An Evaluation of Web-Based Case Studies in Microscopy

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It is often difficult to provide students in introductory science courses with opportunities that mimic the investigative learning experience of doing research. This is particularly true in microbiology courses where advanced microscopy techniques are expensive and difficult to do. To that end, we developed three computer-based case studies around real-life scenarios. Our goals were to: (i) improve students' understanding of advanced microscopic techniques, (ii) give students practice analyzing and interpreting data, and (iii) model a scientific approach to how these techniques are applied to current issues in microbiology. Each case requires students to use references and interpret actual microscopic images, thus giving them a more realistic experience than we could previously provide. We analyzed student learning and perceptions to these case studies. After doing the case studies, students were more able to apply microscopic methods to a realistic problem, thus demonstrating an understanding of how the methods are used. Students appreciated the intellectual challenges presented by having to interpret and analyze actual microscopic images. This approach has allowed us to introduce new areas of content to our course and to stimulate critical thinking skills, a difficult task in a large introductory microbiology course.

There are many reports that question the effectiveness of the lecture-based, teacher-centered approach to teaching science (2, 10), calling instead for a focus on learning and more emphasis on developing higher order cognitive skills (13). This is particularly challenging in large, college-level, introductory biology courses, where many instructors continue to emphasize the rote learning of facts despite research that shows the benefits of investigative learning (12).

Problem-based learning (PBL) has been used to bring student-centered learning into large lecture classes. In problem-based learning, students use authentic problems to acquire knowledge and develop critical thinking skills (4). Learning is enhanced when students engage in real life problems and when the learner can apply and integrate new concepts into his/her own experience (9). By having students solve real world problems, PBL successfully links theory to practice (6) and helps students better develop their critical thinking skills (7).

Microbiology is a lab-based science, relying heavily on microscopy to reveal a world unseen by the naked eye. New molecular techniques in microscopy (such as fluorescent macro-molecular probes and electron microscopy) are driving a renaissance in microbiology, allowing scientists to dissect the complexity of natural and human ecosystems as never before. Unfortunately, because these techniques are complicated and expensive, undergraduate microbiology students do not typically have access to these new and

powerful research tools.

We know from past experience that, after lecturing to students about these methods, most students can successfully define a list of methods with high accuracy. However, when asked "Which method is best to study a given problem and why?" ; many students cannot explain how these methods are applied. We believe that students need practice using these methods before they can truly understand and appreciate them.

We were interested in developing new challenges for our students in microbiology that would help remediate these problems. Because relevant problem-solving activities are easily presented within the framework of a case study (5) and the World Wide Web can be an effective and convenient means through which to present case studies (1, 8), we developed a series of problem-based case studies for our General Microbiology course. Our goals were to: (i) improve students' understanding of advanced microscopic techniques, (ii) give students practice analyzing and interpreting data, and (iii) model a scientific approach to how these techniques are applied to current issues in microbiology.

MATERIALS

Description of Case Studies in Microscopy. *Case Studies in Microscopy* contains three web-based case studies that ask students to interpret microscopic images to solve real-world problems. The URL for the site is <http://instruct1.cit.cornell.edu/courses/biomi290/microscopycases>. In the first case study, "Cryptosporidium and the New York City (NYC) Watershed," students interpret images from fluorescence microscopy to decide whether or not New York City should have to filter its drinking water supply. In "The Fatal Flu," a case based on the severe acute respiratory

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syndrome (SARS) epidemic, students determine the cause of an outbreak using information from Gram stains and fluorescence and transmission electron microscopy. In addition, a third case study was developed after this study. In “Battle of the Biofilms,” students use fluorescence microscopy to determine how to best treat a *Legionella* biofilm found in a cruise ship whirlpool.

All the cases are structured to model a scientist’s approach to a research question: one must research the problem, understand and apply experimental methods, analyze results, then come to a conclusion. Each case begins with an introductory screen that presents the problem and puts the student in the role of a scientist who must ultimately make a recommendation that has some social consequences. Next students are prompted to explore background information about the environment, the disease, various microorganisms, and the microscopic techniques available. The site was designed as a closed case study (3) and contains all the information needed to complete the assignment, such as links to relevant references from the scientific and public press. Next students are presented with the results from various microscopic tests. Cases contain up to three sets of data that are presented as images of micrographs of actual results (Fig. 1) which students must observe and interpret. As in real life, the results are not always clear-cut and require some interpretation. A companion paper worksheet containing a series of directed questions was provided as a PDF file to guide students through the case. Previous experience has shown us that students pay more attention when they have specific questions to answer (11).

