Essay

“Shrink Wrapping” Lectures: Teaching Cell and Molecular Biology within the Context of Human Pathologies

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Students are most motivated and learn best when they are immersed in an environment that causes them to realize why they should learn. Perhaps nowhere is this truer than when teaching the biological sciences to engineers. Transitioning from a traditionally mathematics-based to a traditionally knowledge-based pedagogical style can challenge student learning and engagement. To address this, human pathologies were used as a problem-based context for teaching knowledge-based cell biological mechanisms. Lectures were divided into four modules. First, a disease was presented from clinical, economic, and etiological standpoints. Second, fundamental concepts of cell and molecular biology were taught that were directly relevant to that disease. Finally, we discussed the cellular and molecular basis of the disease based on these fundamental concepts, together with current clinical approaches to the disease. The basic science is thus presented within a “shrink wrap” of disease application. Evaluation of this contextual technique suggests that it is very useful in improving undergraduate student focus and motivation, and offers many advantages to the instructor as well.

Keywords: undergraduate, modular, contextualization, pathology, problem-based, knowledge-based, pedagogy

INTRODUCTION

Among the fundamental assumptions about learning is that students are most motivated and learn best when they are immersed in an environment that causes them to realize *why* they should learn (Fischer and Scharff, 1998; Webb and Romberg, 1992). That is, concepts and knowledge are best introduced when students see their application and their relationship to other concepts (Bransford *et al.*, 1999).

Perhaps nowhere is this assumption better highlighted than when teaching physiology and molecular biology to engineers—an endeavor that is growing more common as biomedical engineering programs flourish. Students transitioning from engineering to biology courses face many challenges, including diverse educational backgrounds, and a comparative lack of quantitative theories and mathematical expressions in molecular biology.

One must also consider what is meant by teaching in a “style” familiar and engaging to engineering students. Aside

from quantitative measures of learning styles, this is often equated with presenting the material within the context of mathematics. However, more familiar and engaging to engineers is application of knowledge to solving real-world problems and not mathematics per se. Thus, seeing the application of the material, as described above, is of critical importance in engineering education. This is supported by an Index of Learning Styles study of biomedical engineering undergraduates that showed them to be both sensory and global learners (Dee *et al.*, 2002). Each of these measures may be interpreted as learning best within a broader context of application.

To this end, we present a knowledge-centered curriculum for teaching cell and molecular biology to engineering undergraduates in a traditional lecture setting, with the goal of motivating learning, and providing an application-oriented bridge to learning. To accomplish this, human pathologies were used as a problem-based context for teaching basic biological mechanisms. The curriculum was very successful in improving student focus and motivation through contextualized and highly modularized lectures. A proposal to teach in this manner has been published elsewhere (Guilford, 2001).

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METHODS

First Implementation

This method was first implemented in the course Cell and Molecular Biology for Engineers (BIOM 304), at the University of Virginia. This is a core course for majors and minors in biomedical engineering. The initial class consisted of 42 second- and third-year students in chemical engineering, systems engineering, and engineering science. All data presented are from this first implementation, although the method has been used in three successive course offerings.

The majority of students enrolled in the course were majoring in chemical engineering, with a biomedical engineering minor. Other students came from the engineering science and systems engineering programs. Approximately one-third of students taking this course go on to graduate study, one-third go to medical school, and the balance enter industry. The only prerequisite to the course is introductory, college-level chemistry. Introductory biology is not a requirement, although many students hold advanced placement biology credit.

Choice and Use of Textbook

The course was divided topically into four broad basic science classifications: 1) overview, 2) molecular biology, 3) cell biology, and 4) cell interactions. This followed the general organization of the textbook used for the course, *Molecular Cell Biology* (Lodish *et al.*, 1999), as did the basic science content of the individual lectures. The text *The World of the Cell* (Becker *et al.*, 2002) was used in previous years, and in the years subsequent to this study.

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 textbooks currently published that are organized according to diseases or biotechnology applications.

Modular Lecture Structure

Each lecture or lecture series was conducted in a modular format:

1. Introduce the disease
2. Teach the relevant concepts in cell biology
3. Present the molecular etiology of the disease
4. Discuss the current clinical approaches to the disease.

