AC 2010-1759: IMPLEMENTING AND ASSESSING A CHALLENGE-BASED MODULE FOR SPECTROSCOPY IN A BIOMEDICAL OPTICS CLASS

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Implementing and assessing a challenge-based module for spectroscopy in a biomedical optics class

Abstract

The importance of biomedical optics is steadily increasing as reliable, fast, and non-invasive tools are becoming exceedingly necessary for disease diagnosis and treatment. Many times, real-world biomedical optics applications are not discussed in a classroom setting, which may limit students' ability to use critical thinking skills to tackle engineering problems, as well as their ability to research and discuss current technologies. There were two goals of this project: 1) implement a challenge-based learning module (based on the Legacy Cycle framework) to diagnose skin cancer with optical spectroscopy in a junior to senior-level undergraduate course on biomedical optics and 2) assess the value of this module compared to previous years' lecture-only method of teaching optical spectroscopy. The experimental design was introduced over one semester. The module was assessed using 3 indicators: comparing test answers between 5 semesters worth of classes, a 1 page study guide on an emerging technology of skin cancer diagnosis created by the students, and anonymous student evaluations and feedback from a post-module survey. Preliminary analysis suggests that challenge-based teaching led to a slight improvement in understanding between the classes who did and did not receive this module. We also received positive feedback, as well as useful suggestions for future implementations of the Legacy Cycle.

Introduction and Problem Statement

Biomedical Optics is an emerging area in the biomedical engineering field, combining engineering and physics with medicine and biology. Regardless of whether students pursue careers in research, academia, engineering companies, or medicine, they will certainly be faced with optical technologies used for sensing, diagnostics, and/or therapeutics. Over the last decade, optical sciences and technologies have been widely developed for new applications and devices, both for basic science research as well as clinical settings. However, at the same time, biomedical optics courses have not been well-integrated into most undergrad biomedical engineering curriculums. At Vanderbilt University, a junior to senior-level biomedical engineering elective course entitled “Introduction to Biomedical Optics” has been developed with the objective of “using light from the far-ultraviolet through the visible into the infrared for diagnostic, therapeutic, and sensing applications in medicine and biology.”[1]

Previous work in the development of this course focused on creating and implementing an interactive instruction module of light distribution.[1] This tool greatly helped students visualize abstract concepts, like light and its interaction with biological matter. Understanding this concept is fundamental to understanding the other processes found in Figure 1. Monte Carlo simulations were used to develop an interactive and visual learning module so students could obtain a conceptual understanding of light distribution in tissue, instead of having to rely on complicated differential equations.

Since 2001, various pieces of the course (Figure 1) have remained unchanged. Most years, student evaluations have indicated that the areas of fluorescence, Raman, and reflectance

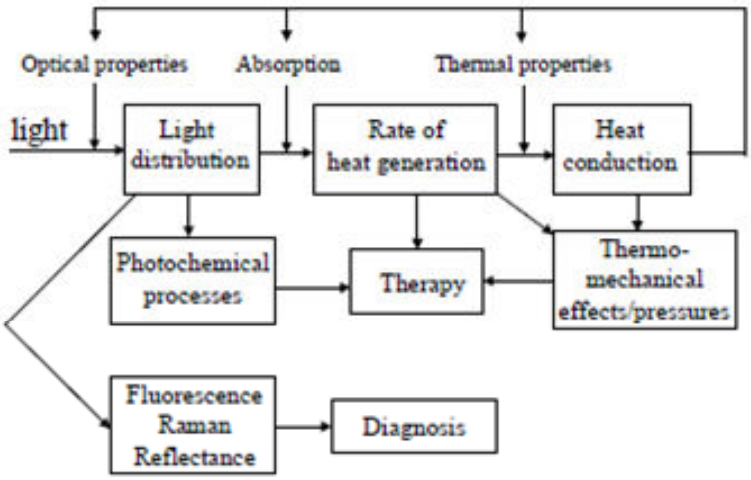

Figure 1. Flow chart describing relationships between optical properties and therapeutic, diagnostic, and sensing applications.[1]

