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Cooking From Scratch: Development of Inquiry Based Activities for the General Microbiology Laboratory

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Introduction

A truly interactive learning setting provides opportunities for students to process, interpret, and internalize the concepts they experience through direct, hands-on experience followed by discussion and expression of the concepts (Leonard, 2000). Hake (1998) defined interactive engagement methods as strategies designed to promote conceptual understanding through activities which yield immediate feedback through discussion with peers and/or instructors. In a survey of 6,000 physics students, he found these methods increase the effectiveness of introductory mechanics courses well beyond that obtained in traditional practice.

One strategy to create an interactive learning experience is through the use of inquiry, where students are presented with questions to be answered, problems to be solved, or a set of observations to be explained (Bateman, 1990). The effectiveness of this approach has been documented in college-level science courses through studies such as those of Waggoner, Schaffner, Keller, & McArthur (2004). These investigators found that the incorporation of inquiry-based activities into the undergraduate introductory biology laboratory resulted in increased self-efficacy for most of the 1,500 participants and achieved the overall goal of improving student confidence in their laboratory abilities.
Another important component of an interactive setting is collaborative or cooperative learning, through which students work together to achieve shared goals aimed at joint completion of specific tasks and assignments (Johnson, Johnson, & Smith, 1998). McCarthy and Anderson (2000) used collaborative exercises to diversify college students' classroom experience and found that students who participated in these activities did better on subsequent standard evaluations that their traditionally instructed peers. Miller and Groccia (1997) examined the impact of a cooperative learning format in the teaching of introductory biology. They found that the cooperative learning experience provided a level of stimulation not found in the traditionally taught course, as evidenced by higher levels of student satisfaction and increased abilities to independently find information and to work with others. Springer, Stanne, and Donovan (1999) reported that various forms of small-group learning are effective in promoting greater academic achievement, more favorable attitudes toward learning, and increased persistence through science, mathematics, engineering, and technology courses and programs at the undergraduate level.

In an effort to improve student learning, a series of laboratory exercises was developed to engage undergraduates in a general microbiology course in inquiry-based, collaborative activities involving research techniques. The rationale for this project was that undergraduate students rarely gain direct exposure to many of the tools and techniques that are vital to the modern-day field of microbiology. They are instead relegated to learning about these advances in lecture presentations that do not involve hands-on, investigative activities. It was hypothesized that improved understanding and appreciation of the techniques would be exhibited if students were provided with the opportunity to practice them directly. The project also provided a venue to extend efforts to incorporate the work of minority scientists into the general microbiology curriculum (Wagner, Havner, & Taylor, 2011).

**Methods**

**Activity 1. Electron Microscopy Exercise**

A laboratory exercise that immersed undergraduate general microbiology students into hands-on investigations using scanning and transmission electron microscopes was developed. Students first learned the components, care and maintenance of brightfield microscopes and viewed specimens such as plankton, yeast, and bacteria using low-power, high-dry, and oil immersion lenses. During the next lab period, the class met in the Stephen F. Austin State University (SFASU) Electron Microscopy Center where they learned about preparing specimens for viewing with scanning (SEM) and transmission (TEM) electron microscopes (Bozzola & Russell, 1999). They viewed the support equipment required for this purpose, including the process of ultramicrotomy used to produce sections of tissue for the TEM. In groups of 4-6, the class examined specimens under both electron microscopes, with the principles of image formation explained at each instrument during the observation session. The students then worked in teams to interpret electron micrographs of bacteria and fungi; examples are shown in Figures 1 - 3. The image stations were designed compare image formation by the TEM (Figure 1) and SEM (Figure 2), review the characteristics of prokaryotic and eukaryotic cells (Figure 1), introduce differences between bacteria and fungi (Figures 1 - 3), and compare resolving power
between electron microscopy (Figure 3) and light microscopy in an investigative, collaborative manner.

A pre- and post-test was designed to measure the students’ comprehension of basic concepts important to the project as well as overall course goals. These concepts included an understanding of resolving power and how it is affected by the wavelength of illumination, how images are formed by compound light and electron microscopes, how specimens are prepared for light and electron microscopy, and the applications of different forms of microscopy. The test included both objective and subjective questions and was administered to a total of 17 students before they began the electron microscopy lab and a second time after they had completed all lab activities related to this project.

