Development of a Microbiology Course for Diverse Majors; Longitudinal Survey of the Use of Various Active, Problem-Based Learning Assignments

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Educators are increasingly being encouraged to use more active- and problem-based-learning techniques and assignments in the classroom to improve critical and analytical thinking skills. Active learning-based courses have been purported to be more time consuming than traditional lecture methods and for many instructors have therefore proven difficult to include in many one-semester science courses. To address this problem, a series of assignments was developed for use in a basic microbiology course involving sophomore-, junior-, and senior-level students from five different biology majors (environmental science, biology, biochemistry, premedicine, and physician assistant). Writing assignments included global, historical, and social themes for which a standardized grading format was established. Students also participated in a class debate in which the merits of the living microbial kingdoms were discussed, with only one kingdom being saved from an imaginary global catastrophe. Traditional lectures were facilitated by the use of a dedicated note packet developed by the instructor and specific for course content. Laboratories involved group analysis of mini-case history studies involving pathogenic microbes. Students' perceptions of the subject were assessed using an exit questionnaire sent to 100 of the 174 students who had taken the course during the 5-year time period. The majority of the 64 students who responded were sophomores (78%), in keeping with the target audience, and their perception of the course's challenge level was significantly higher ($p < 0.03$, 8.7) than their junior and senior counterparts (7.9). Students rated the most useful learning tools as case history studies (9.4) and the class debate (9.1), with the introduction of a dedicated microbiology links web page to the University website representing the sole component resulting in a statistically significant increase in students' perceptions of the importance of the course ($p < 0.03$).

Over the past two decades in higher education, a new paradigm has emerged that seeks to transform traditional passive note-taking and study methods into a more active-learning environment in which students not only memorize information but also develop critical and analytical thinking skills (1, 10). Students who acquire knowledge through active learning are thought to retain the information longer and display a greater understanding of and interest in their subject than those learning solely through traditional methods of lecture and note taking (3, 5, 9). Indeed, investigators have reported that when lecture and discussion are combined, students tend to be more assertive and more likely to ask and respond to questions during class (6).

Although educators have been encouraged to use active-learning skills in the classroom, many have continued with traditional techniques due to concerns about being able to successfully cover the subject (7) and the time that such approaches will take to both prepare and grade (7, 10). Since active- and problem-based-learning assignments clearly play an important role in students' development, the question is how to incorporate them into high-content courses in a manner that neither detracts from the course nor provides a large additional time commitment for the instructor. At the same time, active and problem-based learning can only succeed if students fully understand that these tools are designed to provide a challenging and important learning experience.

Upon joining the faculty of Philadelphia University in 1996, there was a single, one-semester, basic microbiology course which served as an elective for all science majors. It had been previously taught on three separate occasions using traditional lecture-based teaching methods. This was felt to be appropriate at that time, as, for the first two semesters, all students taking the course were junior-level biology majors. In Fall 1995, sophomore physician assistant students first took microbiology as a requirement for their major. Since then the course has become part of the biology core curriculum for both physician assistant and premedicine majors. The course is designed as a sophomore-level course for all biology majors.

Although physician assistant and premedicine students still constituted approximately two-thirds of the students taking the microbiology course during the past 5 years, the types of majors taking the course have grown to include environmental science, biochemistry, and biology. The course has therefore been adapted to accommodate the diverse learning styles of these students and their varied expectations of the subject. My hypothesis was that, regardless of their major, students would have a greater appreciation of the subject if they could view from social, historical, and global standpoints the impact that microbes have had on this planet.