spectroscopy and diagnosis have not been covered in enough detail. Many of these undergraduate students have either already been exposed in general to such applications or have the greatest interest in them. Due to time-constraints usually caused by spending time on other topics in the class, spectroscopy and diagnosis are usually not covered in as much detail as both the instructors and the students would like. A clear didactic problem was thus identified: While students may no longer be struggling with the fundamental concepts of light and light transport, there are several fundamental concepts that are not covered in as much detail as necessary for students to come away with a strong understanding of spectroscopy and its use in diagnostic technologies.

To solve this problem, it became apparent that more time needed to be spent on diagnostic applications. However, the main problem was the lack of time in the class – adding more lectures would only make the problem worse. Furthermore, merely listing diagnostic techniques will not improve the students' learning experience. Instead, they needed a structured set of learning activities that would combine in-class lectures about fluorescence, Raman, and reflectance spectroscopy with their role in diagnostic applications.

The Legacy Cycle (LC) framework (Figure 2) incorporates findings from educational research on how people learn and includes six stages: Challenge, Generate Ideas, Multiple Perspectives, Research and Revise, Test Your Mettle, and Go Public![2] LCs are templates for challenge-based instruction that can keep lecture notes and assignments that were already developed.[3] Challenge-based teaching provides an active learning environment that naturally focuses on the learner's acquisition of new knowledge.[4] From this study, we concluded that introducing a Legacy Cycle into the class for spectroscopy and diagnosis allowed us to cover the same material, but added an overall challenge to guide and motivate six 50-minute class sessions, used the discussion board to elicit students' opinions and ideas, and created an assessment using study guides for a spectroscopic application for diagnosing skin cancer.

Implementation

Creating challenge-based learning tools for engineering classes requires expertise from multiple fields, such as engineering, learning science, learning technology, and assessment.[3] In order to tackle this course, we brought together the instructor (AMJ) with her graduate student (EV) who is a part of the Center for the Integration of Research, Teaching, and Learning (CIRTL) Teaching as Research Project with Vanderbilt University's Center for Teaching. Using the vast resources from these different programs, as well as classes and workshops offered by experts in each of these fields, we had a forum to iteratively refine the components of the module to identify the core learning objectives for the challenge and provide a LC framework for one class of 18 undergraduate students (15 seniors, 3 juniors, all biomedical engineering majors) in the fall semester of 2009. This course has been taught in 5 previous semesters, all by the same instructor. This study was approved by the Institutional Review Board of Vanderbilt University.

Figure 2. Schematic of Legacy Cycle.[6]

As previously described, there are six phases of a Legacy cycles (Figure 2).[2] The first phase – Challenge – provides a question that causes students to wonder about a topic and become engaged with it. It begins to frame the module, allowing students to bring their knowledge and ideas to the table. Generate Ideas, the second phase, is an activity that teases out students' current knowledge, ideas, and preconceptions about the topic. Multiple Perspectives gives two or more outside resources that provide information related to the topic of the challenge. Phase 4, Research and Revise, is when students seek additional information in the form of lecture, readings, websites, review articles, etc. Test Your Mettle is when students try out their ideas with formative assessment, i.e. a test or exam. The sixth phase, Go Public, allows students to display their final conclusions. The following outline provides details on the different stages of the Legacy Cycle used in this class. Text that has been italicized represents notes from each section. Normal text was either on handouts given to the class or the outline of a lecture.

Challenge Question

This question was introduced on the first day of the module using visual aids and Microsoft PowerPoint. The following was handed out:

Your grandmother worships the sun. A lot! So lo and behold, one of her many moles started changing and was recently diagnosed to be a melanoma. Now, she has to keep a close watch on all her other moles and of course no more sun! Currently, the way skin cancers (indeed most cancers) are detected is to take a little snip of tissue (OUCH!) and look at it under the microscope. Only if the pathologist says it is CANCER, does the dermatologist go and take out the whole thing.