The bulk of the lecture time was devoted to basic biological science (step 2 above). However, this was prefaced with approximately 10 min of information about a disease or application. This introductory module included the definition of the disease, its symptoms, prognosis, and socio-economic impact. Students were often asked whether they knew someone with the disease, and were willing to offer some personal perspective.

Once the basic science underlying the disease had been taught, the cellular and molecular etiology of the disease was presented, together with how the defect ultimately leads to the disease state. A final, brief module discussed the current clinical approaches to the disease, and often included time for brainstorming student-generated solutions. This most often began with the question, "Knowing what you know now about the etiology of the disease and the underlying cell biology, what approach might you take to treating it?" This gave students a chance to reflect on what they had learned, and served a further role as formative assessment. They often converged (much to their delight) on the current best-practice approaches to treating the disease.

Figure 1. Graphical outline of the course content, divided into major topical sections. The diseases, disease-related processes, or applications are shown above their associated basic science content.

An example lecture outline (spanning two 75-min lectures) is shown below for cotranslational import of proteins and protein trafficking, which are presented within the context of atherosclerosis and familial hypercholesterolemia. A graphical outline of the entire course (for the year assessed in this article) is given in Figure 1, categorized by major topical area.

Example Lecture Outline

Introduction

1. Definition of atherosclerosis
2. Social and economic impacts
3. Disease progression
4. Symptoms and prognosis
5. Etiology (defects in low-density lipoprotein [LDL] receptor function or expression)

Relevant Concepts

1. Protein import
2. Cotranslational import
3. Insertion of membrane proteins
4. Protein sorting
5. Endocytosis
6. Endosomes and lysosomes
7. Trafficking

Relationship to Disease

1. LDL receptors
2. Systemic lipid transport
3. LDL clearance
4. Cholesterol synthesis feedback
5. Familial hypercholesterolemia
 - a. LDL receptor defects
 - b. Impact on cholesterol synthesis

Treatments

1. Brainstorming
2. Current approaches
 - a. Cholesterol synthesis inhibitors
 - b. Liver transplant

Assessment

Student opinions of the technique were assessed on the last day of class by anonymous questionnaire. The text of questions and their results appear in Tables 1 and 2. Institutional review board approval was not required. Mean, standard error, and population correlation were calculated using Microsoft Excel.

RESULTS

The most notable difference in outcome was remarkably increased student participation and attention (personal observation). Overall student reaction to this pedagogical approach was gauged at the end of the course by numerical scoring of three statements. In each, a value of 1 was equivalent to “very negative,” whereas 10 was equivalent to

Table 1. Student ranking of the contextual teaching method^a

Statement/question	Score
“Score your overall opinion of having each lecture presented within the context of a particular disease.”	8.4 ± 0.2
“Compare the lectures using diseases to those that did not use diseases.”	7.9 ± 0.3
“Would you like to see other biology/physiology courses taught within the contexts of diseases, as we did here?”	8.1 ± 0.4

^aEach question was scored by students on a 10-point scale, with 1 being the lowest and 10 being the highest rating. Scores are given as the mean ± s.e.m.

“very positive.” The questions and results are given in Table 1. Students expressed a clear preference for the contextual teaching method over traditional pedagogy, as evidenced by their high ranking of lectures using disease “shrink wrap” over those that did not (recombinant DNA techniques) as an internal control.

Interest and Perceived Benefit

Students were asked to score their personal interest in the diseases covered in class. They were also asked to score the degree to which they felt the disease benefited them in learning the underlying science, and the lecture as a whole to understanding disease processes. The results are given in Table 2. Students have clearly varying levels of interest for the disease process covered in class, with the most “popular” diseases being the most common (e.g., cancer).

There was no significant correlation between personal interest in a disease and the degree to which students believed it helped them learn the underlying science ($r = .43$). In contrast, the perceived benefit in learning a disease process was strongly correlated ($r = .94$) to the perceived benefit of learning the underlying basic science (Table 2).

DISCUSSION

Students expressed a strong preference for lectures that taught basic science knowledge within the context of human disease. Further, students perceived a benefit of this contextual method to their learning that was separate from the personal interests in the diseases covered. These data suggest that the method is successful from a motivational standpoint, and represents a pedagogical approach to the goal of demonstrating the applicability of knowledge (Bransford *et al.*, 1999). Indeed, the difference in student motivation was palpable. Wrapping the factual information inherent to cell biology within the specific context of an application may also appeal specifically to “active” and “global” learners, as assessed by the Meyers-Briggs Type Indicator (Felder and Siverman, 1998). Assessing whether or not this is the case will be the subject of future study.