In formulating an intensive active-learning microbiology class, where students would be allowed to address the topic in a more interactive fashion, the first step was to ensure that course content would not suffer. This was important as microbiology is a core course for both physician assistant and premedicine students, representing the sole instruction in the

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subject given to these majors. To allow for active-learning-based components to occur during class time, traditional note taking and learning were replaced in the fall of 1998 with a 180-page note packet, which was designed to focus students on the topics covered by the course. This note packet was generated using four microbiology textbooks and several online sources and conformed to ASM guidelines for an introductory microbiology course (<http://www.asmta.org/edu32a.htm#Core>). Students therefore all started on the same page in terms of the information they had at their disposal, and this allowed more time during the course for the development of problem-based-learning skills through the use of case histories, written assignments, and an oral debate. To assist with the completion of the various learning components an additional tool, a web page with a series of microbiology Internet links, was placed on a website created by the instructor in the fall of 2000. Laboratory reports and examination content remained fairly consistent during this time period and will therefore not be dealt with in this paper. Instead, this article will document the changes in the microbiology course during the past 5 years, namely the introduction of a dedicated course note packet, modifications to individual written assignments, and the introductions of an oral debate, mini-case history studies, and access to selected microbiology Internet links. The efficacy of these learning tools has also been assessed by e-mailing a detailed questionnaire to 100 of the 174 students who took the course during this time. This paper will provide data from the 64 students who responded to the questionnaire that supports the use of these learning tools and gives information regarding the impact that microbiology has had on their lives and careers.

ACTIVE LEARNING COMPONENTS

A series of active-learning components, including individual written assignments, a group oral debate, mini-case history studies, and examinations, was incorporated into the Microbiology course during the 5-year period from Fall 1996 to Fall 2001. These components were established following extensive discussions with fellow biologists and with faculty members whose expertise included writing, advising, and learning styles, as listed in the acknowledgments. Prior to submission of written assignments, students were encouraged to seek help from professional writing tutors at Philadelphia University's Learning and Advising Center. A personal website (<http://faculty.philau.edu/CundellID/>) was established in Fall 2000 to act as a resource for assignments and laboratory reports and to encourage students to explore the field of microbiology outside the classroom. Course components are described in the order in which they were introduced.

Individual written assignments. In Fall 1996, students taking the course were required to write three assignments of up to five single-spaced, word-processed pages in length and were given three subject topics for each assignment. Students were encouraged to visit professionals at the learning center for help in constructing the assignments, which were as follows:

1. Students were asked to imagine they were working for a pharmaceutical company and had to design a novel antibiotic for a species or family of bacteria. Each student chose a bacterium, gathered information about it, and then identified a potential "target" within the organism suitable for the creation of a therapeutic. The student composed the assignment as a letter to the divisional head explaining the importance of generating a therapeutic to combat this organism.

2. Students were asked to imagine they worked for the Centers for Disease Control and Prevention and were responsible for combating a protozoal outbreak. Each student chose the location of the outbreak and organism responsible for it. Students had to research their selected protozoal species, explain its mode of transmission and how it could be detected, and offer simple ways to educate the local population to minimize the chances of this epidemic recurring. The format of the assignment was either a memo or letter to a fellow colleague.

3. Students were asked to discuss the classification of viruses and consider where these unusual infectious agents might have originated.

In Spring 1999, the first assignment was changed to comprise two potential topic choices namely:

1. Students were asked to discuss a microbe that had proven either environmentally or socially beneficial to human beings. Students were asked to include an explanation of the microbe's discovery, use, and normal habitat.

2. Students were asked to imagine they were a science correspondent for a local or national newspaper and had to interview or write an obituary for a famous microbiologist. Students chose the paper for which they were a correspondent and presented the interview or the obituary in the appropriate writing style for that newspaper.

The second assignment was also expanded to allow for a second potential choice in which students could examine the social, global, and historical effects of plague, discussing the disease's mode of transmission, symptoms, and progression and describing how it was finally brought under control. In Fall 1999, the third assignment was replaced with a class debate (see below).

