A BIOLOGY JOURNAL CLUB FOR ENGINEERING STUDENTS
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ABSTRACT

Aside from engaging students in original laboratory research, exposing them to the primary literature is perhaps the best way to help them understand what professional biologists do and why. We have incorporated a weekly "journal club" into an introductory biology course for undergraduate and graduate engineering students with no previous college-level biology experience. Here we describe our strategies for selecting the journal articles, assigning homework, and leading in-class discussions of the articles. Most importantly, we recommend (1) choosing articles that relate closely to the lecture material, address a simple question, and will be seen as exciting and important by the students; (2) giving students a study guide that explicitly relates each article to its historical context and to the rest of the course; and (3) leading discussions that allow students to express their confusion and answer each other's questions. Preliminary assessment results suggest that students benefit from and enjoy the journal club format despite the additional work involved.

INTRODUCTION

It is generally agreed that science education should include inquiry-based activities that mimic the work of professional scientists (Mulnix, 2003). One such activity is open-ended, student-directed laboratory or field research; however, the costs of providing students with the needed technical training, supervision, and equipment can be astronomical. A practical low-cost alternative is to have students read and analyze selected pieces of primary literature. The potential benefits are numerous: students learn to exploit library resources (Nussbaum, 1991); they are exposed to the details of how new scientific discoveries are made; they are stimulated to ask complex comparative and cause-and-effect questions (Brill and Yarden, 2003); they grapple with ambiguous and surprising data (Herman, 1999; Camill, 2000); they acquire a healthy skepticism regarding the claims of published studies (Alguire, 1998); they gain confidence in their ability to independently research scientific and medical issues (Alguire, 1998; Houde, 2000; Breakwell, 2003; Russell *et al.*, 2004); and the quality of their own labwork and lab report writing improves (Janick-Buckner, 1997; Herman, 1999; Kuldell, 2003).

To achieve these benefits, several barriers to student understanding need to be removed or at least kept in mind. Obviously, the technical language of the literature can baffle many students (Herman, 1999; Breakwell, 2003). Students do not always see the connections between the literature and other course content (Smith, 2001). Moreover, the Introduction, Methods, and Results sections of articles can all be difficult for different reasons (Deutch, 1992; Muench, 2000; Smith, 2001). For example, in many Results sections, "Data that are not easily visualized are subjected to … analytical approaches too complex to do with pencil and paper" (Muench, 2000). Overall, we believe that students struggle with the primary literature because they do not "filter" it as professional scientists do. While professionals have learned to set aside confusing but minor details in order to quickly grasp the major points of a paper, students cannot judge what is minor and what is major, so they become overwhelmed by the density of information. It is not surprising that many students approach literature assignments with considerable anxiety (Smith, 2001; Mulnix, 2003).

Despite these obstacles, instructors have integrated literature-related exercises into courses in animal behavior (Houde, 2000), biochemistry (Deutch, 1992), chemistry (Drake *et al.*, 1997), environmental studies (Chisman, 1998; Camill, 2000), exercise physiology (Gillen *et al.*, 2004), evolution (Muench, 2000; Smith, 2001), human biology (Russell *et al.*, 2004), medicine (Bennett *et al.*, 1987; Edwards *et al.*, 2001), microbiology (Breakwell, 2003), and molecular/cell biology (DebBurman, 2002; Smith, 2002). Although many of these reports focus on biology majors, several report success in introducing biology literature to nonmajors (Epstein, 1972; Chisman, 1998; Pall, 2000; Breakwell, 2003; Gillen *et al.*, 2004; Russell *et al.*, 2004). As pointed out by Gillen et al., "In college introductory classes, students routinely read difficult primary writings, for example, those of Shakespeare and Kant. Nonscience majors … thus may be familiar with the process of critical analysis of texts" (Gillen *et al.*, 2004). In a few cases, literature-based assignments have even been implemented at the high-school level (Ellis, 1990; Drake *et al.,* 1997; Brill and Yarden, 2003).

We teach a course called "Biological Frameworks for Engineers" to undergraduate and graduate engineering students with no previous college-level biology experience. In running a weekly "journal club" for our students, we have employed some techniques described previously and others that may be new. These techniques are described below. The centerpiece of our efforts is a weekly study guide that accompanies each assigned article; previous study guides are available online for the benefit of interested readers.

