presents plan that will lead to adequate treatment. Such a plan should start with appropriate experiments to measure important parameters and via limited clinical (in vivo) trials ends up with an optimized treatment.
K. The overall response provides an appropriate integration of all the issues that should be considered in the design.

***Figure 4.** Rubric for analysis of question 1. The categories of the rubric were designed to assess learning objectives. Three independent domain experts, blinded to the student's identity scored the students' reponses to the assessment question. Each rubric was scored on a scale from 0 to 4 where, for example, a score of '0' was given if a student "failed to provide a plan that will lead to adequate treatment" and a '4' was given if the student "provided a comprehensive plan".*

IV. Results and Discussion

Figure 5 shows the results of the rubric scores for this question from the students in the Spring of 2002 (VU). Rubric categories A2, B, C, D, and K showed significant improvement between pre and post semester ($p<0.05$). In all other categories there was some improvement but this was not statistically significant. Given that the amount of time given to the students was the same for the pre and the post test, it is likely that students spent more time writing about issues they felt were important and emphasized in the course which in turn may have limited the effort on other categories. From the data it is clear that significant improvements were achieved in those rubric categories that can be summarized as dealing with Tissue Optics which was the one module (PWS) that was delivered based on HPL principles. It is uncertain whether this can be attributed to the HPL method or simply to the fact that more time and effort was spent on this part of the course. While these data are encouraging, it is too early to draw any firm conclusions. Data analysis on material covered in the control group (non-HPL modules) is in progress and will be used to analyze the differences between instructional strategies and learning models. We are currently analyzing similar data for the students (31 seniors) who took the course in the Fall of 2002 (VU) while data collection for the third group (Winter 2003 - NWU) is in progress at the present time.

Data from the observation of student engagement (an example of which is presented in figure 6) shows that in the non-HPL instruction the initial level of student engagement is high but falls off about half-way through the lecture period. This type of loss of interest has been well documented in the literature [Bransford 2000]. In contrast, when engaged in problem-based learning (HPL) student engagement starts off slightly lower typically due to initial set-up time during use of technology but does not exhibit the same dip in the middle of the lecture. This suggests that engaging students actively by implementing an approach of challenge-based learning, students are paying more attention and probably get more out of being in class.

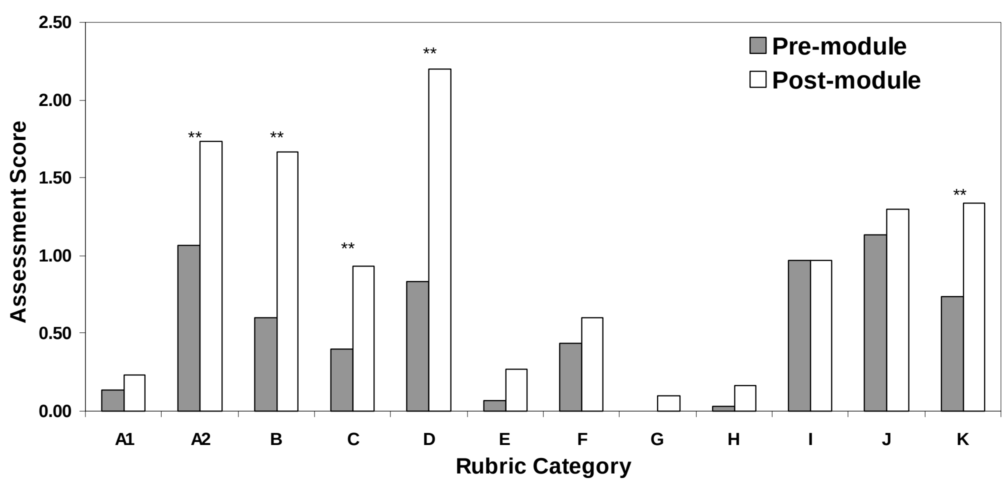

Figure 5. *Pre- and post-module assessments of student responses to assessment question 1 scored by three independent and blinded experts based on rubric shown in figure 4.*

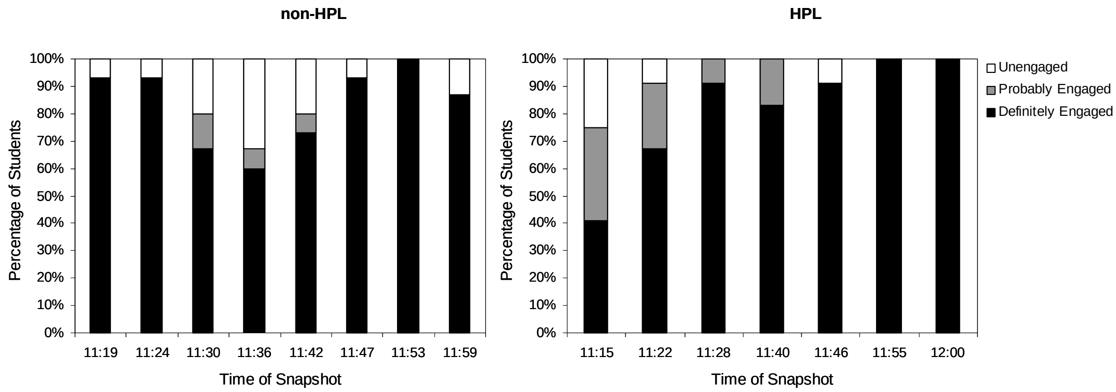

Figure 6. *VOS observation of student engagement during a class period with HPL-based material (A) and without HPL-based material (B).*

V. Conclusions and Future Directions

Development of a challenge-base module to teach tissue optics based on principles derive from the How People Learn (HPL) frameworks is presented. A one-year, three-instructor, two-institution assessment design is presented and preliminary data are shown and discussed. The implementation and assessment of HPL-based modules in the field of Biomedical Optics will continue over the next year at Vanderbilt University and Northwestern University. Additional test sites may become involved in the near future. Additional modules will be developed and implemented in this challenge-based style of learning.

VI. Bibliography

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