Cooperative learning activities—mini-case histories. First introduced in Spring 1998, these mini-case histories were specifically designed for use during the laboratory periods in the second half of the course (<http://www.microbelibrary.org/FactSheet.asp?SubmissionID=494>, <http://www.microbelibrary.org/FactSheet.asp?SubmissionID=497>, <http://www.microbelibrary.org/FactSheet.asp?SubmissionID=496>). Mini-case histories were assigned to students working in groups of three or four, who were given 10 to 15 minutes to discuss the problems and work through them. A suggested strategy was for students to approach the problems by reading through the information and underlining words or phrases that were indicative of the diagnosis (e.g., laboratory data and risk factors such as recent vacations or lifestyle practices). Next, students made a list of all possible organisms suggested by this information and worked cooperatively to determine the suspected pathogen. For each laboratory period, four mini-case histories were

used, involving microbes that had already been covered in class, with one case being assigned to each group of students.

Group oral debate. The premise of the third assignment, introduced in Fall 1999, was that a global catastrophe had occurred necessitating the construction of a new "Noah's Ark" in which there was only room for one living microbial kingdom. Each course section of 14 students was divided into three groups, and each group cooperatively researched the comparative merits of one of the living microbial kingdoms, namely bacteria, fungi, or protozoa, and the negative aspects of the other two kingdoms. Prior to the class session, each student submitted an independently prepared brief list of his or her group's discussion points. Within each of the three debating groups, some students presented the beneficial aspects of their kingdom with the remainder discussing the negative aspects of one of the other two microbial kingdoms. Each student spoke for 5 to 8 minutes on his or her topic. Once all arguments had been presented, the groups responded to the criticisms raised and students were allowed to provide individual comments. At the end of the period, students voted for the kingdom whose speakers had provided the most persuasive argument. Students were informed that their assignment grade was not based on whether their group won but instead on the presentation and preparation of their argument (80% of the grade) and on a reasoned, well-argued response to the critique of the other groups (20% of the grade).

Microbiology links page. Prior to Fall 2000, students were asked to consult the staff in the Gutman Library of Philadelphia University in order to research for their written assignments and oral debate. To assist students and to provide a "jumping-off" point for them to search other areas of microbiology, the instructor spent the summer of 2000 collecting a series of microbiology web pages that covered such diverse topics as epidemics, bioremediation, the antimicrobial components of spices, and antibiotic resistance. These were assembled into a links page and placed on the instructor's website (<http://faculty.philau.edu/CundellD/links.htm>).

Student evaluation of the changes made in the Microbiology course—exit questionnaire. In order to assess how well the changes in the course had been received by students over the 5-year period, 100 of the 174 students who took the course (all those that could be reached) were e-mailed an exit questionnaire, which was also available on the website (http://faculty.philau.edu/CundellD/exit_questionnaire.htm). Students were asked to give their opinions of the importance and challenge of the course and the impact microbiology had on other courses. They were also asked to evaluate the content, ease of reading, usefulness, and interest level of the dedicated note packet and to indicate whether it encouraged or restricted their approach to the subject. Students were asked to assign a number score between 1 and 10, where 1 is poor and 10 is excellent, for the intellectual value, interest level, creativity, and appropriateness of their written assignments, oral debates, and case histories. Finally students were asked to indicate which of the website links they found of interest. Students who did not have the current writing assignments, oral debate, or case histories as part of the course were asked

to access a description of them on the website and then give an opinion as to their usefulness. Those taking the course prior to Fall 2000 were also asked to access the links page (<http://faculty.philau.edu/CundellD/links.htm>) and indicate which of the microbiology websites listed they would have accessed.

Statistical analysis. Data were examined using a commercially available statistical package (SPSS version 10.1 for Windows) and comparisons were made using either the paired *t*-test (website responses) or Wilcoxon signed rank test.