Figure 1. Transmission electron micrograph used to illustrate image formation by the TEM and review the characteristics of eukaryotic cells.
1. Describe what you see in this micrograph.

2. What type of microscope was used to acquire this image? How do you know?

3. Is the organism prokaryotic or eukaryotic? Explain.

Figure 2. Scanning electron micrograph use to illustrate image formation by the SEM and characteristics of bacterial cells.

1. Describe what you see in this micrograph.

2. What type of microscope was used to acquire this image? How do you know?

3. Based on the structures depicted, is the organism a bacterium or a fungus? Explain.
Figure 3. Scanning electron micrographs use to illustrate characteristics of bacterial cells and the resolving power of the SEM.

This micrograph depicts spherical shaped bacterial cells. Approximate the size of these cells. Explain your method for making this estimation.

Activity 2. Transformation Exercise

This lab exercise had two major goals. The first was for the students to learn about recombinant DNA technology and its application by conducting a hands-on exercise on bacterial transformation. The second goal was for the students to study the life and career of Lydia Villa-Komaroff, a pioneering Hispanic scientist in biotechnology. In 1978 she was the lead member of the first research team to transform bacteria to produce human insulin.

Before conducting the laboratory exercise, the students were introduced to principles and application of biotechnology through the use of PowerPoint presentations in lecture and lab. The lab period occurred right after the lecture period for the course, thus allowing a transparent transition between lecture and lab activities.

The students subsequently conducted the transformation lab exercise using procedures similar to those developed by Villa-Komaroff and her colleagues (Villa-Komaroff et al., 1978) to transform *Escherichia coli* to express Green Fluorescent Protein. The materials for this activity were
included in a kit provided by Carolina Biological Supply Company (Burlington, NC). In this procedure, colonies of *E. coli* cells growing on Luria Broth agar plates were collected and added to a solution containing calcium chloride. Exposure to the calcium chloride made the cells competent to receive foreign DNA. The cell solution was then mixed with exogenous plasmids that contained the DNA that encodes for a green fluorescent protein and ampicillin resistance. The cells were subsequently heat-shocked to receive the plasmid DNA and inoculated onto Luria Broth Agar plates containing ampicillin. After incubating at 37°C overnight the plates were observed for colony development.

A second activity was performed in groups of five using an inquiry-based, collaborative approach. Students investigated the *Life and Times of Lydia Villa-Komaroff* using a time line method. Each group worked together to answer questions about one portion of the time line using references provided by the instructors; sample questions are included in Table 1. This period of discovery was followed by an open discussion in which each group presented their findings to the rest of the class. References for this portion of the exercise included Gale Cengage Learning (2012), Villa-Komaroff (2008), and Women in Technology International (1996).

**Table 1**

**Questions included in the "Life and Times of Lydia Villa-Komaroff" portion of the transformation lab exercise.**

<table>
<thead>
<tr>
<th>Family History</th>
<th>Education</th>
</tr>
</thead>
<tbody>
<tr>
<td>• When and where was she born?</td>
<td>• How did Texas College help her get into science?</td>
</tr>
<tr>
<td>• How is her family connected to Pancho Villa?</td>
<td>• What made her change her major from chemistry to biology?</td>
</tr>
<tr>
<td>• Which relatives shared as good role models; in what ways?</td>
<td>• Women made up ___ of her graduate class at MIT. Did this have an effect on her work?</td>
</tr>
<tr>
<td>• How did her father help by bringing home a copy of the World Book encyclopedia?</td>
<td>• What did Villa-Komaroff say about being a female graduate student?</td>
</tr>
</tbody>
</table>
| Groundbreaking Research! | • Where did Villa-Komaroff spend 3 years in a post-doctorate?  
|                        | • How did the city of Cambridge impact her studies; what was the fear?  
|                        | • Describe the situation and precautions she had to take when she worked on Gilbert’s recombinant DNA team.  
|                        | • What major breakthrough did she make in 1978? |

As with the electron microscopy laboratory, a pre- and post-test was designed to measure the students’ comprehension of basic concepts important to the project as well as overall course goals. These concepts included an understanding of the principles of transformation, the use of this technique in recombinant DNA technology, the basic steps used to create transformed *Escherichia coli* cells capable of producing human insulin, and the role that Lydia Villa-Komaroff played in transforming these cells. The test included both objective and subjective questions and was administered to a total of 19 students before they began the transformation lab and a second time after they had completed all lab activities related to this project.

