A Problem-based Approach to Teaching Cell and Molecular Biology to Engineers

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Teaching the biological sciences to engineers presents special problems. These include stylistic differences in teaching biology versus engineering, diverse educational backgrounds, and a comparative lack of quantitative theories and expressions in molecular biology. Transitioning students from a problem-based style of education to a knowledge-based style can prove particularly difficult in terms of student learning, engagement and testing. Indeed, one must ask whether teaching biology as biologists do is the most effective way to convey the material, or if it is more effective to adapt the teaching style and biological content to engineers?

To answer this question, one must first consider the educational background of the students one is trying to teach. Diversity in backgrounds is a problem common to all biomedical engineering (BME) programs, as the discipline tends to draw students from across the entire range of engineering and medical sciences. With respect to cell and molecular biology, some students have had extensive biology training while others have had none. For example, in order to provide some uniformity in backgrounds, BME minors at the University of Virginia are expected to have had either our introductory biology course (BIO 201) or high school advanced placement biology as a prerequisite to our physiology and cell biology courses. Indeed, the text used by the Department of Biology (Campbell et al.[1]) includes a relatively large amount of cell biology. However, many of out students have much more extensive familiarity with biology, including laboratory experience. Thus many students find the "basics" (material suitable regardless of the student's background) to be too basic. At the same time, other students enter the course strictly with the background provided by introductory biology, and need this background information.

One must also consider what is meant by teaching in a "style" familiar and engaging to engineering students. This is often equated with presenting the material within the context of mathematics. However, possibly more familiar and engaging to engineers is "problem solving," and not the mathematics *per se*.

The problem then becomes, how does one teach cell and molecular biology to engineering students in a manner that:

a) presents sufficient introductory material for all students with the proper prerequisites,
b) allows in-depth study of specific topics to hold the interest of more advanced students,
c) engages engineering students with a "problem oriented" approach, and
d) provides students with information of specific value to biomedical engineers.

We present an outline for a course in Cell and Molecular Biology for Engineers in which human pathologies are used as a clinical, problem-based context for teaching basic biological mechanisms. To further emphasize the interface between engineering and the biomedical sciences, students write “review articles” covering the application of engineering to a particular problem in cell biology and engage in the process of peer review. A representative curriculum is provided which is currently in use at the University of Virginia.

I. Choice and use of textbook

The course is divided topically into four broad basic science classifications (denoted by thick lines in the table, section V): (1) overview, (2) molecular biology, (3) cell biology, and (4) cell interactions. This follows the general organization of the textbook for the course, *Molecular Cell Biology* by Lodish et al.[2], as does the basic science content of the individual lectures.

Following a prepared text is necessary to ensure an even-handed approach to the basic science topics, even when they do not fit neatly within a small number of disease themes. We are aware of no appropriate textbooks that are organized according to diseases or biotechnology applications. Regardless, *Molecular Cell Biology* was chosen for its “Medical and Biotechnology” highlights and excellent multimedia support. Further, the publisher-maintained web site provides excellent opportunities for advanced study in graduate course sections.

II. Daily lecture structure

For each lecture, we follow a four-part lesson plan. (1) The disease is presented from clinical, economic and pathophysiological standpoints to identify the problem and the engineering need. (2) Fundamental concepts in cell biology are presented that are relevant to that disease process. (3) The cellular and molecular basis of the disease is discussed based upon these fundamental concepts. (4) Cutting-edge clinical approaches to the disease are described, and followed (where appropriate) by with brainstorming alternative bioengineering solutions.

In short, the disease serves as a problem within which a knowledge-based learning style can be enveloped and expanded. For example, during the course introductory lecture on "Membranes and Cell Structure" (see table, section V) we use asthma as an example disease process. We begin by placing the disease within its clinical and social contexts.

Asthma

Definition: Reversible airways obstruction not due to any other disease.
Symptoms: Coughing, wheezing and shortness of breath. Chest pain, etc.
Incidence and social impact: The seventh-ranking chronic condition in America.
Etiology: Uncertain.

This is a "hook" to immediately engage students - a real-world problem with economic consequences. The instructor next turns to the underlying cell biology. The choice of which topics

to teach under any given disease heading is a difficult decision, and sometimes rather arbitrary, but an example is:

- Review of Cell Structure
  - Limits on cell size and shape
  - Membrane Compartmentalization
    - Membranes
      - Structure & function
      - Lipids
      - Fluidity
    - Membrane-compartments of the cell
  - Free organelles
  - Morphology of white blood cells

Once the underlying basic science has been covered, the instructor returns to the disease process. In this instance, asthma is related to membranes and free organelles through the structure and function of mast cells and eosinophils.