METHODS

Course Background

"Biological Frameworks for Engineers" is an elective one-quarter course offered to undergraduate juniors and seniors as well as graduate students. The students typically have not taken any biology since high school.

The class consists of about 20 students per quarter. We meet twice per week for 120 minutes per session. The course begins with introductory material on the components of a cell, transcription and translation, protein structure and function, and genetic diseases. The rest of the course content varies somewhat depending on the quarter. With chemical engineers, we cover topics such as cellular metabolism, metabolic engineering, and bioremediation; with electrical engineers, we discuss circuit models of gene expression, cells as batteries, and "lab-on-a-chip" devices.

We believe that engineers learn best when engaged in solving problems. Consequently the course includes numerous problem sets, discussions, computer simulations, and labs as well as traditional lectures.

Journal Club Format

Aside from the two regular 120-minute sessions per week, graduate students are required to attend a weekly 60-minute "journal club" session. (The journal club is optional for undergraduates.) Each journal club session is an instructor-led discussion of a piece of literature handed out a week earlier along with a study guide. The graduate students are graded on their participation in these discussions, accounting for 10% of their overall course grade. We give each student a grade for each session immediately after the session, while their contributions are still fresh in our mind (Janick-Buckner, 1997).

Article Selection

We use several criteria to select articles that are interesting and appropriate for students with minimal biology background. Our criteria overlap somewhat with those of Muensch (Muench, 2000). Examples of articles and notes on why they were chosen are presented in Table 1.

<u>Length.</u> Two to four pages – the length of many short reports in *Nature* and *Science* – is ideal. Students should have time to read the paper twice, since most papers make a lot more sense the second time through. Using short articles also limits the number of different experimental techniques that students encounter in a given article (Muench, 2000).

<u>A generalist audience.</u> Multi-discipline journals such as *Nature*, *Science*, and *Proceedings of the National Academy of Sciences* tend to publish biology articles that are accessible to non-biologists (Herman, 1999; Muench, 2000). Articles from medical journals also tend to be relatively accessible, since their audience includes physicians with little research training (Pall, 2000).

<u>Connection with lectures and labs.</u> The more closely an article relates to the rest of the course, the better. Lectures and labs should supply background information that will help the students understand the articles; ideally, an article will cover experimental techniques that the students do in lab (Camill, 2000). Care should be taken to avoid the perception that articles are randomly selected and unrelated to lecture material.

<u>Significance of findings.</u> Although students can benefit from studying seriously flawed papers (Meers *et al.*, 2003), we generally select articles whose importance genuinely excites us. Examples are "classic" papers in which Nobel Prize-winning work was first reported and recent cutting-edge papers, often related to a disease. Students are more willing to struggle through a paper if they're convinced that it represents a major breakthrough. To promote the students' interest, we give each series of articles a provocative title such as "Great Moments in Biology" or "Breakthroughs in Biology."

What's the question? We favor papers that address a very simple question (even if the answer turns out to be somewhat complicated). Students should continually be thinking about how the details of a paper relate to the overall question being addressed. This will be much easier if they actually understand the question.

Clear Introduction and Methods sections. Clear prose is helpful in general but especially important in the Introduction and Methods sections. The Introduction provides the big-picture context for the details to follow, and if students do not grasp the big picture they are unlikely to digest or care about the details. Methods sections are often incomprehensible to novice biologists, but a few authors actually identify their control experiments as such and group experimental steps together in meaningful ways. Look for helpful summary statements such as, "We tested our hypothesis in the following three ways…" and "The overall purpose of the 17 steps listed below was…"

Clear figures. These are particularly useful for visual learners and, if designed well, can compensate for mediocre text by compactly highlighting key methods and data. Good figures facilitate good class discussions (Smith, 2002; Kuldell, 2003), since the basic "story" of the article can often be reconstructed by discussing the figures in the order that they appear (Janick-Buckner, 1997).

Back-up option: review articles. If suitable primary literature cannot be found, we assign a review article instead. Examples include the articles in Table 1 by Kandel and by Lindstedt et al. Reviews can summarize huge amounts of data, reconcile seemingly contradictory studies, and generally provide a broader perspective than primary research articles. Students can benefit from all of these advantages.

Study Guide Design

Our study guides bear some resemblance to those of Deutch (Deutch, 1992), who lists the goals of the study, definitions of key terms and techniques, and questions to guide students through the article. Study guides for all of the articles listed in Table 1 are available at www.biologyforengineers.org. In general, our study guides include the following features.