**Student Survey**

Each student was asked to complete an anonymous survey (see Table 2 below) in order to determine whether the project aided in her or his comprehension of key course concepts. Emphasis was placed on their opinions regarding the two new lab activities. The survey was given to the students at the end of the semester, after they had reported on their results and completed any assigned work for the lab activities. In order to ensure anonymity, the instructor gave the typed survey to all students and explained how to complete it, emphasizing that they should not place any identifying marks (name, identification number, etc.) on it. The students were given the option of completing the survey or not, but were asked to complete the entire survey if they chose to participate. Once these instructions were given, the instructor left the classroom and a student assistant collected the completed surveys.

**Results and Discussion**

Results of pre- and post-testing associated with the electron microscopy exercise (Figure 4) revealed that this approach helped the class to appreciate the array of microscopic tools available and to understand the applications of each instrument. The mean score on the pretest was 44%; this value improved to 70% on the post-test. All 17 students improved in their level of knowledge as a result of the activity; the range of improvement was from 10 – 36%, with a mean value of 26%.
Figure 4: Pre- and post-test results for the electron microscopy laboratory exercise (n = 17).

Improvement in student content knowledge was also observed when comparing the transformation lab pre- and post testing results (Figure 5). The mean score on the pretest was 42%; this value improved to 58% on the post-test.

Figure 5: Pre- and post-test results for the transformation laboratory exercise (n = 19).

Individual item analysis was used to evaluate instructional effectiveness for each concept associated with the two new exercises so that areas requiring increased emphasis in future semesters could be identified. For the electron microscopy exercise, additional exposure to the preparation techniques and more examples of applications will be included. During the transformation lab, closer connection between the original transformation procedure and the
hands-on experiment will be established using the primary research article by Villa-Komaroff et al., (1978). DebBurman (2002) incorporated a thorough examination of one primary research article into a sophomore-level introductory cell biology course, resulting in improved student attitudes toward reading the primary literature and developing research-associated skills. A step-by-step walk through of transformation represents an ideal activity to provide general microbiology students with this valuable learning experience.

Results of the student survey indicated that the two new exercises were positively received and generally appreciated by the class (Table 2). High ratings were recorded in response to questions about the role of the activities in the enhancement of learning and preparation for assessments. In addition, students strongly agreed that the activities should be repeated in subsequent semesters.

**Table 2**
Results of student survey regarding two new lab activities in general microbiology course

<table>
<thead>
<tr>
<th>Electron Microscopy Lab Exercise</th>
<th>Rating Range</th>
<th>Rating Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>This activity brought pictures and text in the book to life and helped me understand operation and use of electron microscopes.</td>
<td>4 – 5</td>
<td>4.6</td>
</tr>
<tr>
<td>This activity helped me prepare for laboratory and lecture assessments concerning microscopy.</td>
<td>3 – 5</td>
<td>4.1</td>
</tr>
<tr>
<td>This activity encouraged me to consider taking upper division courses that focus on electron microscopy.</td>
<td>2 – 5</td>
<td>3.2</td>
</tr>
<tr>
<td>This activity expanded my horizons for careers in biology that involve the use of microscopy.</td>
<td>2 – 5</td>
<td>3.9</td>
</tr>
<tr>
<td>This activity should be repeated during subsequent semesters.</td>
<td>4 – 5</td>
<td>4.6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Transformation Lab Exercise</th>
<th>Rating Range</th>
<th>Rating Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>This activity brought pictures and text in the book to life and helped me understand the process and uses of transformation.</td>
<td>3 – 5</td>
<td>4.3</td>
</tr>
<tr>
<td>This activity helped me prepare for laboratory and lecture assessments concerning biotechnology.</td>
<td>3 – 5</td>
<td>4.3</td>
</tr>
<tr>
<td>This activity encouraged me to consider taking upper division courses that focus on molecular biology.</td>
<td>2 – 5</td>
<td>3.4</td>
</tr>
<tr>
<td>This activity expanded my horizons for careers in biology that involve the molecular biology.</td>
<td>2 – 5</td>
<td>4.0</td>
</tr>
<tr>
<td>This activity should be repeated during subsequent semesters.</td>
<td>4 – 5</td>
<td>4.6</td>
</tr>
<tr>
<td>This activity helped me understand the important contributions that minority scientists like Lydia Villa-Komaroff made to science.</td>
<td>2 – 5</td>
<td>4.3</td>
</tr>
</tbody>
</table>

