Serial dilution and plate counting is often taught in courses for both microbiology and allied health students. Lecture examples and examination questions addressing how the method is used can sometimes be contrived: artificial data sets may have little or no meaning other than to have students perform a calculation. Here we provide a set of activities employing data sets acquired from the primary literature. Our objective was to have the students think critically about a real scenario in which serial dilution and plate count was used. Each activity requires students to read a paragraph describing the study, predict the results, perform the appropriate calculations, and then evaluate the results in light of their predictions. To test the efficacy of these activities, a pretest quiz was given to approximately 100 students in an allied health/general microbiology course. After a lecture on how microbes are enumerated, students were given a different quiz. The class was then divided randomly into groups of three or four students and assigned one of the activities. A postactivity quiz was also administered. Approximately two weeks later, a serial dilution/plate count question was used on an examination and served as a final posttest. Standardized learning gains were calculated for the quiz administered after each learning activity. Even though learning gains were significantly higher after the lecture, there was also a significant improvement between the lecture and the activity. Using an exercise based on an authentic set of data significantly improved student learning gains, and is a useful practice for teaching microbiology.

INTRODUCTION

Active learning strategies often use practice problems or assignments to reinforce core concepts. Such activities have become increasingly popular in science classrooms, as instructors focus more on student learning than just on lecturing (4, 7). Higher-order thinking skills in science courses should require students to synthesize, analyze, and evaluate (1, 2). For example, serial dilution and plate count problems can often be contrived and focus merely on calculations. One solution is to create activities using authentic data and scenarios derived from the primary literature.

Authentic learning has been defined as activities that engage students in exploring and discussing real-world problems in ways that are relevant to them (3). Carlson claims that there are three principles of authentic learning that can be employed for classroom activities (3). First, authentic learning is student-centered — meaning that students should be free to engage in discussions with other students, to ask questions, pose hypotheses, and evaluate data. Second, students need to learn actively by asking questions, discussing problems, and trying to reach a solution. Third, activities must be “authentic” — in other words, they must involve real data and/or situations. Students should be able to place what they’re learning in the context of the scientific method; additionally, instructors should develop authentic activities relevant to the subject matter at hand.

Employing authentic activities is not new to instructors of microbiology. Case studies in which students examine a patient history, diagnose the disease, and propose a treatment strategy, for example, is an authentic exercise. A case study involves a real-world problem and one that may have personal significance to the student. There can be discussion with other students, asking questions, and evaluation of data. In inquiry-based laboratory courses where students develop their own hypotheses and experiments, authenticity is also obvious. Students can work with real samples, analyze the data, and develop appropriate conclusions. Engaging students in authentic exercises allows students to make connections to their existing knowledge, develop relationships between procedures and practices, and to explore concepts in a new context (5). In the microbiology classroom, such authenticity may not be as easily achieved because the experimental aspect of the discipline is missing. Additionally, the length of time often associated with authentic activities may seem prohibitive (6).

Our objective was to create a set of brief activities with authentic datasets using data from the primary literature.
In research articles, only the values from a serial dilution and plate count that are statistically relevant are reported. Generally, this includes plates on which there are between 30 and 300 colonies. In order to demonstrate that more than one dilution was included in the experiment, values that were not reported in the literature needed to be fabricated. It is emphasized that fabricated data points used in our activities are instructive only to illustrate that additional plates were used and that they were and are not statistically meaningful. The primary purpose of these activities was to have students employ higher-order thinking skills when considering enumeration of microorganisms by the plate count method. We also wanted to emphasize the significance of this technique in a variety of areas of microbiology that we usually don’t stress or have time to address.

**Intended audience**

While this activity was created for an allied health/general Microbiology lecture course with 100–200 students divided into small groups, it is still appropriate for Microbiology and Biology courses with lower enrollments or for students working individually. The activities may be used in classes with or without a laboratory component. Specifically, they may be used as a pre- or postlaboratory exercise.

**Learning time**

Each activity is comprised of the following:

1. An introduction describing the setting and experimental design.
2. Questions requiring the students to form hypotheses.
3. Data for computation and analysis.
4. Follow-up questions for the evaluation of student hypotheses.

Assuming prerequisite student knowledge (see intended audience), each activity is designed to be completed within 20 minutes.