At the end of each case, students were required to write a summary of the results and a recommendation for action in a one to two page essay. For example, the instructions for the *Cryptosporidium* case were: “Based on the information presented in this case study, do you think it is necessary for NYC to filter its water supply to control the spread of *Cryptosporidium*? Support your decision with appropriate evidence and arguments.” The instructions for the Fatal Flu case study were: “As an epidemiologist, you must now write a report to the World Health Organization regarding the outbreak. Based on the information presented in this case study, what do you think caused the outbreak and why?” The cases are increasingly more complex with respect to the data presented and the difficulty of interpretation.

This site was designed in collaboration with faculty and instructional, graphic, and web designers. Using Macromedia’s Contribute software, faculty can add and edit the cases as needed.

Implementation in the course. These case studies were evaluated by students enrolled in the General Microbiology lecture and lab courses. Students took a pretest 1 week before the first case study (*Cryptosporidium*) was assigned as a homework assignment. Students were told to visit the website and view the *Cryptosporidium* case study. One week later, they were required to hand in a final essay worth 10 points (out of a total of 220 points). A few weeks later, students were assigned the Fatal Flu case study and were

asked to turn in a 10-point essay after 1 week. Evaluation forms were filled out immediately after completing each case study. Two weeks after the Fatal Flu case study was due, students answered questions on a final exam as a posttest. With the exception of the pretest, all of these activities were done by students in the lecture course. Unfortunately, we could not administer the pretest in the lecture class, so we had to give it in a lab recitation. Of the 184 students in the lecture class who did the activities, 61 students took the pretest in the lab recitation. Because we have only one section of microbiology per semester, we were unable to do a controlled study of students who did the case study versus students who did not.

This study was done as part of a course evaluation, so therefore qualified for exemption from the Cornell University Committee on Human Subjects.

METHODS

Formative evaluation. We evaluated the design and pedagogy of these case studies throughout the development stage. Three undergraduate and three graduate students were asked to go through the cases and the worksheets. We conducted group interviews and solicited written feedback from these students. Substantial feedback was incorporated into the website and worksheet design.

Evaluation of learning outcomes. (i) Control variable (pretest). The pretest consisted of a matching question about the definition of the direct fluorescent antibody assay and two open-ended questions:

- “Explain why the direct fluorescent antibody assay would be a good method to use to determine if your roommate’s potato salad contains *Salmonella*.”
- “Explain why transmission electron microscopy would be a good method to use to identify the cause of a viral outbreak.”

This material was covered briefly in lecture approximately 1 month earlier but was not emphasized. Students were told that the purpose of the pretest was to help evaluate these case studies, and their score did not count toward their grade.

(ii) Dependent variable (posttest). The posttest consisted of three questions on the final exam for the lecture course, one multiple-choice question about the definition of the direct fluorescent antibody assay and two open-ended questions:

- “Give one reason why the direct fluorescent antibody assay is a good method to use to identify *Cryptosporidium* in water samples.”
- “Give one reason why electron microscopy is a good method to use to identify a new emerging viral pathogen.”

Our analysis includes only the grades from students who had taken the pretest and posttest and turned in both final essays ($n = 61$).

Evaluation of student perceptions. We investigated students’ perceptions of learning and the benefit of the case studies through a web-based questionnaire with both Likert-

Case Studies in Microscopy

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Cryptosporidium and the New York City Watershed

Your Results

Now that you know how to find *Cryptosporidium* in the environment, it is time to get some samples from the watershed. The map below shows the NYC reservoir system.

As you look at your results, record them on your worksheet and answer the questions in Part 3 at this time.

sampling site: **Cow Manure**

You collected 5 manure samples at different times over the course of a week. Manure samples were mixed with sterile, distilled water and filtered through 0.45 μm filters to catch particles. The filters were treated with the *Cryptosporidium* fluorescent antibody and rinsed.