Essential background information. We define a few vocabulary words that must be understood for the paper to make sense. We also put the article in its historical context, explaining what was and wasn't known at the time of the study.

"Thought questions." We move students through the paper with questions that focus their attention on the aspects we consider most important. We make some of the questions very easy (so that every student will arrive at the discussion with some confidence and something to say) and others very hard (so that even the best students will arrive at the discussion eager to clear up some uncertainties). Rangachari and Mierson have published a useful checklist of "critical evaluation" questions that can be applied to *any* article (Rangachari and Mierson, 1995); however, we prefer to tailor our questions to each article according to our specific pedagogical objectives.

Suggestions to ignore parts of the article. Since we are not aiming for 100% comprehension of the articles, we feel justified in telling students to ignore certain aspects of them, thus minimizing the time they spend agonizing over tangential details. Other instructors have achieved this same goal by removing or rewriting difficult parts of articles (Smith, 2001; Brill and Yarden, 2003), but we have left the articles intact for any curious or motivated students who want to see things as originally published.

In-Class Discussions

Leading engaging discussions is something of an art. We have had reasonable success by adhering to the following guidelines.

Keep groups as small as possible. Even a group size of eight to ten may suppress input by some students, in which case groups can be subdivided for part of the discussion period.

Base the discussion around the study guide questions. After all, the questions on the study guide represent the most important aspects of the article. However, we try not to stick *too* rigidly to the study guide, since student questions and comments may send the discussion off in other fruitful directions. Also, if discussions are devoted solely to the study guides, some students who think they have already mastered the study guides may not participate.

Be supportive of confused students. For example, DebBurman (DebBurman, 2002) tells his students that they are not expected to understand more than one-fourth of an article when they discuss it with him for the first time. This relatively low baseline makes it clear that students should not be ashamed by their initial confusion.

Let students answer each other's questions. Student questions are usually directed to us, but we often redirect the questions back to the class. Also, we sometimes have students work in groups of three for the first few minutes of the period, with no instructor involvement, so that they can resolve some issues without having to demonstrate their confusion to the instructor and the entire class.

Get students to use the blackboard. Drawing out molecular structures, expected data, etc. will often reveal assumptions or misunderstandings (Camill, 2000). In addition, discussing a figure is often easier than can discussing an abstract thought.

Point out the strengths and limitations of each article. Students need to be reminded that even well-done research is not infallible.

Assessment

Two types of assessment of the journal club have been performed thus far. First, a standard end-of-course student comment sheet is distributed at the end of each quarter to collect input on all aspects of the course. This sheet asks open-ended questions such as, "What aspects of this class contributed most to your learning?" and "What aspects of this class detracted from your learning?" Second, an additional journal club-specific survey (see Figure 1) was given to the graduate students who took the course in the winter quarter of 2004. Anonymity was preserved for all questionnaires, and students were assured that their comments would be read only after final grades were turned in.

RESULTS

A total of 29 students have participated in the journal club over the three quarters in which it has been offered. One might hypothesize that the students would be resentful of the journal club, since it represents a fifth hour of in-class work for a course for which they only receive three credits. Indeed, one student complained about this on his/her comment sheet. However, this student was the only one to list the journal club as an aspect of the course that detracted from their learning. Nine other students (31%) specifically mentioned the journal club in response to the question, “What aspects of this class contributed most to your learning?”

This generally positive attitude toward the journal club is also reflected in the one club-specific survey administered thus far. As indicated in Table 2, the students surveyed felt that the workload was appropriate and that the journal club was a useful supplement to the rest of the class. Students also gave fairly high marks to most of the articles selected for discussion. Although most students thought they had adequate chances to express themselves during the discussions, one student disagreed.

A variety of written comments concerning the journal club were also made on both surveys. A representative sampling is shown in Table 3. Two themes seem to emerge from the comments. First, many students praised the tight connection between lecture material and the articles. Second, some students felt the journal club was sufficiently worthwhile to expand it – to extend it by an extra week, for example, or to include undergraduates or divide the main discussion group into subgroups.

