Using the Primary Literature in an Allied Health Microbiology Course

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A strategy was adapted for using the primary literature to foster active learning in an allied health microbiology course. Recent journal articles were selected that underscored the fundamental microbiological principles to be learned in each course unit. At the beginning of the semester, students were taught the relationship between the layout of scientific articles and the scientific method. During the rest of the semester, students were oriented to the topic of each paper by viewing videos from *Unseen Life on Earth: an Introduction to Microbiology*, reading assigned pages from the text, and participating in mini-lectures and discussions. After all preparatory material was completed, a paper was read and discussed in small groups and as a class. Students were assessed using daily reading quizzes and end-of-unit concept quizzes. While reading quizzes averaged approximately 93%, concept quiz grades averaged approximately 82%. Student recognition of the terms used in each unit's scientific article was assessed with pre-read and post-read wordlists. For the self-assessment, the percent change between pre-read and post-read word cognition was, as expected, highly significant. Approximately 80% of students agreed that reading the scientific articles was a valuable part of the class and that it provided meaning to their study of microbiology. Using the primary scientific literature facilitated active learning in and out of the classroom. This study showed that introducing the scientific literature in an allied health microbiology class can be an effective way of teaching microbiology by providing meaning through the current literature and understanding of the scientific method.

As scientific information becomes more accessible to the public, an ability to read and comprehend the primary literature will become increasingly important. Additionally, since biology is dynamic, learning it must become more focused on the process that drives scientific investigations (12, 13). The primary literature is defined as the body of information describing original studies that employ the scientific method (17, 24). The skill of reading the scientific literature can be taught not only to microbiology majors but also to allied health students who take a microbiology course as part of their curriculum. One approach is to teach students to read the primary literature by using examples from these resources in the classroom. In one of the earlier reports encouraging the use of primary literature with beginning students, it was postulated that once students were taught how to read the literature, they were capable of asking appropriate scientific questions and finding the answers through reflective and analytical research of the paper or papers they had read (19). Certainly, using the primary literature in an allied health microbiology course will contribute to a more scientifically literate community.

As science educators move toward inquiry-based and active-learning strategies (2, 12, 22, 29), discussing the scientific method and reading primary literature provides another way for instructors to incorporate these strategies into their classrooms. This approach is supported by current constructivist philosophies (3, 12, 18). Simply stated, constructivists believe that students make relationships and build new ideas on a framework of knowledge that they have acquired previously (3, 8, 30). However, there are some pit-

falls of trying to apply constructivism in the classroom. For example, some concepts taught in a class may be completely foreign to a student and require a foundation provided by the instructor (1, 6). Also, a considerable amount of time is required to develop a well-constructed approach that encourages students to discuss concepts and ideas not only with the instructor but also with each other (1). Perhaps the best implementation of it will be when the subject mirrors the process constructivist philosophy seeks to describe, and in which the class has allocated time for much discussion. My observation is that the scientific method and the learning process are inherently constructivist in nature. Students construct their knowledge based on what they already know, on the new information they see and hear, and on the observations they make; they have to make and remake assumptions and ideas when new information is presented. In the same way, scientists, based on their observations and on previously published work, engage in testing hypotheses, the results of which either weaken or strengthen the support for those hypotheses. Both scientists and student-learners establish lines of evidence until structures of understanding emerge. One way for students to comprehend the science of microbiology, short of actually working in the laboratory, is by evaluating the scientific literature (9, 10, 13, 14, 15, 21, 28).

For example, I, along with others (15, 18, 21, 28), have acknowledged that nonmajors or beginning students are often unfamiliar with the complex vocabulary required to understand a scientific paper. One strategy to alleviate this problem is to introduce students to core concepts and vocabulary before reading a paper (15). As a result, my approach incorporated reading of scientific articles by first providing instruction on the scientific method and the structure of scientific papers, and then by introducing salient material as a foun-

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dation for understanding each paper. By providing students with features common to all scientific articles, and by showing relationships between core concepts and vocabulary, students can be more comfortable reading papers (15, 18, 19).