Student participants rated each statement using the following scale in answering the questions:

1 = strongly disagree  
2 = disagree  
3 = neutral  
4 = agree  
5 = strongly agree
Students also agreed that the transformation activity help them understand the important contributions of minority scientist Lydia Villa-Komaroff, one of the major goals of this project. Jones Eaton (2004) stressed the importance of providing role models for undergraduate students in the sciences by including the contributions of females and non-White minorities throughout their curriculum. She encouraged faculty to expand their knowledge on this topic, stating that the time involved in searching the literature to find resource materials for their courses would be well invested.

Conclusions

These new laboratory exercises for general microbiology fit the description of process-oriented-guided-inquiry-learning as defined by Prince and Felder (2006), with students working in small groups on instructional modules that present them with information or data, followed by leading questions designed to guide them toward formulation of their own conclusions. This strategy, as well as other methods of inductive teaching and learning, promote intellectual development and help students acquire critical thinking and self-directed learning skills (Prince & Felder). Our results indicate that the time it took to develop and conduct these “cooking from scratch” activities was well spent. Students were effectively engaged through active learning, improved in their content knowledge, and were directly exposed to research techniques. In the future we plan to expand the number of laboratory exercises where we employ this type of approach.

Acknowledgments

The authors appreciate the participation and cooperation of students in the Spring 2012 SFASU General Microbiology class. We especially appreciate the work done by student assistants Colleen Embersics and Marlena Alosi in preparing and assisting these laboratory exercises. Electron micrographs for this project were provided by Hafiza Rahman and Michael Elder.

Authors’ Biographies

Josephine Taylor is a Professor of Biology at Stephen F. Austin State University and has taught non-majors biology, mycology, plant pathology, and electron microscopy for over 19 years. She earned a Bachelor’s Degree in Agriculture from Stephen F. Austin State University and a Doctorate Degree in Plant Pathology from the University of Georgia. Her research involves the use of microscopic techniques to investigate fungal diseases of plants, with particular emphasis on mechanisms of disease resistance.

Stephen Wagner is a Professor of Biology at Stephen F. Austin State University and has taught non-majors biology, cell biology, microbiology, and space biology for over 15 years. He earned a Bachelor’s Degree in Environmental Biology from Heidelberg College, a Master’s Degree in Microbiology from North Carolina State University, a Doctorate Degree in Soil Microbiology from Clemson University. His research focuses on biology education and microbial ecology. Most recently he has directed projects funded by NASA and the U.S. Dept. of Education to train pre-service and in-service teachers to use inquiry-based approaches to teach science.
Sarah Canterberry in 2001, earned her Bachelor of Science in Animal Science and completed a Ph.D. in Genetics in 2006, both at Texas A&M University. From 2006 to 2008 she was a Postdoctoral Research Scientist in the Department of Veterinary Physiology and Pharmacology at Texas A&M. In this position she worked with both graduate and undergraduate students on research projects and was responsible for training these students to conduct a variety of laboratory techniques. In 2008 she became an Assistant Professor at Stephen F. Austin State University, where her primary role is that of a lecture professor. She currently teaches Principles of Cell and Molecular Biology (BIO130), Senior Seminar (BIO470), Molecular Biology (BIO431/532), and the lecture components of two non-majors courses: Concepts of Biology (BIO121) and Human Biology (BIO123). In her current position she has the opportunity to direct graduate and undergraduate students on research projects in her laboratory.

References