DISCUSSION

Our assessment data, while limited, suggest that most students benefit from and enjoy the journal club in its current format. Several students praised the close ties between the assigned articles and lectures. The only problems cited by students are the additional work required by the club and the difficulties of getting a chance to speak during a discussion in which everyone has something to say. Although the latter complaint initially surprised us – we didn’t think this would be a problem in a discussion group of eight people – we took it to heart and have since broken up the main group into subgroups when possible. As noted in the Methods, we tend to do this toward the beginning of sessions so that students can bounce ideas off of each other before having to present them to the entire group.

Our approach to the literature differs from previously described approaches in several respects. Many of these differences probably stem from differences in the students being taught, the number of articles studied, and/or the amount of in-class and out-of-class time devoted to each article. Nevertheless, a few are worth mentioning here.

To ensure that students prepare thoroughly for in-class sessions devoted to literature, many instructors quiz students on the articles or have them hand in written summaries (Janick-Buckner, 1997; Houde, 2000; Levine, 2001; Smith, 2002; Breakwell, 2003; Gillen *et al.*, 2004). We did not do this because we did not want to further increase the workload associated with this portion of the course, especially since one of our main goals was to make reading the literature less stressful and intimidating to novice biology students. Some professors allow students to select their own articles to read (Pall, 2000), which seems reasonable as long as the instructor provides some guidance and reviews the selections. Also, some have their students write down all of an article's unfamiliar vocabulary words (DebBurman, 2002); this probably works well with advanced students, but given the potentially lengthy lists of our students, we focused on a holistic understanding of the articles rather than a comprehensive attack on the vocabulary. Finally, some literature series are structured so that the students are "weaned" away from the instructor's help over the course of the semester (Deutch, 1992; Muench, 2000; Smith, 2001; Kuldell, 2003). We heartily endorse this progression when the course and articles are confined to a fairly specific field; if the articles overlap in terms of terminology, research questions, and methods, they should get progressively easier for the students. Unfortunately, our course is so broad that each article is rather unlike the others, so we do not make the study guides progressively shorter.

In summary, we have combined others' approaches to teaching primary literature with our own strategies to create a journal club that appears useful for students with limited training in biology. Consistent with previous work, preliminary feedback suggests not only that nonmajors are capable of reading the literature, but that many of them genuinely enjoy the experience when given appropriate assistance and encouragement. We offer our study guides to other instructors in the hope that they can be adapted for other classes.

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Herman, C. (1999). Reading the literature in the jargon-intensive field of molecular genetics. J. Coll. Sci. Teach. *28*, 252-253.

Houde, A. (2000). Student symposia on primary research articles: A window into the world of scientific research. J. Coll. Sci. Teach. *30*, 184-187.

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TABLES

Table 1. Examples of biology articles selected for use with engineering students.

Article	Comments
V. M. Ingram, "Gene mutations in hæmoglobin: the chemical difference between normal and sickle-cell hæmoglobin," *Nature* **180**: 326-328, 1957.	Many courses, including ours, teach protein structure using hemoglobin as an example. This paper is a natural extension of that, allowing us to discuss how a single amino acid change affects tertiary and quaternary structure. We also consult the genetic code to determine the DNA mutation responsible for the amino acid change.
W. Gilbert and B. Müller-Hill, "The *lac* operator is DNA," *Proceedings of the National Academy of Sciences USA* **58**: 2415-2421, 1967.	The *lac* operon is a standard model for understanding the control of gene expression. This study helped unravel how it works. The first three pages can be read independently of the rest. Gilbert is a Nobel Prize winner.
E. M. Purcell, "Life at low Reynolds number," *American Journal of Physics* **45**: 3-11, 1977.	A transcript of a delightfully informal lecture (with hand-drawn figures) in which principles of physics and engineering are used to illuminate the swimming behavior of bacteria. Good for convincing engineers that their knowledge is relevant to biology.
F. Sanger et al., "DNA sequencing with chain-terminating inhibitors," *Proceedings of the National Academy of Sciences USA* **74**: 5463-5467, 1977.	Sanger won his second Nobel Prize for papers such as this one, which describes a method of DNA sequencing still used today. Our students send a DNA sample to a sequencing facility, and reading this paper ensures that they understand how DNA sequencing is done. Well written, with a good Discussion on the strengths and limitations of the method.
H.-R. Lüscher et al., "How the size of motoneurones determines their susceptibility to discharge," *Nature* **282**: 859-861, 1979.	This study, from Elwood Henneman's lab, concerns his famous "size principle," which dictates that the largest motor neurons are the last to be recruited. Can we understand why based on the physical properties of the neurons? Well written.
E. R. Kandel, "Calcium and the control of synaptic strength by learning," *Nature* **293**: 697-700, 1981.	A review describing how a complex phenomenon (learning) can be explained in part by changes at the cellular level. Good for exploring the topic of how synapses work, with less jargon than most neuroscience papers. Well written. Kandel won a Nobel Prize.
S. L. Lindstedt et al., "Limitations to aerobic performance in mammals:	Models the oxygen cascade (lungs to blood to muscles) as a series of resistors and asks whether one resistor limits the overall flux or