You decide that "There has got to be an easier way!!" Given you are in a biomedical optics class, you naturally realize "Hey! I can use light to look at the various moles and see if they are normal or not."

Generate Ideas

The handout with the challenge also contained these questions. Students were given 5 minutes to write down their thoughts. They were then given an opportunity to share their answers with the class. Their answers were written down in a PowerPoint slide and posted online.

What are your initial ideas? What do you know about skin and skin cancer already? What more do you need to know? What do you know about optics already? What more do you need to know?

Multiple Perspectives

The following links were posted onto the discussion board of Vanderbilt's electronic academic environment (OAK). The first was posted after the challenge was discussed. The second was posted after Topic 1 (see below) in Research and Revise.

NPR news story on biopsies in skin cancer (shows what the process is like)
http://www.npr.org/templates/story/story.php?storyId=9968857

ABC News story on new product for skin cancer diagnosis MelaFind
http://abcnews.go.com/video/playerIndex?id=8688866.

Through the discussion board and with help from the instructors, students were able to revisit their generation of ideas. Did students see the need to clearly understand what physiological factors are important when skin cancer develops?

Research and Revise

The following topics were covered during five 50-minute lectures.

Topic One: What is the background on skin and skin cancer?
Understand biochemical differences between normal moles and abnormal moles. Can light be used to see the differences between them?

Topic Two: What is fluorescence spectroscopy?
Discuss fluorescence spectroscopy. Introduce Jablonski diagram.

Topic Three: How is fluorescence measured?
Discuss instrumentation that can be used to measure fluorescence. Have students provide ideas on what types of components are needed to set up a fluorescence spectroscopy system. Bring in an actual system (briefcase system) from the lab and look at samples with fluorescence and ask for volunteers to measure their skin. Notice differences between light skin, dark skin, hairy skin, sun burnt skin, and moles, etc.

Topic Four: What is Raman spectroscopy?
Talk about history of Raman spectroscopy, story of how C.V. Raman thought of scattering and how he did his first sets of experiments with extremely limited equipment. The Jablonski diagram is revisited, with students putting up the types of light scattering that they have already learned, i.e. fluorescence, absorption, and reflectance. Raman scattering is then added to the diagram.

Topic Five: How can Raman scattering be measured?
Some repetition will be included in this topic; however, the differences between measuring fluorescence and Raman will be highlighted. A Raman system will be brought into the class and similar readings as with the fluorescence system will be done.

Eight students, about half of the class, were in the laboratory section associated with this class. They were able to use the fluorescence and Raman instrumentation through the lab. The rest of the class used the equipment in the classroom when topics three and five were discussed.

Test your Mettle

In-class activities were used to quickly get the students thinking and to serve as a refresher of the previous topic. These activities were given as handouts at the beginning of class. Students were allowed to complete the activities and were then asked to share their answer with a partner, the class, or on the board (see appendix for examples).

One homework assignment was given during the module, looking at different Raman signatures for molecules and student's ability at disseminating information from research papers. One take-home test was given at the end of the module. See appendix for more information.

Go Public

In pairs, students designed a 1-2 page study guide on a different technique than the ones described in class. Their peers used this study guide on their take-home exam. See appendix for the rubric used in grading the study guide.

Assessing Legacy Cycle

The success of adding a LC module to the class was assessed using three methods. The first was by having 3 separate graders grade the study guide and test using a standard rubric. The second method compared grades from specific questions on the test to grades from the five previous semesters of this course. These five semesters were all taught by the same instructor and the questions on the exam were the same (with only slight wording differences). The final method of assessing the challenge-based learning was through a survey given to the students upon completion of the module.

Results and Discussion

First, three people graded both the study guide and the test separately using the same rubric. Figure 3 shows that there was a very low standard deviation among the scores by the three graders (two graduate students and the instructor of the course). It also shows that very little correlation existed between how the students performed on the study-guide versus how they did on the test. The study guide was done in pairs, possibly skewing the results a bit.