This approach is similar to the “truncated problem-based learning” approach developed by M.R. Walters for medical school settings (Walters, 1999). Walters used patient case studies to preface and follow traditional physiology lectures in endocrinology, and found improvements in student

Table 2. Student perceptions of the contextualized lecture approach, sorted by disease and basic science topic

Disease topic	Biology topic	Helped understand biology ^a	Helped understand disease ^b	Personal interest ^c
Asthma	Cell morphology	7.3 ± 0.4	8.0 ± 0.3	7.4 ± 0.3
Arthritis	Immune cell biology	7.8 ± 0.4	8.3 ± 0.3	8.0 ± 0.3
Diabetes	Transcription	7.2 ± 0.4	7.7 ± 0.3	7.8 ± 0.3
Bladder infections	Replication	6.7 ± 0.4	7.3 ± 0.3	5.5 ± 0.4
Down syndrome	Cell cycle regulation	7.5 ± 0.4	8.4 ± 0.3	6.4 ± 0.4
Atherosclerosis	Protein sorting	7.0 ± 0.3	7.7 ± 0.4	7.9 ± 0.3
Cystic fibrosis	Membrane transport	7.1 ± 0.3	7.9 ± 0.3	6.4 ± 0.3
Multiple sclerosis	Excitability	7.5 ± 0.3	8.1 ± 0.3	6.5 ± 0.3
Listeriosis	Cytoskeleton	6.8 ± 0.4	7.2 ± 0.4	6.0 ± 0.4
Familial hypertrophic cardiomyopathy	Contractility	6.4 ± 0.4	7.4 ± 0.3	6.5 ± 0.5
Cholera	G proteins	6.2 ± 0.4	7.0 ± 0.4	5.9 ± 0.4
Cancer	Tyrosine kinases	7.0 ± 0.4	7.6 ± 0.4	8.8 ± 0.2
Overall score		7.1 ± 0.3	7.7 ± 0.3	6.9 ± 0.3

^a“Score each of the diseases we covered in terms of how well they helped you understand the underlying cell biology (1 to 10, with 1 being ‘didn’t help at all’ and 10 being ‘was critical to my understanding’).”

^b“Score each set of lectures in terms of how well they helped you understand disease processes (1 to 10, with 1 being ‘didn’t help at all’ and 10 being ‘was critical to my understanding’).”

^c“Score each of the diseases we covered in terms of your personal interest in the disease (1 to 10, with 1 being ‘couldn’t care less’ and 10 being ‘highly interested’).” All values are means ± s.e.m.

interest and active participation. These methods stand in contrast to small group, case-based learning scenarios (Hudson *et al.*, 2001) that, while very effective in promoting interest and problem-solving skills, are not practical for every class. Encapsulating traditional lectures within a real-world problem is applicable to virtually any discipline, and at virtually any educational level.

Modularity

An added advantage of this technique is that it renders individual lectures modular. A basic science topic may be encapsulated or “shrink wrapped” by any number of relevant diseases. Thus, while the bulk of the lecture may remain static, the disease context (which is normally a much smaller fraction of the lecture) may be changed as needed or desired.

For example, in the class assessed here, antibiotics and bladder infections were used as a context for teaching DNA replication. The relationship between these two is that certain powerful antibiotics, such as ciprofloxacin, interfere with bacterial DNA replication by inhibiting DNA gyrase. Following the anthrax terror attacks (September 18, 2001) the lecture was easily switched to the context of *Bacillus anthracis* as a specific bacterial threat. The switch entailed no significant change to the lecture material on replication (approximately 75% of the lecture content). In 2003, the context was expanded to include mustard gas, which interferes with replication through guanine base modifications, as the second Gulf War was central in student’s minds. Once again, the overall change in the lecture content was minimal, yet the improvement in student motivation was tangible, and students were vocally appreciative of the focus on current events. In fact, one student has related being offered a job specifically because of the bioterrorism information conveyed in class.