Other reports have provided suggestions for selecting papers for use in biology or environmental science courses (4, 21). Briefly, papers should be selected by their relevance to the content of the unit, the quantity of biological concepts discussed, and the clarity (or sometimes lack thereof) of tables, figures, and definable results and conclusions.

Using primary literature to teach biology majors is not a new strategy, and once appropriate papers have been selected, its use has been applied in a variety of ways (9, 10, 11, 13, 14, 15, 19, 21, 28). Regardless of the approach, however, some common elements exist. First, students are engaged in the topic and encouraged to explore for themselves and explain to others what they are learning. Second, a short lecture or learning exercise is used to elaborate on the concepts studied. Third, evaluation or assessment of the learning occurs (3, 19). Using these elements, the purpose of this study was to examine an approach incorporating reading of primary literature in an allied health microbiology class at Brigham Young University (BYU). The fundamental hypothesis of this study was that learning by reading the scientific literature would be demonstrated by assessment conducted not only by the instructor, but also when the students evaluated themselves. This would be evident by increased familiarity with and recognition of the vocabulary of microbiology.

METHODS

Microbiology 221 is a general microbiology course taught for allied health and nonmajor students at BYU. The course that was studied and discussed in this report was taught in

winter semester 2002. The section had 81 students, which was of average size for this course at BYU. Approximately 75% of the class were either prenursing majors or in a health-related major. The remaining 25% of students were food science, nutrition, dietetics, engineering, or other life sciences majors. The course met for 80 minutes, twice a week, for the 15 weeks of the semester.

The course format was based on the learning phases proposed by Biological Sciences Curriculum Studies. Briefly, this model has five instructional phases: engage, explore, explain, elaborate, and evaluate (3). Following an introduction to the scientific method and scientific literature, the remainder of the course was divided into units. The structure of the units and each class period are outlined below and are shown in Fig. 1.

The units focused on epidemiology and public health, cell structure and function, microbial growth and metabolism, control of microbial growth, and the immune system. While a unit covering topics in diversity and environmental microbiology was planned for the course, it was eliminated due to time constraints. Infectious disease material was covered daily in what was called "Diseases of the Day."

Each unit followed the same sequence of class periods. A one-class-period preview of the unit introduced the topic with the aim of engaging the students. For the preview, brief lectures were given and videos from *Unseen Life on Earth: an Introduction to Microbiology* (http://www.microbeworld.org/html/mam/is_telecourse.htm) were shown to provide an overview and give context to the discussion. Since the course used primary literature, the videos provided excellent vignettes about research discussed by experts. Following the one-class introduction, four to six class periods were used to discuss key concepts and to provide a foundation for reading a relevant paper and for further

FIG. 1. Flow chart representing the overall course design.

TABLE 1. Summary of course units, topics, and scientific articles

Course unit	Topic	Title of scientific article (full reference)
1	Epidemiology and public health	Multidrug-resistant urinary tract isolates of <i>Escherichia coli</i> : prevalence and patient demographics in the United States in 2000 (25)
2	Cell structure and function	<i>Borrelia burgdorferi</i> periplasmic flagella have both skeletal and motility functions (19)
3	Microbial growth and metabolism	Oxygen requirements of the food spoilage yeast <i>Zygosaccharomyces bailii</i> in synthetic and complex media (23)
4	Control of microbial growth	Bacterial spores survive treatment with commercial sterilants and disinfectants (24)
5	The immune system	Stress-induced enhancement of skin function: a role for γ -interferon (7)

discussion about the topic. The culmination of each unit was the reading of a selected article from the recent literature before coming to class and a discussion about that paper in class. Papers were selected based on the criteria proposed by Muench (21). Briefly, papers were selected for the breadth of biological concepts discussed, clear demonstration of results in figures and tables, and their general interest to students. For example, of the papers selected for this study (Table 1), one article describes the effect of commercial sterilants and disinfectants on the survival of bacterial spores (26). The principles of microbial control and time of exposure to specific agents that students may encounter later are demonstrated. In each unit, class periods followed a similar format.