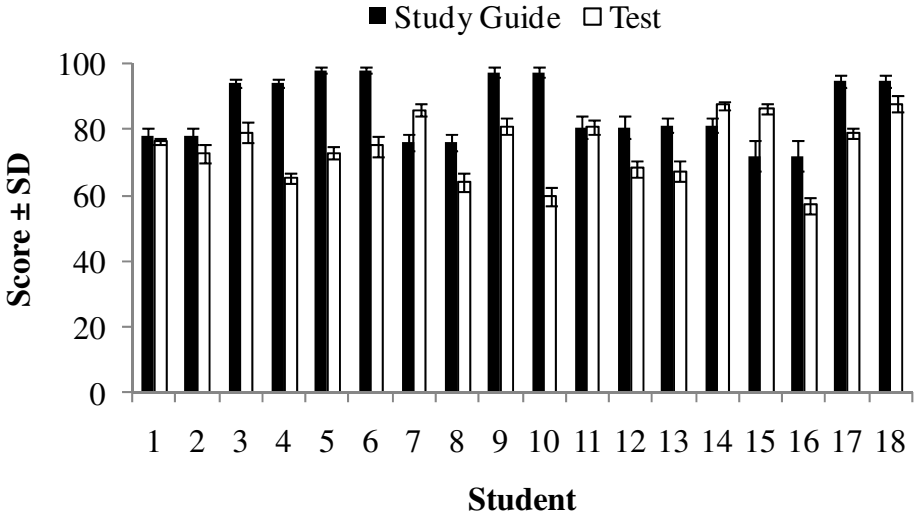

Figure 3. Scores compiled by 3 separate graders for the study guide and test 2 from the class in Fall 2009.

In order to understand what was happening in more detail, we compared 5 groups of students: the class that was exposed to the challenge-based module (n=18, Fall 2009) against a cohort of 4 classes who had the original module (n=93). Two questions were compared. The first was an abstract spectroscopy question and the second was a concrete calculation question (Beer's law, absorption, etc.). It was our hypothesis that the first question would be helped with the addition of the LC framework, especially by the creation of the study guides. We looked at both questions to account for years when teaching or the student population may have varied significantly.

Figure 4 shows that there was a slight increase in the scores on the spectroscopy question in Fall 2009. However, it is hard to tell what is occurring, since the scores vary so much from year to year. For this reason, we "normalized" the scores by dividing the score from the spectroscopy question by the score from the calculation question (Table 1). If, for example, class A did poorly on both questions (i.e. 10 on both, out of 25) and class B did well on both (20), we may unfairly say that class B was the better class and the teaching practices implemented within that class were more desirable and well suited to the students. By normalizing, we would see that class A and B were equal (1) and no conclusions about who had the better teaching practices could be made. Table 1 shows the results after normalizing. Compared to the earlier courses, with normalizing, the LC framework may have improved the scores slightly. However, the data graphed in both Figure 4 and Table 1 were not statistically significant.