Microscopic fields of samples treated with fluorescent antibodies and viewed using fluorescence microscopy. Note the 5 μm marker bar.

References

[> Worksheet](#)

NYC watershed

[> Map](#)
[> History](#)
[> Agreement](#)

Cryptosporidium

[> Life cycle](#)
[> Disease 1](#)

Methods

[> FISH](#)
[> Fluorescent antibodies](#)
[> Gram stain](#)
[> Phase contrast](#)

FIG. 1. Screenshot from the results section of the “*Cryptosporidium* and the NYC Watershed” case study, showing a map of the sampling sites within the watershed, the microscope images for that sample (in this case, cow manure), and the reference bar on the right.

type and open-ended questions. Students were given one extra point (out of a total of 220 points) for filling out each questionnaire. About 180 students filled out the evaluations, but not every student answered every question. In the Likert-type questions, students were given a statement and were asked to strongly agree, agree, disagree, or strongly disagree (Fig. 2). Here, we present data for three open-ended questions, for which students wrote their own responses. The questions were: “What did you like most about the case studies?” “What did you like least about the case studies?” and “Please elaborate on your experience writing the final essay.” Open-ended written comments were

analyzed by subjectively grouping similar responses. Results are reported as the number of responses that fit into a given category (Table 2 and 3).

Statistical analysis. All the pretest and posttest questions were marked as either correct or incorrect. We assessed learning outcomes by doing a paired *t* test analysis on the pre- and posttest scores ($n = 61$). Results are reported as the percentage of students who got each pre- and posttest question correct, with the *P* value from a paired *t* test analysis comparing pre- and posttest scores (Table 1).

For the Likert-type questions, students were given a choice of: strongly disagree, disagree, agree, and strongly

agree. Each response was given a score of 1 (strongly disagree) to 4 (strongly agree). Results are reported as the averages and standard deviations of the responses for each question (Fig. 2).

RESULTS

Evaluation of learning outcomes. Table 1 shows the percentage of students who got each question correct, for the pre- and posttests. The results of a paired *t* test showed students performed significantly better on the posttest in all cases ($P < 0.05$; $n = 61$). Many students confused direct and indirect fluorescent antibody methods in the matching questions on the pretest. Given this, it is not surprising that many students were unable to apply the direct fluorescent antibody method (Q2). However, students seemed to understand these differences much better in the posttest. And although many more students were familiar with electron microscopy before the activity, some students were better able to apply this method after doing the case studies.

Evaluation of student perceptions. (i) Likert-type questions. We investigated students' perceptions of learning by having students answer an evaluation questionnaire with Likert-type questions (Fig. 2, questions 3–5). These results show that most students agreed that both case studies helped them to better understand the microscopic techniques and how scientists approach a research question.

We also used Likert-type questions to investigate how students utilized resources in the case studies (Fig. 2, questions 6–9). Most students agreed that they found the readings interesting. They indicated that they read each reference fully, rather than skimmed them. When asked directly how they decided which method to use, 77% of all students (in the *Cryptosporidium* case study) indicated that they used the references, compared to 16% who relied on previous knowledge, or 8% who guessed. In the Fatal Flu case, 84% of students indicated that they used the references to help them interpret the microscopy results, while 15% used previous knowledge.

(ii) Open-ended comments. To obtain a qualitative measure of the students' overall perception of the case studies, we asked open-ended questions and subjectively categorized each response into one of several categories

(Table 2). The most common response to the question: "What did you like most about this case?" concerned analyzing and interpreting the results. For example, "I liked being able to take a lot of information and formulate my own ideas about it, instead of having to answer very directed questions." Students stated that they enjoyed learning about the content and applying information to real-world scenarios. "I liked learning about a current real life problem, because sometimes I feel like I live in a bubble and do not understand much about what is happening outside of Cornell University."

Related to this were responses concerning the images. Students commented that they appreciated that the results were given as images of real micrographs that they had to interpret. For example, "Actually being able to collect virtual samples and interpret them as one would in a lab, especially since they were actual microscopy slides and not some hand-drawn graphic." For the *Cryptosporidium* case, which was given first, many students remarked that they appreciated having the activity on the Web, both because of the images and because they could do the activity at their convenience.