**Prerequisite student knowledge**

Students should understand the scientific method, serial dilutions, colony-forming units, plate counts, and dilution factors before participating in the activity.

**Learning objectives**

At the completion of this activity, students should be able to:

1. Read a descriptive paragraph and form hypotheses based on the information provided.
2. Calculate the standard plate count from a set of data.
3. Analyze and draw relevant conclusions from the data they calculated.

**PROCEDURE**

**Materials**

Students will need one or more of the handouts and a calculator. Instructors will need the instructor version of the handouts, which includes an answer key.

**Student instructions**

The class is divided into small groups of 3 or 4 students and provided with one of the handouts (see Appendices 1–4). They are instructed to read the descriptive paragraph and form a hypothesis. For example, they might write a response to the following question: Of the kitchen or bathroom, where might you predict there will be more bacteria? Next, they are instructed to determine the standard plate count for the dataset provided on their handout and to complete a results table. Students then must analyze the data they generated to evaluate their hypothesis. For example, they are asked questions such as: Where are the most bacteria found in the home? How does this answer correspond with your hypothesis from question 1? Finally, other questions are asked that require development of other hypotheses and evaluation of them using the dataset.

**Instructor notes**

As part of our 80-minute class, a brief (15-minute) lecture was delivered, introducing students to ways by which microbes are enumerated. Included in the lecture were the principles of serial dilution and plate counting. It was stated that this method is used in a variety of areas of microbiological study, including water and food analysis, hygiene, and environmental testing.

Following the lecture, the class was asked to form into groups of 3 or 4 students. Each group was given one of four different handouts and instructed to proceed. The students were informed that similar questions would appear on their examination. Student discussion was encouraged; however, each student was required to record his or her own response. Answer keys and comments for the instructors are contained in Appendices 5–8.

**Suggestions for incorporating activities and determining student learning**

Since these activities are designed to take 20 minutes, there is easily enough time to complete this activity within a 50-minute class period. Our field-testing fit a pretest, the lecture, activities, and posttests within an 80-minute class period.

In our field-testing and in subsequent use of these activities, we have used the handouts as small group assignments. However, they may be used in a variety of different ways. For example, the activities might be given as an individual or group homework assignment, and either as a single handout...
or as a packet. The activities may also be used as part of a dry laboratory exercise to reinforce the utility of serial dilution and plate counts.

The activities themselves were not graded in our class. However, the pre-, postlecture, and postactivity tests were graded for our assessment of student learning only. These scores did not count as part of their grade. By contrast, we did ask questions on the midterm examination to assess retention of the concepts of serial dilution and plate counts.

For an instructor, these activities may be used as part of a lecture, with the calculations done as a class. Alternatively, parts of the handouts can be employed as test questions. Instructors could grade these assignments and inform the students that they would be used as part of their formal assessment in the class.

Sample data

Student consent to participate in this study was given by signature on the pretest forms. Consequently, data generated for students that chose not to participate have not been included here. Examples of student work are provided in Appendix 9. The relationship between learning outcomes and all assessments are represented in Table 1.

DISCUSSION

Field testing

This activity was tested in a general Microbiology course at Brigham Young University and has been used for the past four semesters. The class included approximately 100 students who identified themselves as majoring in disciplines other than Microbiology. More specifically most were allied health majors. The activity was field tested in winter semester 2010. It has since been used each semester in that course, and in an Introductory Microbiology class for students majoring in Microbiology.

Prior to the field-test class period, students were given access to slides for a PowerPoint presentation. The slides included information about serial dilutions and plate counts. At the beginning of lecture, a short, four-question pretest was administered (see Fig. 1). It consisted of calculating the standard plate counts for four sets of data. Students then listened to a brief lecture on enumerating microorganisms, including the use of serial dilutions and plate counts. Terms such as “standard plate count” and “dilution factor” were defined. Explanations were given regarding the appropriate ways to select or calculate the correct dilution factor and how to calculate the standard plate count. Since no specific discussion about the pretest had occurred, students were then given the pretest as a short postlecture test.

Immediately following the postlecture test, the class was divided into groups of three or four students and given

![Yeast, Schizosaccharomyces
Lactobacillus bulgaricus is species of bacteria often used to cultivate yogurt. To examine the effects of galactose (a sugar) on growth of L. bulgaricus, a growth experiment was conducted. The same volume of a logarithmically growing culture was inoculated into fresh medium with and without galactose. After a period of time, growth was determined by performing a serial dilution and plate count for each treatment. The results of the experiment are recorded in Table 1.