Each class followed an approach recommended by Klionsky (16). Students were provided with an assigned reading and questions to answer from the text to complete before coming to class. Their preparation was assessed using a reading quiz during the first 10 minutes of class. Following the reading quiz, a 30 to 45-minute mini-lecture and/or group activity ensued. The lecture or activities were designed to provide additional experience with tables and figures from the literature and the concepts critical to understanding the unit. Each class period concluded with approximately 15 to 20 minutes of infectious disease material (Diseases of the Day).

At the completion of each unit, a concept quiz was used to assess how students were able to construct and apply what had been taught and learned. While the reading quizzes required primarily recall, concept quizzes assessed analysis, synthesis, and evaluation skills and reflected the activities performed previously in class. For example, a reading quiz from the unit entitled, "Control of Microbial Growth" had the following questions:

1. Define sterilization.
2. What type of agent would you use to destroy organisms on an inanimate object?
3. Name the method that is used to lower the number of microbes on eating or drinking utensils to safe public health levels.
4. If you were to plot microbial death on semilog paper, what would the graph look like?
5. Name two methods by which heat (temperatures greater

than room temperature) can be used to control microbial growth.

6. Name two physical methods, other than heat, for controlling the growth of microorganisms.

Alternatively, concept quizzes provided an opportunity for students to evaluate pertinent examples from the literature. The following question was extracted from the concept quiz for the "Control of Microbial Growth" unit:

Chronic *Helicobacter pylori* infection is reduced with *Allium*, onions and garlic, vegetable intake. The following scenario is adapted from a paper (23) in which various garlic materials were tested for their activity against this bacterial pathogen. The figure (Fig. 2) represents the destruction of *H. pylori* cells over time when exposed to various concentrations of garlic powder. Garlic powder forms allicin (diallyl thiosulphinate), a substance that has bactericidal properties. Interpret the data using the questions as your guide.

1. Which concentration was the most effective at con-

FIG. 2. Figure used in concept quiz question. The figure is adapted from data reported in O'Gara et al. (23). The legend refers to concentrations of garlic powder used in the original report.

trolling *H. pylori*?

2. For how long should the bacteria be exposed to allicin before 90% of the bacteria are killed?

3. For how long should the bacteria be exposed to allicin before all of the organisms are killed?

Two other kinds of assessments were performed during the course. First, at the beginning and conclusion of each unit, a student self-assessment was conducted. The self-assessment consisted of checklists containing words chosen by the instructor and derived from the scientific paper read in each unit. Students were asked to check only those words with which they were familiar or which they felt they could determine the meaning of from the context of the paper. Since the papers did not have the same number of unknown words, the difference in the percent of the pre-unit and post-unit words was calculated. The average difference for each unit was evaluated. The mixed procedure in the Statistical Analysis System was used to evaluate, by regression, the trend and statistical significance between units. A mixed model assumes that not all of the observations were independent as would be the case in an ordinary least squares regression and accounted for the fact that some of the words were common between units. Second, near the end of the semester, the students were given an evaluation in class to assess their opinion about the course. This tool was not the formal evaluation required by the university. Of the 81 students enrolled in the course, 75 were present for this evaluation.

RESULTS

In this study, principles previously advocated in the literature to incorporate reading of primary literature into an introductory, allied-health microbiology class were used (4, 9, 10, 11, 13, 14, 15, 19, 28). Briefly, the class was introduced to the scientific method and the layout of scientific articles. Course units then prepared the students by providing content and practice working with examples from papers prepared by the instructor. Student learning was assessed with reading and concept quizzes. At the conclusion of each unit, a paper from the recent literature was read and discussed. This approach was also evaluated using student self-assessment and course evaluations.