RESULTS

General information from students surveyed. Of the 64 questionnaires received, 42 were from current students (66%) and 22 from graduates (34%). Student respondents were a representative sample of the total population of microbiology students with the majority (59%) being physician assistant or premed majors and the remaining 41% comprised of biology (35%), biochemistry (5%), and environmental science (2%) majors. Most student respondents (78%) were sophomores at the time they took the course, with 14% being juniors and 8% seniors. Eighty-three percent of respondents stated that microbiology had been useful in other biology courses with the five top responses being that the microbiology course had improved their approach to science (40%), or had increased their knowledge of immunology (32%), pathophysiology (28%), anatomy, physiology, and histology (23%) and pharmacology and physical diagnosis (15%). Mean responses on the 64 student questionnaires gave the course an importance rating of 8.6 with its challenge as 8.5. Of these, the importance rating increased over the 5-year period, although not significantly (Fig. 1). The challenge rating was also not affected by major, with mean ratings from physician assistant and premedicine students and biology, biochemistry, and environmental science majors being similar (means of 8.6 and 8.5, respectively). The student perception of challenge was, however, influenced by whether the respondent was a sophomore or an upper-level student (junior or senior), with sophomores giving significantly higher ratings ($p < 0.03$, mean 8.7 compared with 7.9).

Study guide. The majority of students rated the study guides as excellent in terms of intellectual content (72%), usefulness (83%), and interest level (62%), although the ease of reading was somewhat split between excellent (53%) and good (38%). The majority of those surveyed felt that the guide encouraged further examination of the subject (76%), with 12% suggesting it restricted exploration, 7% stating it did neither, and 5% that it was both encouraging and restrictive.

Written assignments. Over the 5-year period, mean ratings for writing assignments were 8.7 for intellectual content, 9.1 for appropriateness to course, 8.8 for creativity, and 8.9 for interest. None of these ratings changed significantly following modifications in the assignment topics, although the appropriateness rating did increase from a mean of 8.7 to 9.3. This learning tool was not found to significantly impact

FIG. 1. Perception of importance and challenge of the Microbiology course over a 5-year period. Data represent means of students' numerical ratings during the five time periods. Numbers of students surveyed were 10 from 1996-1997, 9 from 1998, 15 from 1999, 12 from 2000, and 18 from 2001. Analysis of the data, using SPSS version 10.1 for Windows, showed that none of the increases observed reached significance.

either the students' perceptions of the importance or the challenge of the course (Fig. 2).

Case histories. Case histories were found to be the most popular of all the learning tools, receiving the highest ratings from students. Over the 3-year period, mean ratings for case histories were 9.3 for intellectual content, 9.5 for appropriateness to course, 9.3 for creativity, and 9.6 for interest. This learning tool was not found to significantly impact either the students' perceptions of the importance or the challenge of the course (Fig. 2).

Class debate. The class debate was found to be the second most popular learning tool, as rated by the 41 students who participated in it (64% of surveys). Introduced in Fall 1999, over the two-year period mean ratings were 9.0 for intellectual content, 8.9 for appropriateness to course, 9.2 for creativity, and 9.1 for interest. This learning tool was not found to significantly impact either the students' perceptions of the importance or the challenge of the course (Fig. 2).

Microbiology links page. All students who had access to the website (30 of the respondents) said they used it during the microbiology course (mean of 8 times, range 4 to 15). Of the eight topics covered by the website those most likely to be accessed were epidemics, protozoa, and antibiotic resistance (90%, 83% and 83%, respectively). Least likely to be used were those areas involving famous microbiologists or bioremediation (50% and 27%, respectively). Students who did not have access to the website during their course tended to be interested in similar topics, although they were more likely to look at sites on famous immunologists (85%) and bioremediation (65%) as a group. These changes, however, did not result in a significantly different overall pattern in topic selection between the two groups. Analysis of whether this learning tool impacted the students' perceptions of the importance of the course revealed that significantly higher importance ratings were given to the course after the links page was introduced ($p < 0.03$, mean of 9.4 compared with 8.5), although this was not matched by the challenge ratings (means of 8.6 and 8.4, respectively) (Fig. 2).