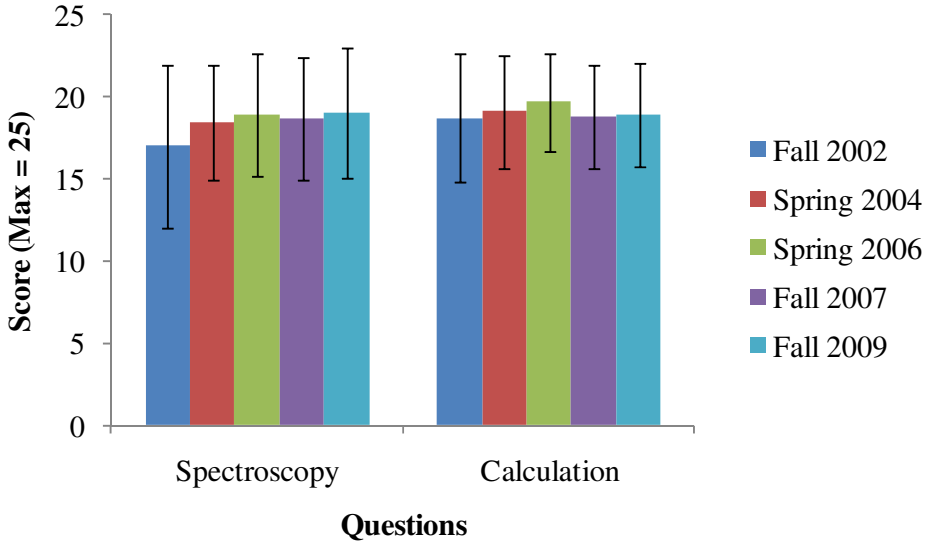

Figure 4. Comparing test questions from 5 different classes showed variations among them, but the scores from Fall 2009 were among the highest across the groups. However, there is no statistical significance in the results among the 5 groups.

Year	Normalized Value (Spectroscopy/Calculation)
Fall 2002	0.91
Spring 2004	0.96
Spring 2006	0.96
Fall 2007	0.99
Fall 2009	1.01

Table 1. Normalizing scores of test questions to see real effect of adding LC framework. There was no statistical significance among the 5 groups.

An online survey (through OAK) was administered to the students around 2 weeks after the module and assignments were completed (Figure 5). Most of the students enjoyed the module and thought it was helpful. All 18 students responded (after a few reminder emails). In order to

see what student group consisted of, we also asked what the student planned on doing after graduation (Figure 6). Half of the students will be applying to or are interested in medical school, which is consistent with the Biomedical Engineering department at Vanderbilt as a whole.

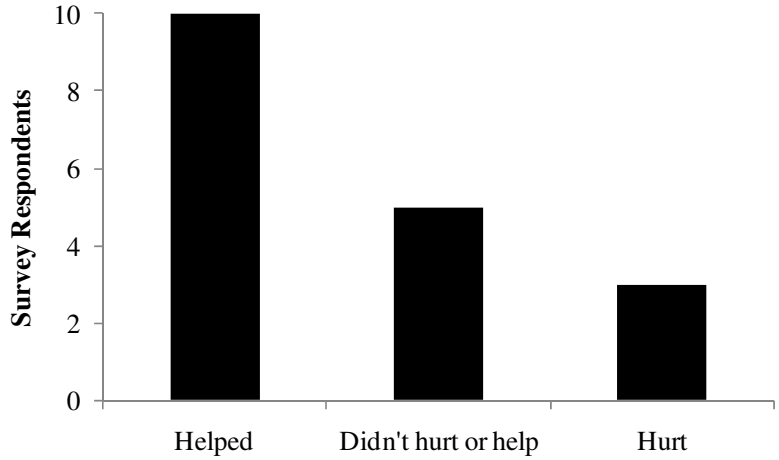

Figure 5. Feedback from students regarding challenge-based module.

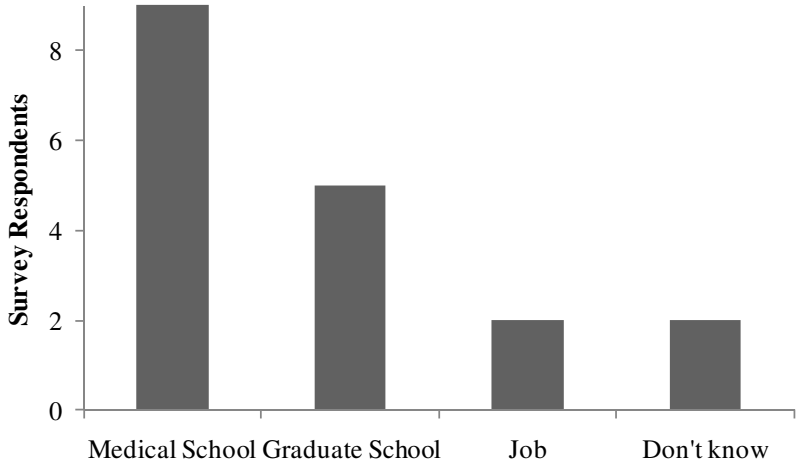

Figure 6. Students' plans after graduation.