When the reading and concept quiz scores were examined, they revealed an average reading quiz score of 93.3% + 10.8% (standard deviation (SD)) and an average concept quiz score of 82.0% + 10.5% (SD). Student perceptions of using the primary literature in the class are shown in Fig. 3. Of the students agreeing, strongly agreeing, and very strongly agreeing, almost 40% reported that they did not know how to read primary literature before taking the course. By contrast, almost 90% of students felt comfortable reading a scientific article at the conclusion of the course. The same percentage of students felt that they had benefited by learning to read a scientific paper, with the greatest proportion of these students very strongly agreeing that this was true. In a similar fashion, 80% of students agreed that reading scientific

FIG. 3. Student perceptions of using the scientific literature in an allied health microbiology class. Data represent the percentage of students responding to an end-of-course survey. Approximately 93% of enrolled students participated in the survey.

FIG. 4. Student perceptions of course format. Data represent the percentage of students responding to an end-of-course survey. Approximately 93% of enrolled students participated in the survey.

articles in class provided context to their study of microbiology. In commentary, the term “context” was described to the students as understanding how microbiologists do science. They responded that reading the articles was an effective way of learning how microbiologists study and practice their discipline.

I was also interested in the students’ opinions about the class’s overall approach and specifically about the daily format that was employed. The results of this part of the assessment are reported in Fig. 4. Ninety-five percent of students responding agreed that the format of the class was a good strategy for learning microbiology. The lecture or activity portion of the class, daily reading quizzes, and “Diseases of the Day” also rated highly, with over 80% of students responding that they very strongly agreed or strongly agreed that these activities provided context to their study of microbiology or were effective in helping their study of microbiology. Most students (~80%) also admitted that the concept quizzes were good measures of their knowledge and understanding. In general, the videos from *Unseen Life on Earth: an Introduction to Microbiology* were also seen as useful in learning microbiology.

A student self-assessment tool was completed at the be-

ginning and the conclusion of each unit. Table 2 shows the results of the mixed model and the comparison between the differences between pre-read and post-read recognition of terms. The mixed means model used assumes that the pre-read score is not independent of other pre-read scores. Adjusted *P* values were used to determine statistical significance, because they take into account that multiple comparisons (that is, between each unit) were performed. The regression data show a significant difference between change in percentage of words recognized between units 1 and 5. The difference between units 2 and 3, 2 and 4, and 2 and 5, were highly significant. My hypothesis was that the change in percentage of words recognized would decrease over the semester as vocabulary increased. Although there was not a significant difference between units 1 and 5, the differences between unit 2 and the following units were significant or highly significant. A comparison of the observed percent differences (between pre-read and post-read recognition of terms) and the predicted values fit with the mixed model is shown in Fig. 5. Whereas the observed percent change decreased over the semester, the values predicted using the mixed model increased.

Table 2. Statistical comparison of the percent change in student word recognition self-assessment scores

Unit	Unit	Estimate	Standard Error	t value	Adjusted P value	
1	2	6.012	2.314	2.60	0.153	ns ^a
1	3	-3.960	1.933	-2.02	0.399	ns
1	4	-3.632	2.229	-1.63	0.618	ns
1	5	-7.734	2.347	-3.30	0.031	*
2	3	-9.972	2.237	-1.46	0.001	**
2	4	-9.644	2.473	-3.90	0.005	**
2	5	-13.746	2.565	-5.36	<0.0001	**
3	4	0.328	1.837	0.18	1.000	ns
3	5	-3.774	1.771	-2.13	0.341	ns
4	5	-4.102	2.056	-2.00	0.411	ns

^aThe data were compared using Duncan's New Multiple Range Test, where ns = not significant, * = $P \leq 0.05$ and ** = $P \leq 0.01$

DISCUSSION

Using reading and concept quiz scores and student opinion of the class, the class format and structure discussed here seem to provide a successful way of incorporating active learning into the allied health microbiology classroom through interpretation of data from, and reading of, the primary literature.