DISCUSSION

During the past 5 years, the single-semester, sophomore-level Microbiology course taught at Philadelphia University has been developed to include specific learning tools that have proven successful, as assessed by an exit questionnaire completed by a representative group of those who took this class. In addition, the current design of the course also appears to provide a significantly greater challenge ($p < 0.03$) to its target group of sophomore students than to juniors and seniors. Several taxonomic systems have been developed to differentiate between levels of student learning and analytical skills (2, 10). Beck and LeGrys (2) have proposed a three-level scheme involving recall, interpretive skills, and problem solving and have suggested that all three should be considered when creating an instructional program. The learning tools of written assignments, case histories, and an oral class debate not only cover all areas of Beck and LeGrys' scheme but also are deemed to be effective by the students, as judged by their evaluations. In addition, the generation of a dedicated study guide for the Microbiology course has meant that a range of topics can be covered more rapidly, students who miss class can more easily keep up with the material, and the majority of students (76%) can be encouraged to examine the subject further, as assessed by the results of the exit questionnaire. Negative comments from the survey about the study packet included one from a physician assistant student in Spring 1999, who stated "it was all right there, and inherently students become lazy when the subject matter is readily available."

Many instructors have, however, balked at active-learning techniques due to the significant time commitment required in both initial development and subsequent grading (7, 10). Developmental time for the current form of the Microbiology course was considerable, with research and generation of the dedicated study guide requiring six weeks and discussion and design of the written assignments and oral debate taking three weeks each. However, once established, modifications are nominal and mostly confined to the study

FIG. 2. Effect of learning tools on perception of (A) importance and (B) challenge of the Microbiology course over a 5-year period. Data sets shown represent means of student responses obtained both before and after a particular learning tool was instituted. For writing assignments, before data were obtained from 19 students and after data from 45; case histories, before data were obtained from 12 students and after data from 52; class debate, before data were obtained from 23 students and after data from 41; and microbiology links, before data were obtained from 34 students and after data from 30. Analysis of the data, using SPSS version 10.1 for Windows, demonstrated that neither students' perceptions of challenge or importance of the course were affected by writing assignments, case histories, or a class debate ($p < 0.1$). The introduction of the Microbiology links page on the professor's University website did, however, significantly increase students' perceptions of the importance ($p < 0.03$).

guide. Similarly, grading of active-learning assignments has been made considerably less time consuming by the establishment of clear objectives, guidelines, and grading criteria that are posted on the University website (<http://faculty.philau.edu/CundellD/assignments.htm>) and are also given to the students and to the University's writing faculty.

The earliest tools to be added to the course were the writing assignments. First introduced in Fall 1996 and modified in Spring 1999, these added to the development of creative and analytical writing skills above and beyond the existing lab reports. Student perceptions of all aspects of the topics of these assignments have been good with mean ratings of 8.9 over the 5-year period.

Learning tools receiving the highest ratings were case histories and the in-class oral debate, with mean overall ratings of 9.4 and 9.1, respectively. Mini-case histories were originally developed in summer 1998 and are now a component of the ASM MicrobeLibrary website (<http://www.microbelibrary.org/FactSheet.asp?SubmissionID=494>, <http://www.microbelibrary.org/FactSheet.asp?SubmissionID=497>, <http://www.microbelibrary.org/FactSheet.asp?SubmissionID=496>). Since receipt of the following statement from an environmental science major who took the course in 1997, "I do think that those tools were effective and should be an integral part of any microbiology course that is medical based,

while similar tools should be used for any ecological based microbiology course," the instructor is generating case studies based on environmental situations such as contamination of the water supply or soils. Interestingly, of the 12 students surveyed who were not given case histories as part of their course seven responded very positively as to how useful they would be. Indeed, one physician assistant student from Fall 1996 stated, "Case studies really make you apply what you know to real life. Instead of just having facts memorized about a particular bacteria/disease...you have to apply the facts. This is a great idea."