Conclusions

This paper describes how challenge-based learning can add to students' experiences in classes. Principles for designing effective learning environments have helped us to constantly reflect on the content needed to be presented and change things as needed.[3] This process also helped the instructors and students identify various methods for assessing progress during the module, from the short in-class activities to the study-guide assignment.

From our results, it seemed like shifting to a challenge-based module allowed us to solve the problem found in earlier iterations of this class – we were able to introduce the idea of using spectroscopy techniques for diagnostic applications without taking any more time. In fact, we ended up with about 30 extra minutes of lecture. Having students learn under the context of the challenge question allowed us to tackle the problem of using spectroscopy for diagnostic applications. While we specifically made the challenge question about skin cancer – a topic we felt many students could relate to – this module could be easily adapted to focus on any other type of diagnostic application.

The discussion board was an efficient outlet for students to work as a team to tackle problems. From the entries, it was clear that students were tackling the challenge together, simulating the many collaborative efforts that are made in the real-world as engineers.[5, 7] Many entries on the discussion board began with "I agree with [student's name]" or "[Student] has a good point," for example. Out of the 18 students in the class, 10 took advantage of the discussion board.

We also found that in introducing the LC framework, we continue to fulfill ABET criteria, such as Criteria a) an ability to apply knowledge of mathematics, science, and engineering, e) an ability to identify, formulate, and solve engineering problems, and g) an ability to communicate effectively.[8]

In the future, we would like to set up two sections of this class to have a full analysis of the benefit of this challenge-based module. In doing so, we could have a complete comparison directly between the two classes.

This paper represents an attempt to introduce another challenge-based learning module into engineering education. We found that by merely motivating the students with the challenge, we were able to cover two topics in their entirety, which usually did not happen in the class over 4 other semesters. At this point, we would like to work on the different parts of the LC framework in order to refine the process. Some of the feedback from the students stated wanting the challenge to be presented on the very first day of class. Others wanted more than the 2 weeks we gave them to really understand the problem and answer it to the best of their abilities.

Overall, adding the Legacy Cycle facilitated more discussion and activities from the students. The students were more motivated to complete the assignments, thinking of the big picture of applying optics and photonics engineering to medical problems. Adding this module actually ended up providing more time than what was originally planned, most likely because we had a very structured method of going over these topics. Future implementations will also include an overarching LC, implemented from the beginning of class. Even institutions that do not have optics programs or access to optical equipment can modify this LC module for their classes and utilize equipment like fluorescence microscopes to explain the process.

The field of biomedical engineering is constantly growing. For students to understand the many biomedical engineering concepts, they take classes on fundamental basic science, like biology, chemistry, physiology, physics, calculus, etc. It can be easy for them to lose track of the purpose of this field – to use these concept and techniques to positively affect human health. By the time these students become juniors and seniors, we must remind them of this ultimate goal.

Incorporating real-world examples and having students tackle more abstract problems on their own is one way to do so.

1. E. Jansen, A. Mahadevan-Jansen, W. Lin, S. Brophy and M. Mackanos. *Development and Implementation of an Interactive Instructional Module of Light Distribution in Tissue*. 2001.
2. J. Bransford, National Research Council (U.S.). Committee on Developments in the Science of Learning. and National Research Council (U.S.). Committee on Learning Research and Educational Practice., *How people learn : brain, mind, experience, and school*. Expanded ed. 2000, Washington, D.C.: National Academy Press. x, 374 p.
3. T. Giorgio and S. Brophy. *Challenge-based learning in biomedical engineering: A legacy cycle for biotechnology*. 2001.
4. R. Roselli and S. Brophy, *Effectiveness of challenge-based instruction in biomechanics.* Journal of engineering education, 2006. **95**(4): p. 311-324.
5. P. Gibbings and L. Brodie, *Assessment strategy for an engineering problem-solving course.* International Journal of Engineering Education, 2008. **24**(1 (Part II)): p. 153-161.
6. *What is a Legacy Cycle?* January 6, 2010; Available from: http://water.j3web.net/legacy.asp.
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Appendix.