interaction of structure and demand," *International Journal of Sport Medicine* **9**: 210-217, 1988.	whether the resistors are tuned to each other. Good for electrical engineers trying to understand biological fluxes. Also a good example of "meta-analysis" figures drawing upon data from numerous previous studies.
G. J. Lutz and L. C. Rome, "Built for jumping: the design of the frog muscular system," *Science* **263**: 370-372, 1994.	The length-tension curve and force-velocity curve are fundamentals of muscle physiology. This study revisits them in order to figure out how frogs can jump so far, another problem that resonates with engineers.
K. P. Lemon and A. D. Grossman, "Localization of bacterial DNA polymerase: evidence for a factory model of replication," *Science* **282**: 1516-1519, 1998.	A paper that combines three topics covered elsewhere in our course: green fluorescent protein (GFP), the *lac* operon, and DNA polymerase. The question posed is wonderfully simple: does DNA polymerase move along the DNA, or does the DNA move while the polymerase remains stationary? And the first five or so paragraphs are beautifully written.
M. B. Elowitz and S. Leibler, "A synthetic oscillatory network of transcriptional regulators," *Nature* **403**: 335-338, 2000.	An interesting example of how cells can be engineered to behave in interesting, non-natural ways. In this case, an artificial cellular "clock" with oscillating GFP levels was created. Expands on lecture material about circuit models of gene expression; combines modeling with experiments.
Y. Shav-Tal et al., "Dynamics of single mRNPs in nuclei of living cells," *Science* **304**: 1797-1800, 2004.	How can you detect and track the movement of individual molecules inside cells? This sort of detection problem is perfect for collaborations between biologists and engineers.

Table 2. A journal club assessment survey given to electrical engineering graduate students who took the course in the winter quarter of 2004. See Table 1 for complete citations of journal articles. The number of students choosing a given answer is shown next to each answer.

1. The workload for this portion of the course (Thursday noon discussions) was:

0 much too heavy

0 somewhat too heavy

7 about right

0 somewhat too light

0 much too light

2. "These assignments/discussions were a useful supplement to the rest of the course."

5 agree strongly

1 agree somewhat

0 not sure

0 disagree somewhat

0 disagree strongly

3. "In these discussions, I had adequate opportunities to express my opinions and ask questions."

5 agree strongly

1	agree somewhat
0	not sure
1	disagree somewhat
0	disagree strongly

4. Please rate each of the following assignments on a scale of A (extremely worthwhile) to E (not at all worthwhile).

5 As, 2 Bs	Ingram, 1957
6 As, 1 C	Elowitz & Leibler, 2000
6 As, 1 B	Sanger et al., 1977
5 Bs, 1 C, 1 D	Kandel, 1981
2 As, 1 B, 4 Cs	Lindstedt et al., 1988
2 As, 3 Bs, 1 D	Lemon & Grossman, 1998

Table 3. Sample comments regarding the journal club compiled from anonymous end-of-quarter surveys.

• *"I … dislike lit review sessions – 5 hours of meeting for a 3-credit course."*

• *"Breakout discussion groups would allow more people to contribute."*

• *"The literature review sessions … were excellent ways to ingrain the course material."*

• *"I think that the papers were extremely topical. It is hard to make suggestions for other topics when the ones chosen matched so well with lecture topics."*

• *"All papers assigned were extremely relevant to the material being covered at the time. The only topic(s) I would have liked to cover more was the basics of DNA replication, transcription, translation, protein folding, or types of protein structure and what it does. That's a lot to ask for from one course early on, but if for instance we had started this literature review one week earlier, such a paper might have fit in well."*

• *"I liked having papers that were normally a few pages in length, because the material could easily be looked over within an afternoon and I thought most of the papers were interesting and easy to understand (particularly after going over them in review sessions)."*

• *"Should make [reading of research literature] mandatory for undergrads, too."*