For the *Cryptosporidium* case, the most common response to the question "What did you like **least** about this case?" concerned reading all the references, "Having to find the answers in the huge amount of reference material." For the Fatal Flu case, many students had trouble interpreting the Gram stain images. "Those confusing Gram stain results. I guess the point was it's not bacteria, but there could've been a hint or two."

Many students commented that they thought the activity took too much time. A common comment was: "It was a lot of work for 10 points." Our survey revealed that 17% took under 1 hour, 25% took between 1 and 1 1/2 hours, 25% took between 1 1/2 and 2 hours, and 33% took over 2 hours to complete the case study and write the essay.

Some students didn't like writing the essay. "I did not enjoy writing the final conclusion. I think learning about it was enough." "I didn't like writing an organized paper with all of our thoughts." To further explore the students' experience with writing the final essay, we asked the open-ended question, "Please elaborate on your experience writing the final essay." The responses were again categorized and counted (Table 3). One of the most common responses was

TABLE 1. Percentage of students who got pre- and posttest questions correct^a

Question	Pretest (%)	Posttest (%)	<i>P</i> value ^b
Q1) Matching question on definition of direct fluorescent antibody method	25	90	<0.001
Q2) Open-ended question on the use of direct fluorescent antibody method	42	60	0.02
Q3) Open-ended question on the use of electron microscopy	73	98	<0.001

^a $n = 61$.

^bPaired *t* test analysis comparing pre- and posttest scores.

that writing the essay was straightforward. For example, “I was able to put all my results and data together to write a knowledgeable response and was able to back it up with facts.”

Related to this, students commented that the worksheet was very helpful in organizing the information. Comments included: “I went back to the questions in the worksheet to help direct my thoughts and organize my ideas.” “[It was] relatively easy to follow, quick to write because the worksheet organized ideas.”

Not surprisingly, students had different views on the case studies. Many students noted that they felt the case studies were challenging and that they learned a lot. “It took a long time to understand all of the concepts, but once I started writing it all came together for me.” “Writing the response to the concluding question helped me to understand the problem and to analyze the data more effectively.” Others complained that they didn’t have enough information to answer the questions adequately. “I was confused about what exactly the question was asking. The data all seemed to conflict and I wasn’t sure if that was the point of the activity or if I was just missing something.”

Particularly with the *Cryptosporidium* case, students felt that writing the essay took too long or they didn’t like having

to write one to two pages (the recommended length). “It seemed to be a lot of reiteration of information already expressed on the worksheet.” “I felt a lot of information needed to be collected and sorted through before the actual writing could begin.”

DISCUSSION

Our first goal was to improve students’ understanding of advanced microscopic techniques. The results from the pre- and posttests (Table 1) show that students better understand the microscopic methods after doing the case study. While it doesn’t tell us if the case studies are more or less effective than other types of instructional methods, we did achieve our goal. In our case, because the activities are self-directed and were done outside of class, we were able to introduce new material to the class without sacrificing material we were already teaching.

In addition, students believe that the case studies helped them to understand how the techniques work and how they are used (Fig. 2). The understanding of **how** these techniques are used is especially important to us, because previous students seemed to have difficulty in applying these methods to new situations. While we were not able to bring the actual experimental methods into our classroom, the case studies

FIG. 2. Responses from General Microbiology students after completing the *Cryptosporidium* (●) and Fatal Flu (■) case studies. Responses were given values (1 = strongly disagree; 4 = strongly agree) and are reported as average $\pm$ standard deviation.

TABLE 2. Number and different kinds of responses (out of total number of responses) from students asked open-ended questions about the case studies

Question	Type of response	Number of responses	
		<i>Cryptosporidium</i> case study	Fatal Flu case study
What did you like most?	Analyzing and interpreting the results	44	41
	Learning about the content	29	32
	Applying the information to a real-world problem	29	21
	Viewing the visual images	20	16
	Accessing the activity on the Web	34	6
	Other	10	9
	Total responses	166	125
What did you like least?	Reading the references	58	9
	Interpreting the Gram stain	n/a ^a	32
	Interpreting the results	14	9
	Writing the essay	26	15
	Answering the worksheets	9	12
	Spending too much effort or time	23	9
	Other	27	22
	Total responses	157	108

^an/a = not applicable.