- Asthma
  - Antigens attach to antibodies in the lung and bronchi
  - These are recognized by mast cells (basophil descendents)
    - Mast cells release leukotrienes
    - Leukotrienes are derived from cell membrane arachidonic acid.
  - Leukotrienes promote:
    - Eosinophil homing
    - Increased vascular permeability
    - Bronchiole constriction
    - Mucus secretion by respiratory epithelial cells
  - Eosinophil structure and function
    - Morphology
    - Eosinophil transmigration
    - Cytotoxin release

Finally, the instructor presents the current accepted clinical approach to the disease, and the class brainstorms alternative approaches.

- Treatment
  - Bronchiole dilators
  - Anti-inflammatory - reduce granule release
  - New: Lipoxygenase inhibitors

III. Writing review articles

Teaching students to write effectively has been a major concern of educators for many years. It is possible that students do not recognize a practical need for technical writing skills, particularly in engineering and the applied sciences. Yet it has been estimated that a typical engineer spend as much as one-third of each day writing[3]. To improve students' written communications skills and to reinforce specific areas in cell biology, students in this course prepare a "review article" as described in the guidelines for the *Annals of Biomedical Engineering*, and then engage in the peer review process.

Pairs of students select a subject that fits the topical requirements of the course, and submit this as a "letter of inquiry" to the instructor, who serves as "Editor." If the topic is acceptable, the students begin research and writing. The first draft of the paper is due mid semester. This version of their paper, however, was not graded.

One copy of this draft is read by the instructor, and two more are given to other students in the class, chosen according to similarity in the topics of their papers. The identity of the reviewers is strictly confidential. Within two weeks students return their critiques, which are given to the authors along with a summary from the instructor. Given the comments of their peers and the instructor, students write a final draft that *is* graded. Students are also graded on the quality of reviews they wrote, but not on the reviews their papers receive.

Use of this approach has many benefits for both the instructor and the student when compared to traditional "term paper" approaches.

(1) Students learn the process of writing for scientific and technical publishing.
(2) Students learn the value of peer review.
(3) Students learn to write in a style and according to guidelines with practical relevance.
(4) By requiring the format of a scientific journal, students are given much clearer information about the purpose and expectations of a paper[4].

Details of this approach, together with grading expectations, are being published elsewhere[5], and are available on the course web site[6].

IV. Pitfalls and limitations

Three specific problems arise using these techniques for teaching cell and molecular biology to engineering undergraduates. As pointed out earlier, there are no textbooks on cell or molecular biology that are organized according to disease processes. One must "force-fit" specific topics into assorted diseases as best possible. Clearly, a text could eventually be developed that presents the whole of cell and molecular biology within the contexts two or three broad disease classifications (e.g. immunology, cardiovascular disease, and cancer).

Second, presenting background on human diseases takes valuable lecture time, and restricts the

amount of basic science information that can be fit into any given lecture. The instructor must hone the lecture to encompass only the most important topics, and restrict remedial material to the most relevant. Once again, a textbook written within only a few disease contexts would limit the number of occasions new diseases must be introduced, and recoup much of this cost.

Finally, teaching a class in this manner represents a significant workload. The instructor must develop a superficial knowledge of each disease that is presented. Further, the review articles take large amounts of instructor time at mid semester, when the first drafts and reviews must all be read and summarized.

V. Table of possible course topics

The following table shows a possible ordering of lecture topics, including the relevant chapters in Lodish et al.[2], disease themes and relative due dates for review article sections. Breaks and exams have been omitted. Thick lines indicate general topical breaks.

Topic	**Chapter**	**System / Disease**	**Paper**
Introduction			
Membranes and cell structure	5	Asthma	
Protein structure & methods	3	Transplant rejection & autoimmune disease	
The central dogma	4		Letter
Recombinant DNA and genomics	7	Diversity in immunity	
Genes and chromosomes	9	Immunity: antibody diversity	
Regulation of transcription	10	Diabetes	
RNA processing	11		
Replication	12	Bladder infections & antibiotics	
Cell cycle regulation	13	DNA damage and malignancy	
Protein sorting and endocytosis	17	Atherosclerosis	First draft
Extracellular matrix	22	Inflammation	
Membrane transport	15	Cystic fibrosis	
Excitability and nerve cells	21	Duchainne-Barr syndrome	
Microfilaments and contraction	18	Hypertrophic cardiomyopathy	Reviews
Microtubules and IFs	19	Kartagener syndrome	
G proteins and second messengers	20	Cholera	
Cancer	24	Cancer	Final draft

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