Samples of Student Assignments and Tests

Student Assignment B: Fluorophores

Select 3 natural biological fluorophores

1. Find their chemical structure
2. Excitation maxima
3. Emission/Fluorescence Maxima
4. Function

Student Assignment C: Fluorescence Spectroscopy

1. What is an Emission Spectrum?

2. What is an Excitation Spectrum?

3. What is an EEM?

4. A fluorescence excitation emission matrix of a dilute solution is given below where the excitation runs from 200 to 350 nm in 50 nm steps and the emission wavelengths run from 400 to 550 nm in 50 nm steps.

2	5	4	2
5	11	13	10
4	10	8	3
2	5	4	1

How many fluorophores are present in this solution?

Student Assignment D: Raman Spectroscopy I

1. What is 337 nm in wavenumbers (cm^{-1})?

2. If λ_{ex} = 337 nm and the Raman shift is 1645 cm^{-1}, what is the

λ_{em} ?

Is this shift Stokes or anti-Stokes Raman?

Student Assignment H: Go Public Study Guide Rubric

Score	Formatting 10%	How it works 30%	Instrumentation 25%	Applications 25%	References 10%
3	Contains plenty of details in all 3 sections All sections can be easily understood Contains formatting for a study guide – short phrases, attention to key terms, diagrams	Clearly defines how technique works Adds some theory and/or history behind the technique Written in a manner that can be easily understood Defines key terms, acronyms, anything necessary to understand technology Advantages and disadvantages are listed	Clearly states how instrumentation is used, including anything specific to this technique Includes a diagram or an extremely clear description of what a typical system would look like and what it would include	Lists and describes at least two different applications of this technique Details relevance of technology in specific application – is this technology actually useful for this application? Contains details from various references so that alternatives can be understood	Includes a range of references that are applicable to all parts of the of study guide, particularly the application part Section should be formatted properly, so that any reader can easily look up the references
2	Contains details in most of the 3 sections Some details are lacking or hard to understand	Some background on how technique works Little to no theory and/or history behind the technique Written in a manner that can be understood Few definitions of key terms, acronyms, anything necessary to understand technology Some advantages and disadvantages	States how instrumentation is used, but is not clear Does not state if anything is different, specific to this technique Description what a typical system would look like and what it would include is vague	Lists and describes one to two different applications of this technique Does not include information on if this technology is actually useful for this application Contains details from few references, making it hard to understand alternatives	References are applicable, but not to all parts of the study guide Section should be formatted properly, so that any reader can easily look up the references, but may include small errors
1 (20-40)	Sections are missing Lack of details within sections	Has multiple errors in explaining technique Explanation is inaccurate and does not engage reader Poorly worded and confusing Contains no definitions, key terms, etc.	Very few details on instrumentation No diagrams or clear explanations of instrumentation setup	Only lists one application, without a description Contains few, if any, descriptions of how the application work Contains no criticism of technique	Few to no references Formatting of references is incorrect, with a lot of missing information

BME 285 – Introduction to Biomedical Optics
Assignment 10 – due December 7, 2009

1) (a) Prepare a table that characterizes 5 biological chromophores that absorb in the UV-VIS. Include name of chromophore, its molecular structure, its primary biological function and the wavelength(s) of its major absorption peaks.

   (b) Prepare a table that characterizes 5 biological fluorophores that emit in the UV-VIS. Include name of fluorophore, its molecular structure, its primary biological function and the wavelength(s) of its excitation-emission maxima in the form (λ_{exc}, λ_{em}).

   (c) Prepare a table that characterizes the Raman bands of 5 known biological compounds (in pure form, not in tissue). You can find these in the literature or from Atlases of Raman spectra that can be found in the Science library. If it is easier, include the Raman spectrum for each and highlight the bands in your figure.