TABLE 3. Number and different kinds of responses (out of total number of responses) from students asked to elaborate on their experience writing the final essay

Kind of response	Number of responses	
	<i>Cryptosporidium</i> case study	Fatal Flu case study
It was straightforward	36	23
There was not enough information	29	45
I learned and/or was challenged	21	27
It took too long/The essay was too long	27	5
The worksheet was helpful	11	19
It was interesting	19	4
Total responses	143	123

allowed our students to think about microscopy in ways that were not previously possible.

Our second goal was to give students practice analyzing and interpreting data. The essay was the mechanism through which students were asked to bring all the information together. Some students appreciated the value of summarizing and analyzing the information and found it interesting and challenging. They saw value in using the worksheet to organize ideas and help them understand the important issues. The worksheets had a table in which to write results, which many students remarked was helpful to them. It was important for us to keep in mind that some of our students need help in developing analytical skills, such

as how to organize data and information. Some of our most venomous comments were about the writing assignment because it took too long, was too difficult, or was redundant. However, we feel that the benefits of writing the essay in terms of developing critical thinking skills far outweigh the complaints.

Students clearly appreciated learning about relevant problems. These problems were particularly interesting to our students because many Cornell students live in or near New York City and because many had heard of the SARS epidemic, but didn't know that much about how the virus was identified. Many students noted that because the material was interesting, they enjoyed reading and answering

the questions. Presumably, this involvement with the material should lead to more learning.

Our third goal was to model how scientists approach research problems. When given a new research problem, a scientist first defines the problem, thus limiting the specific information needed. As one begins searching the literature, one would skim a wide range of resources to determine which are most relevant. These would then be read more thoroughly before deciding in which direction to go. In our case studies, we tried to mimic this approach by first presenting the problem, then giving students a worksheet with defining questions to direct them to the relevant information. Students were told that this was the purpose of the worksheet. With these in hand, we expected students to skim the resources provided as they looked for the answers to the questions. While students agreed that the case studies helped them model how scientists approach a problem, other questions revealed some surprises as to how students were using the references (Fig. 2). Most students thoroughly read all references; many fewer skimmed the reference until they found the answer. While the references clearly helped them understand how to choose the appropriate method or interpret the results, this approach was problematic to some students. The *Cryptosporidium* case study in particular had some lengthy references on Environmental Protection Agency methods and the NYC watershed plan. While some of the information was directly related to the case study, some of it was peripheral. Also, some references presented similar information in different ways. This led to some comments that students didn't like some references and the perception that the case study took too long (Table 2). This study made it clear to us that some of our students need guidance as to how to best utilize references and their time.

Another way we tried to model research science was to present students with images of actual micrographs that they then had to interpret. Students' responses to this reinforced what most educators know—that students like to be creatively and intellectually challenged. Again, there were differences in the two case studies. The interpretation of the results in the *Cryptosporidium* case was very straightforward. The challenge was not so much in interpreting the micrographs, but in choosing the methods and figuring out what the information meant with respect to the movement of pathogens within the NYC watershed. By contrast, there were three different methods involved in the Fatal Flu case (Gram stains, direct fluorescent antibody assay, and transmission electron microscopy). As was true in the real quest for the SARS pathogen, the results of all three tests did not fit together perfectly. The Gram stains of human sputum had some human cells that confused some students. (We have since clarified the Gram stain section.) Some students thought the results from the direct fluorescent antibodies assay conflicted with the transmission electron micrographs. However, after thinking about the problem, most students realized that there was an interpretation that

accounted for all results. The students who discovered this appreciated the challenge of analyzing difficult results; those that didn't became frustrated.

Many students appreciated the way the case studies were presented. The *Cryptosporidium* case was given first, and one-fifth of the responses to "What do you like most" were about accessing the Web (Table 2). They had few problems using the site, and they appreciated the convenience. They liked the simple design and the visual images themselves. From our perspective, the Web allowed us to incorporate colorful and intriguing images that we could not have used in paper-based activities. Because the case studies are self-contained, distribution to our students, as well as any others who would like to use the material, is free and easy, and information can be updated and edited with little effort.

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