<table>
<thead>
<tr>
<th>Dilution</th>
<th>Time 0</th>
<th>Time 8 h</th>
<th>Time 0</th>
<th>Time 8 h</th>
</tr>
</thead>
<tbody>
<tr>
<td>10^{-1}</td>
<td>1722</td>
<td>TN TC 1735</td>
<td>191</td>
<td>439</td>
</tr>
<tr>
<td>10^{-2}</td>
<td>1</td>
<td>74</td>
<td>1</td>
<td>44</td>
</tr>
<tr>
<td>10^{-3}</td>
<td>0</td>
<td>7</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>10^{-4}</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10^{-5}</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

1. What was the standard plate count for the culture growing without galactose at 0 hours?
2. What was the standard plate count for the culture growing without galactose at 8 hours?
3. What was the standard plate count for the culture growing with galactose at 0 hours?
4. What was the standard plate count for the culture growing with galactose at 8 hours?

FIG. 1. The pretest used to determine student ability to determine plate counts given a small set of authentic data.

<table>
<thead>
<tr>
<th>Learning Objective</th>
<th>Type of Question Asked</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Read a descriptive paragraph and form hypotheses based on the information provided.</td>
<td>Having read the paragraph provided, predict what the effect of microwave on the microbial count for both scrubbing pads and sponges.</td>
</tr>
<tr>
<td>2. Calculate the standard plate count from a set of data.</td>
<td>Using the data from Table 1, determine the plate count for each treatment and record your results in the table below.</td>
</tr>
<tr>
<td>3. Analyze and draw relevant conclusions from the data they calculated.</td>
<td>What do these data inform us about the use of microwave to control microbes in kitchen sponges and scrubbing pads? How do these results correspond with what you predicted?</td>
</tr>
</tbody>
</table>
one of the four learning activities (see Appendices). Students could ask questions of the teaching assistants and instructor, and appropriate time was given to complete the activity. The different studies described in the student handouts were then briefly discussed as a class. The discussion highlighted the relevance of serial dilutions and plate counts to different areas of microbiology. Next, students were given another activity as a short postactivity test, which was similar to the postlecture test administered previously.

Evidence of student learning

One pretest and three posttests were used to assess student learning. Scores were only analyzed for students who were present for all four tests (n = 96) and are shown in Table 2.

Normalized learning gains were calculated for each student, and the class means for each assessment were evaluated using a one-way analysis of variance. Furthermore, the means were compared for significance (p < 0.05) with Dunn’s Multiple Comparison Test (Fig. 2).

Our field-test data show that not one student in the class was able to calculate a simple standard plate count problem prior to the lecture. They also show that, although students learned how to calculate the standard plate count as a result of the lecture, their learning gains were significantly greater following the activity. Our data also demonstrate that students were still able to perform the calculations, at least through the exam. A serial dilution problem was given on the comprehensive final examination, but that question and those data are not reported here.

Our data support the assertion that these learning activities significantly increased student learning beyond that of a lecture about serial dilution and plate counting. Ideally, our analysis might have directly used a control section of the class in which only a lecture was given, but in which authentic activities were not. However, the postlecture assessment effectively demonstrated that learning gains were considerable (0.68) following the lecture, but not as effective as the activity was (0.92). It is difficult to uncouple the effects of the lecture on the activity since they were used sequentially, but this is how the material would generally be taught.

Possible modifications

These activities may be used in a variety of ways other than how we field-tested them here. For example, they may be used as homework assignments for groups or as individuals when each topic is presented in class. They may also be used for group or individual student presentations.

While not presented in the activities described in this article, further data may be extracted from the primary research paper and used to expand the learning activity. For example, the article used for Appendix 1 has plate count data for enterococci, total coliforms, and E. coli. Additionally, the research literature is continuously providing new and relevant examples of how serial dilution and plate counts are used in studying microorganisms.

Suggested resources


Supplemental materials

Appendix 1: Student Handout
Appendix 2: Student Handout
Appendix 3: Student Handout
Appendix 4: Student Handout
Appendix 5: Instructor Notes
Appendix 6: Instructor Notes
Appendix 7: Instructor Notes
The authors declare that there are no conflicts of interest.

REFERENCES