Introduction of the oral debate in Fall 1999 created opportunities for students to express ideas and opinions, provided flexibility in student-teacher interaction, and encouraged students to consider microbiology not only in scientific terms but also to examine the global, historical, economic, and social impact that microbes have had on our planet. Many of students come from Philadelphia and the surrounding farming areas and for them it is a revelation that the drugs and vaccines freely available in this country have little relevance to developing countries that cannot afford to purchase them. Class discussions have been suggested as a means to promote the development of higher-order questions (4, 10) and to allow students to share their experiences (8), a concept that is shared by a Fall 2000 student who wrote, "I thought

the class debate was a creative assignment and the best part of the course. It gave me a chance to view different microbes from different perspectives and forced me to be objective since I was assigned a microbe and not allowed to pick my choice to support or oppose.” Of the 23 students who took the course prior to Fall 1999, 14 student respondents were very enthusiastic about the debate although one note of caution was raised by a physician assistant major from the Fall 1998 class, “This assignment could go two ways, either it could be very interesting or it would turn out rather juvenile and less intellectually stimulating than the other assignments.” The importance of moderating the debate to foster creativity within specific guidelines is therefore underlined.

The final addition to independent, active learning for the Microbiology course, came in Fall 2000 when a set of microbiology links covering eight separate microbial topics were added to the Philadelphia University website. Of the 64 students surveyed, thirty had access to the website during the Microbiology course and, not unsurprisingly, the links most commonly accessed represented those associated with the written assignments, namely epidemics, antibiotic resistance, and protozoa. In contrast, those who did not have this learning tool as part of the course were more likely to access everything, although both groups showed a lack of interest in famous microbiologists. During Spring 1999, the writing assignment options were increased by the addition of the opportunity to be a newspaper reporter who either interviews a famous microbiologist following his/her major discovery or writes an obituary on him/her. It is hoped that this will promote the students’ exploration of the role that these past luminaries have played in the development of modern microbiology. The importance of a dedicated website as a learning tool is also underlined by the fact that it was the only tool that appeared to significantly improve ($p < 0.03$) student perceptions of the importance of the course, which is probably reflective of the computer savvy generation it is designed to serve.

Students have been shown to perform better and work harder at courses which they find relevant and interesting (8, 9). The results of this survey suggest that the construct of the current Microbiology course allows students to develop the creative and analytical skills they require, while at the same time remaining stimulating. Microbiology is typically taken at Philadelphia University as a sophomore-level course and this survey suggests it plays a significant role in the development of a positive approach to science and provides a firm foundation for many and diverse subjects. The importance of using several tools to teach science skills is echoed in the words of an environmental science major who took the course in 1997, “The integration of technology and other resources offers more educational opportunities for the students, who in return will receive a better education. It is always a good thing when a professor uses the available tools and alternative methods to the lecture models when teaching students. While some aspects may not work, use of these tools usually only has a positive effect on the class and the students.”

ACKNOWLEDGMENTS

I thank Matt Baker, Physician Assistant Program, Philadelphia University, for his constant support and advice on the content of the study-guide note packets; Gloria Delisle, Department of Microbiology and Immunology, Queens University, Kingston, Ontario, for her help and clinical advice in the preparation of the mini-case histories; John Eliason, Writing Program Director, Philadelphia University, for his advice on the preparation of this manuscript; Deborah Rossen-Knill, English Department, Rochester University, New York, for her help in the design of grading criteria for the writing assignments; John Pierce, Department of Psychology, School of Science and Health, Philadelphia University, for performing the statistical analysis; Nancy Sorkin, Writing Tutor, Learning and Advising Center, Philadelphia University, for her guidelines to students in completing writing assignments; and Tom Terry, Department of Molecular and Cell Biology, University of Connecticut, for his support and help in the preparation of the mini-case histories. Thanks also to my fellow biology educators, Edward Dowden and Rachel Wilson, for their help and advice in the construction of laboratory reports. Finally, my warmest thanks go to all the students who spent time completing the questionnaires and provided valuable insight into the Microbiology course.

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