Modular lectures are a new thrust in biomedical engineering education (Enderle *et al.*, 2002), although evidence of the effectiveness of modular courses is largely anecdotal. Our

finding of a strong correlation between the perceived benefits of the method in learning both the disease and the basic science suggests that integration between the lecture modules is critical. Integration between the disease and the basic science content has been improved with subsequent offerings of the course. The current year’s syllabus, along with detailed lecture outlines, notes, graphics, and lecture recordings, is available online (Guilford, 2004). That said, while students are clearly more interested in some diseases than in others, our data suggest that the choice of disease is not critical to perceived benefit as long as the integration of disease process and basic science is strong.

Pitfalls and Limitations

Certain difficulties exist in implementing this method. The initial “self-education” by the faculty member on unfamiliar diseases can be time-consuming, and can lead the instructor into areas where he or she lacks expertise. This is made obvious in class and in evaluations by an inability to answer some student questions. Thus, frequent changes of disease context are not recommended, because it hinders the year-to-year improvement in the instructor’s knowledge.

A comment made by some students in their evaluations was that the method sometimes leads to “lack of flow” in the lecture. Several students noted that leaving the disease to teach the basic science, and then returning to it at the end of the day can leave an impression of disorganization. Bearing this in mind in subsequent years, the disease context is more frequently referred to during the basic science section. This has proved beneficial, even if it is only a reminder that “we will talk more about this and its relationship to the disease at the end of lecture.” No similar complaints have been recorded in subsequent years.

A final difficulty is that no textbooks teach cell and molecular biology within the context of diseases, nor do texts have a strong disease focus. Such a text is clearly possible,

and in fact has been published on physiology. The book *Best & Taylor's Physiological Basis of Medical Practice* (Brobeck, 1979) was outstanding in its use of disease processes as a mechanism for teaching human physiology to medical students, though the basic science was not fully contextualized as we described here.

Overall, the disease context not only provides interest and motivation, but it helps engineering students connect the basic science back to their major. As one student wrote, “the disease-based lecturing was a novel and interesting approach. It helped by giving real examples of biological processes. In addition, this use of real applications distinguished the class as an engineering class rather than a college biology class.”

REFERENCES

- Becker, W.M., Kleinsmith, L.J., and Hardin, J. (2002). *The World of the Cell*, New York: Benjamin Cummings.
- Bransford, J.D., Brown, A.L., and Cocking R.R., eds. (1999). *How People Learn*, Washington: National Academy Press.
- Brobeck, J.R., ed. (1979). *Best & Taylor's Physiological Basis of Medical Practice*, Baltimore: The William & Wilkins Company.
- Dee, K.C., Nauman, E.A., Livesay, G.A., and Rice, J. (2002). Research report: learning styles of biomedical engineering students. *Ann. Biomed. Eng.* 30, 1100–1106.
- Enderle, J.D., Ropella, K.M., Kelso, D.M., and Hallowell, B. (2002). Ensuring that biomedical engineers are ready for the real world. *IEEE Eng. Med. Biol. Mag.* 21, 59–66.
- Felder, R.M., and Siverman, L.K. (1998). Learning and teaching styles in engineering education. *Eng. Educ.* 78, 674–681.
- Fischer, G., and Scharff, E. (1998). Learning technologies in support of self-directed learning. *J. Interactive Media Educ.* 98, 1–32.
- Guilford, W.H. (2001). A problem-based approach to teaching cell and molecular biology to engineers. *Proceedings of the ASEE Annual Conference and Exposition*, Albuquerque, New Mexico.
- Guilford, W.H. (2004). Class Web site for BIOM 204/304, “Cell and Molecular Biology for Engineers.” <http://yakko.bme.virginia.edu/biom204> (accessed 31 January 2005).
- Hudson, J.N., Buckley, P., and McMillen, I.C. (2001). Linking cardiovascular theory to practice in an undergraduate medical curriculum. *Adv. Physiol. Educ.* 25, 193–201.
- Lodish, H.A., Berk, A., Zipursky, S.L., Matsudaira, P., Baltimore, D., and Darnell, J., eds. (1999). *Molecular Cell Biology*, New York: W.H. Freeman and Company.
- Walters, M.R. (1999). Case-stimulated learning within endocrine physiology lectures: an approach applicable to other disciplines. *Adv. Physiol. Educ.* 21, S74–S78.
- Webb, N., and Romberg, T.A. (1992). Implications of the NCTM Standards for Mathematics Assessment. In: *Mathematics Assessment and Evaluation: Imperatives for Mathematics Educators*, ed. T.A. Romberg. Albany: State University of New York Press.