Teaching within the Context of Disease

Teaching Cell and Molecular Biology within the Context of Human Disease

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Abstract: 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 problem-based to a knowledge-based classroom can challenge student learning and engagement. To address this, human pathologies were used as a problem-based context for teaching knowledge-based biological mechanisms. Lectures were divided into four modules. First, a disease was presented from clinical, economic and etiological standpoints. Second, fundamental concepts in cell biology were taught that were directly relevant to that disease. Finally, we discussed the cellular and molecular basis of the disease based upon these fundamental concepts, together with current clinical approaches to the disease. Evaluation of this contextual technique suggests that it is very useful in improving student focus and motivation, and may result in improved student achievement.

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 (7, 14). That is, concepts and knowledge are best introduced when students see their application and their relationship to other concepts (2).

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 (BME) programs flourish. 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. Other challenges include stylistic differences in teaching biology versus engineering, diverse educational backgrounds, and a comparative lack of quantitative theories and expressions in molecular biology. 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?

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, possibly more familiar and engaging to engineers is “problem solving,” 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 (ILS) study of biomedical
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engineering undergraduates that showed them to be both sensory and global learners (4). Each of these measures may be interpreted as learning best within a broader context of application and knowledge.

To this end, we present an assessment of a knowledge-centered curriculum for teaching cell and molecular biology to undergraduates. Human pathologies were used as a problem-based context for teaching basic biological mechanisms. A proposal to teach in this manner has been published elsewhere (8). The curriculum was very successful in improving student focus and motivation. However, the method was not as successful when teaching cell biology to engineering faculty. The reasons for this difference are explored, as well as the benefits of using contextualized and highly modularized lectures.

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 BME. The initial class consisted of forty-two 2nd and 3rd year students from Chemical Engineering, Systems Engineering and Engineering Science. It was also utilized in a summer short course for engineering faculty. All data presented are from these initial two implementations, though the method has now 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 to industry.

Choice and use of textbook: The course is divided topically into four broad basic science classifications: (1) overview, (2) molecular biology, (3) cell biology, and (4) cell interactions. This follows the general organization of the textbook used for the course, Molecular Cell Biology by Lodish et al. (12), as does the basic science content of the individual lectures. The text “The World of the Cell” by Becker et al. (3) was used in previous years, and in the year 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 is conducted in a “modular” format.

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

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The bulk of the lecture time is devoted to the basic biological science. However, this is prefaced with ten to twenty minutes of information about a disease or application. This introductory module includes the definition of the disease, its symptoms, prognosis, and socio-economic impact. Students are often asked if they know someone with the disease, and would be willing to offer some personal perspective.

Once the basic science underlying the disease has been taught, the cellular and molecular cause of the disease is presented, together with how the defect leads to the final effect. A final, brief module discusses the current clinical approaches to the disease, and often includes time for brainstorming student-generated solutions. An example lecture outline (spanning two 75 minute lectures) is shown below for co-translational 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
2. Social and economic impacts
3. Disease progression
4. Symptoms and prognosis
5. Etiology (defects in LDL receptor function or expression)

Relevant Concepts
1. Protein import
2. Co-translational import
3. Insertion of membrane proteins
4. Protein sorting
5. Endocytosis
6. Endosomes & 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
   c. Early, advanced atherosclerosis

Treatments
1. Brainstorming
2. Current approaches

Figure 1: Graphical outline of the course content, divided into major topical sections. The diseases, disease-related processes or applications are in bold.
Assessment: Student opinions of the technique were assessed on the last day of class by anonymous questionnaire. Questions covered both the technique as a whole, and individual lectures/diseases. Mean, standard error and population correlation were calculated by standard methods using Microsoft Excel®.

Results

Overall student reaction 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” while 10 was equivalent to “very positive.” The questions and results are given in table 1. Students expressed a clear preference for the contextual teaching method over traditional pedagogy.

Interest and Perceived Benefit: Students were also asked to score their personal interest in the various diseases covered in class. They were also asked to score the degree to which they feel it benefited them in learning the underlying science and the disease process. The results are given in figures 2 and 3. As is evident from the figure 2, students have clearly varying levels of interest for the disease process covered in class. In the year assessed, infectious diseases ranked lowest in student interest, while the more common diseases of cancer, arthritis and atherosclerosis rank highest.