Based on reading and concept quiz scores and other assessments, the primary literature can be used effectively to teach nonmajors. It can provide context and relevance to their study of microbiology. From personal communication and by written comments, students reported that using daily reading quizzes encouraged preparation that was sustained over the semester. The average reading score was higher than expected. One student suggested that the reading quizzes could have been more difficult. Although this may have been true, the purpose of the reading quizzes was to encourage out-of-class preparation and to facilitate in-class discussion. Perhaps the greatest advantage of these quizzes was frequent evaluation and feedback for the students and fostering of good classroom practice (5). Since the objective in using this assessment technique was to encourage student preparation before class, the results from the reading quizzes suggested that what I wanted the students to acquire from the reading of the text was actually being learned.

The concept quizzes focused on the ability of students to decipher and interpret data in light of what they had learned in each unit. In formative assessments conducted periodically throughout the semester and in speak-

ing with the students, the students felt that they could not study for concept quizzes well using traditional examination preparation methods. I agreed, but encouraged them to actively participate in the class activities as their preparation for the concept quizzes. Although study sessions were conducted before the concept quizzes, it was felt that learning should have occurred throughout the unit and that the students' preparation for the quiz would have already been accomplished. The average score on these quizzes was higher than I had previously experienced (data not shown), and perhaps the strategy worked by preventing students from studying at the last minute. Another reason that may explain this

FIG. 5. Comparison of observed and predicted percent change in words recognized in a student self-assessment. Predicted data were determined by a mixed model. (List of articles in Table 1.)

result is that there were more concept quizzes in this format than I had previously used with less-frequent examinations. Consequently, the quantity of material covered on each concept quiz was less per unit than I had previously tested. I had previously used three midterm examinations and a final examination for the course. However, I felt that using five concept quizzes, daily reading quizzes, and a final “Diseases of the Day” examination provided adequate assessment of student performance in the class.

Most students enjoyed the class and felt as though the articles had contributed much to the study of microbiology. Student comments included the following:

- “I learned more because of the continuous learning approach: daily quizzes, diseases of the day, concept quizzes. Reading papers contributed greatly to learning and applying our knowledge.”
- “Amazing setup has allowed me to explore [a] difficult subject matter in a way that still allows me to maintain my GPA and feel excited about class.”
- “This is one class where I don’t watch the clock because my brain is constantly, actively engaged in learning.”

The positive results reported here and the comments recorded by students corroborate those reported by Smith (28). However, he reported that, in his opinion, it would have been unproductive and ineffective for first-year students to read the literature. Although I did not analyze the distribution of students in my class per se, the students reported having had varying experience with college and scientific articles (Fig. 3) and success seemed independent of the student’s year in college. These results also support the observation that a progressive and concept-building design would alleviate students’ hesitation to delve into scientific articles (28). By basing the course format on the engaging, exploring, explaining, elaborating, and evaluating phases of a constructivist model (3, 18), and by instructing the students in the relationships between the scientific method and scientific literature, it was possible to successfully teach to a wide variety of student learning styles and experience.

Perhaps one of the greatest factors discouraging instructors from using primary literature with freshmen and sophomores is the large vocabulary associated with the sciences. Other instructor-researchers have reported that they require students to underline unknown words as they read a paper (13, 19). The approach of using wordlists from each of the articles serendipitously provided students with a study tool in my class. The plan was to use the wordlists only as a way of observing learning that was gauged by the students themselves. It was found that students asked for the wordlists because they found that if they looked up the words or learned them during class discussions, their understanding of the paper, when we read it, would be enhanced. This may explain the significant difference between pre-read and post-read unit scores over the course of the semester, that is, between units 1 and 5, 2 and 3, 2 and 4, and 2 and 5 (Table 2). However, as the semester progressed, the differences between units became insignificant. It appears that as students learned how to read the primary literature, they identified the vocabulary