NOTE: Please do not include in your 5 (in questions 1-3) any of those presented in class.

2) You were given several handouts, covering the techniques of diffuse reflectance, OCT, Fluorescence and Raman scattering. From reading these, Create a table that contains the following: Definition of each technique, typical instrumentation and list of advantages and disadvantages of each technique (what it is good for and not).

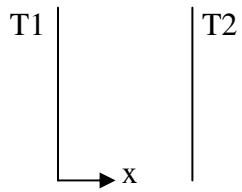
3) Find the thermal conductivity and diffusivity of:
   a) water
   b) silica (glass)
   c) tissue (any tissue will do – see what you can find)

4) Assume a tissue temperature of 80 ^{o}C (after laser radiation) and an environmental temperature of 21 ^{o}C. The emissivity of the tissue surface, $\varepsilon = 0.93$. Compute the radiative heatflux and determine whether or not it is important compared to the convective heat flux. Assume the tissue is dry skin and has a convection heat transfer coefficient, h = 8.36 W/m^2 ^{o}C.

5) Consider steady state conditions for one-dimensional conduction in a plane wall having a thermal conductivity, k = 50 W/m K and a thickness, L = 0.25m, with no internal heat generation.

   Determine the heat flux, and the unknown quantity for each case and sketch the temperature distribution, indicating the direction of the heat flux.

Case	T_1 (^{o}C)	T_2(^{o}C)	dT/dx (K/m)
1	50	-20	
2	-30	-10	
3	70		160
4		40	-80
5		30	200



6) Read the paper: "Pathologic analysis of photothermal and photomechanical effects of laser-tissue interactions" by Dr. Sharon L. Thomsen and write a short summary of this paper (1/2 to one page).

Sample Take-Home Test Questions

1) My best friend's father has an artificial aortic valve. He has his blood drawn and checked every two weeks to ascertain the "clotting capability" of his blood. This then helps his cardiologist determine how much anti-coagulants he needs to take. In essence, the labs use an indirect method (by measuring the rate of coagulation/clotting in the blood sample) to estimate the level of prothrombin in his blood. He is currently a participant in a clinical trial, testing the use of a self-administered device (similar to that used by diabetes patients) by which the patient draws a drop of blood and performs the same lab test on this blood sample in a miniaturized setup.

   When I saw this last Christmas, it seemed to me that we should be able to come up with an *in vivo* optical method to measure the level of prothrombin in a patient's blood.

   Design an *in vivo* optical diagnostic device that can transdermally measure the amount of prothrombin (and hence the "clotting capability") in a patient's blood.

   (a) What optical technique will you use? Why?

   (b) Draw a schematic of a clinical system for this technique. Explain the function of each component. Explain the design of your fiber optic probe if any.

   (c) What wavelength will you use for your source? Why?

   (d) In order to obtain quantitative concentration values, you will need to correct the spectra to obtain absolute intensities. How would you correct your spectra for this purpose? How would you calibrate your system so that the acquired spectra could be readily compared with that acquired from any other system?

2) Assume a pulsed dye laser with 20ms pulses and a spot size of 500 microns is used to treat a Port Wine Stain. Consider the skin with PWS to be a three-layered sample (top to bottom) that has the following absorption and thickness.

Top	Absorption	Thickness
Layer 1 – Epidermis	12%	200 microns
Layer 2 – Melanin	52%	50 microns
Layer 3 – Blood	31%	150 microns

The remaining light ends up in the subdermal layers. Assume a resting temperature of 37ºC, an index of refraction of air as 1 and that of the three layers to be 1.42. Further assume that no thermal losses occur due to conduction/convection/radiation etc.

a) Calculate the absorption coefficient of each layer.

b) Plot the fluence as a function of depth for the first 400 microns.

c) Plot the heat source as a function of depth for the first 400 microns.

d) Calculate the power of the laser needed to achieve a maximum temperature of 69ºC at the vascular layer.