There was no significant correlation between personal interest in a disease and the degree to which students felt it helped them learn the underlying science (\(\rho = 0.43\)). In contrast, the perceived benefit in learning a disease process was strongly correlated (\(\rho = 0.94\)) to the perceived benefit of learning the underlying basic science (figure 3).

The most notable difference in outcome was remarkably increased student participation and attention. Though admittedly a poor measure of improvement, there was also a trend toward improved overall exam grades (+1.8 ± 1.4 points). However, the improvement was not significant from the previous year where a traditional pedagogical approach was used.
Application to Faculty Instruction: The method was similarly applied in a short course on cell and molecular biology for engineering faculty at the University of Virginia. The short course encompassed 5 daily 4-hour lectures, and was structured essentially as the undergraduate course described above, but with less detail and fewer topics. The individual lectures were assessed similarly to those in the undergraduate course, but through online survey. The faculty learners were somewhat less enthusiastic with the technique of teaching within the context of disease than were the students (satisfaction ranking of 7.2 compared to 8.4 for the students). This assessment was also reflected in personal communications from the faculty students. In contrast to the students, there was a significant correlation (p=0.87) between personal interest in a disease and the degree to which the faculty learners felt it helped them learn the underlying science. It was not possible to do correlation analysis of perceived benefit in learning a disease process versus perceived benefit of learning the underlying basic science, as there was not a clear one-to-one correspondence between the topics in this course format.

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 (2). Indeed, the difference in student motivation was palpable. Wrapping the factual information inherent to cell biology within the broader picture of an application may also appeal to “active” and “global” learners, as assessed by the Meyers-Briggs Type Indicator (6). Assessing whether or not this is the case will be the subject of future study.

Unfortunately, the data do not support a significant improvement in summative assessment. However, no direct comparison may be made of this method with traditional lectures since this is a single-section course. Changes in class size, lecture content and exam material have annually...
made the course more challenging. Thus, the observed change in overall exam scores (+1.8 points) may be an underestimate of the improvement in student achievement.

This approach is similar to the “truncated problem-based learning” approach developed by Walters for medical school settings (13). Walters used patient case studies to preface and follow traditional physiology lectures in endocrinology, and similarly found improvements in student interest and active participation. These methods stand in contrast to small group, case-based learning scenarios (10) which, 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 makes lectures “modular.” A basic science topic may be encapsulated 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, like Cipro®, 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 war in Iraq 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 that she got a job specifically because of the bioterrorism information conveyed in class.

Modular lectures are a new thrust in biomedical engineering education (5), though 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 careful choice of disease, and integration between the lecture modules, is critical. Integration 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 (9).

**Pitfalls and Limitations:** There are certain difficulties 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/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

<table>
<thead>
<tr>
<th>Statement / question</th>
<th>mean ± s.e.m.</th>
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<tbody>
<tr>
<td>“Score your overall opinion of having each lecture presented within the context of a particular disease”</td>
<td>8.4 ± 0.2</td>
</tr>
<tr>
<td>“Compare the lectures using diseases to those that did not use diseases.”</td>
<td>7.9 ± 0.3</td>
</tr>
<tr>
<td>“Would you like to see other biology/physiology courses taught within the contexts of diseases, as we did here?”</td>
<td>8.1 ± 0.4</td>
</tr>
</tbody>
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*Table 1: Student ranking of this contextual teaching method*
context are not recommended, as 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 proven 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 made in subsequent years.

A final difficulty is that there are no textbooks that teach cell and molecular biology within the context of diseases, or even texts that 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” (1) 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.

**Comparison of Student and Faculty Learning:** Faculty learners did not respond as positively to the disease context as did undergraduates. Further, the data support the idea that faculty only found value in the technique when the disease happened to be a personal interest. These results, combined with verbal and written comments from the faculty who took the short course, suggest that learners who already have a well-established motivation or application in mind are unlikely to benefit as much from an applied context. Indeed, one of the faculty stated plainly that she wanted to learn the basic science, and didn’t care about the applications. This is perhaps a reflection of the fact that adults are able to transfer their knowledge to application in a much shorter time than can traditional students (11), or already have an application in mind.

For undergraduates the case is clearly quite different. The disease context not only provides interest and motivation, but 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.”

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**Literature Cited**


9. Guilford, W. H. 2003 Class web site for "Cell and Molecular Biology for Engineers" at the University of Virginia, BIOM 304 [Online].