they needed to learn and set about accomplishing that task as the unit progressed. Over the semester, their ability to read and understand papers must also have increased, because their working knowledge of microbiology terminology had improved. This observation was also demonstrated in Fig. 4. Over the semester, the percent change represented by the difference between pre-read and post-read terms recognized decreased. As the semester progressed, terms became more familiar to the students. However, the standard deviations for these data were large and the difference between the articles read was not statistically significant. When these data were fit with the mixed model, predicted values showed a positive trend over the semester. Notably, the mixed model considered that scores were not independent, that is that words were not unique, for each paper read. Constructivist theory describes learning based on previous knowledge and experience. In this regard, the mixed model illustrated the significance of this study. Since the percent change in words understood was significantly different when comparing early and late units, this positive trend suggests that the ability of students to learn microbiology was enhanced as the semester progressed. This information, demonstrated by an increase in the percent change in words recognized, may well support the constructivist model, because by the end of the semester students identified more terms that they did not know and were able to ensure that they learned them.

It has been suggested that applied biology is more accessible to students than modern physics or molecular biology (19) because of the jargon and complexity of terms in these disciplines. However, at least one of the papers employed in this study contained several advanced principles from molecular biology. Each paper related directly to the material covered, and in most cases covered multiple concepts within the units’ topics. The concept quiz scores (73% + 16% (SD), 78% + 15% (SD), 83% + 10% (SD), 90% + 13% (SD) and 86% + 17% (SD), respectively), including the one with significant molecular biology (i.e., Unit 2, Table 1) suggest that an introduction to fundamental principles and vocabulary can engage the students in the scientific literature (3, 11, 15, 18). The average reading quiz and concept quiz scores (93.3% + 10.8% (SD) and 82.0% + 10.5% (SD), respectively) suggest that in coming to class the students were well prepared and had met the objectives I had assigned them in the text. Admittedly, the concept quiz score average was somewhat lower. As a result, this instructor plans to incorporate more concrete learning objectives into the “Content and Concepts” class periods. The present study agrees with the practice of providing students with the critical concepts that are essential for enabling them to read scientific articles.

The results of the course evaluation also suggested that most students found that the videos from *Unseen Life on Earth: an Introduction to Microbiology* provided context to their study of microbiology. Because a unit on diversity and environmental microbiology was omitted from the experimental semester, the videos entitled *Microbial Evolution*, *Microbial Diversity*, and *Microbial Ecology* were not shown in class. To omit these videos was a difficult decision for me

to make. However, the other videos provided enough examples of the ecology and diversity of microorganisms to satisfy even this soil microbiologist!

Another factor that might point to the success of this approach is the length of class periods. Other researchers using the primary literature for class discussions have used 90 and 120 minutes (16, 18). Likewise, my experience with an 80-minute class period provided time for a variety of activities and the development of discussion. Notably, a comparison of science classes using active-learning models would be informative.

While this and other studies have used longer class periods, the described approach can be modified to accommodate 50 or 55-minute class periods. The following suggestions are made to facilitate this: increase the number of "Content and Concept" class periods to ensure that course material is adequately covered prior to discussion of the scientific article (Fig. 1); require a written summary due on the day on which the primary literature article is discussed to guarantee that students are prepared for discussion of it; and place the videos on reserve in the library for students to view on their own time.

Additional methods might be used to further enhance the success of using primary literature in a nonmajor's course. For example, an assignment to write a critical analysis of the paper before class may facilitate discussion of the paper (15). Ultimately the best test of this approach is to have students analyze a scientific article as an assignment or examination. Although it was not required in this class, the student evaluations and quiz scores suggest that students are willing and capable of discussing the primary literature and developing critical learning skills necessary to do so.

From this study, it is proposed that using the primary literature in an introductory class can make microbiology more accessible to the students, because it provides context to their study of this discipline and their understanding of how scientists practice microbiology. The students were more engaged in learning outside of class (as demonstrated by high average reading scores), and they participated more in class (based on personal observation). They succeeded in reading the articles and were able to interpret what the papers, and their contribution to the discipline, meant. Reading the primary literature is a useful skill for all students to acquire, and a strategy for using primary literature in the classroom is facilitated by providing salient concepts before reading them.

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