Learning Strategies to Initiate and Motivate Students of an Introductory Microbiology Laboratory Class to Perform Cooperatively an Inquiry-based Project.

Subir Ghosh

Division of Natural Sciences, College of Natural & Applied Sciences,
University of Guam,
UOG Station, Mangilao, Guam 96923.
E-Mail: sghosh@triton.uog.edu

Abstract

Pre-nursing students of an introductory Microbiology laboratory class, having learnt typical microbiological techniques during the semester, gained the confidence of conducting an inquiry-based project as part of their lab course work. Students cooperatively performed a microbiological analysis, to evaluate safety of sushi. This paper presents learning strategies and assessment methods to prepare and motivate the students for undertaking an investigative project. Approaches are discussed that were taken to continually assess the students during the performance of the project in order to ensure harmonious group activity and transition through the various stages of the investigative project. Students commented that their investigative experience had increased their thinking and analytical skills and heightened their awareness of the process of scientific discovery.

Key words: Introductory Microbiology laboratory course; Pre-Nursing majors; Inquiry; Cooperative Learning

Introduction

For quite some time, education experts and many biology teachers have been urging critical thinking exercises, hands-on experimentation, and inquiry-based science education in conducting undergraduate biology courses. Human society has become rapidly technological and science has assumed a major presence in the everyday functioning of an increasing number of people. It is, therefore, imperative for the young student to gain an understanding of the process of science and how researchers make discoveries in order to make informed decisions in today's world (American Association for the Advancement of Science, 2011; Somres & Ham, 2009; National Academies of Sciences, Engineering, and Medicine, 2015, 2017). Numerous reports of successful inquiry-based undergraduate laboratory teaching in biology have been reported (Mitchell & Garziano, 2006; Marshall, 2007; Madhuri & Broussard, 2008; Spiro & Knisely, 2008; Walker et al., 2008; Hurd, 2008; Lu et al., 2008; and, Zhang, 2008). Further, it has been shown that when investigative approaches are performed by biology students in a cooperative manner working together to achieve a common goal, higher levels of student achievement are attained compared to traditional methods of teaching (Goyette & DeLuca, 2007; Goldberg & Dintzis, 2007; Seifert et al., 2009; Weisman, 2010; Premo et al., 2018). One of the key findings in cooperative learning has been that student's self-esteem is significantly enhanced. Cooperative learning also provided the students with an opportunity to acquire interpersonal communicative skills, enhance their motivation for learning, and to discover and exercise their critical thinking skills (Weiman, 2009). It is, therefore, important that biology and other science courses should be taught based on inquiry, research, and teamwork.

Typically, inquiry-based projects in an undergraduate laboratory course are conducted for biology juniors and seniors who have previously completed a set of biology courses including rigorous laboratory courses and students work on the project throughout the semester (Seifert et al., 2009). At the University of Guam, pre-nursing majors are required to take an introductory one semester-long microbiology laboratory class. The students have limited science background and have not had the opportunity to engage in investigative projects in science lab classes. As part of efforts at improving the laboratory course experience for pre-nursing majors, an inquiry-based cooperative learning approach was tested. After ensuring that students acquired the skills in experimental microbiology in par with national standards for such an introductory course, the students were motivated to utilize these skills in conducting an inquiry-based project in a cooperative manner, in the last three weeks of the semester.

In this paper, are presented: (i) the steps taken to initiate and motivate the students into conducting an inquiry based cooperative project; (ii) the food microbiology investigative project decided upon by the students and general design of the project; (iii)

student microbiological skills assessment and evaluating student preparedness for undertaking the project; (iv) learning outcomes; (v) approaches taken to enhance cooperative learning; (vi) assessment of student's performance of the inquiry-based project; (vii) conclusions and discussion that students arrived at by consensus among the class; and (viii) post-project feedback from students.

The successful completion within a limited time and budget of an inquiry-based project by pre-nursing students clearly shows that such an investigative, cooperative learning approach can be introduced in an introductory microbiology lab course. It was also found that at the end of the semester, the students had a heightened awareness of the process of scientific discovery and the significance of basic science in providing breakthroughs in understanding disease, in medical diagnostics and in developing therapeutics. Students exhibited a high level of excitement and enthusiasm for microbiology and the molecular life sciences.

The Inquiry-based Cooperative Learning Strategy and Student Assessment

The conceptual strategy for initiating and conducting the inquiry-based food microbiology analysis project in a cooperative manner, the evaluation design, learning outcomes, and assessment of student performance of the project are discussed below. Students were assessed prior to the start of the project and during the performance of the project to test the student's knowledge of microbiological techniques required for the food analysis, their preparedness for undertaking the project, and, efficient conduct of the project in collaboration with their peers. This was followed by a post-project analysis of student's experience of the classroom investigation.

A. Initiation of Inquiry project

Earlier in the semester, students isolated from their own skin surface resident bacteria using typical culturing methods and were surprised to learn that they harbor the potential human pathogen Staphylococcus aureus. Students also learnt of the immense diversity of microbes present in the surrounding environment. Students identified potential problems that microbes may cause on the island of Guam, ranging from those in hospitals and clinics, to the drinking water supply, sewage treatment plant and release of raw sewage and garbage directly into the coral reef areas. Some students voiced their concern over the safety of salads and sushi that is served in food store outlets. Students also remembered, from their lecture class, that many bacteria produce toxins which can be introduced into food during processing, preparation, and handling. Students agreed to undertake, as part of their lab course work, an inquiry project to evaluate microbiological contamination if any present in the sushi.

B. Microbiological Analysis Project Design

Eighteen microbiology students formed three groups of six students each, to determine the levels and nature of microbial contamination of sushi. The three groups planned on testing three sushi samples of the same variety, essentially to obtain results in triplicate. Students agreed to perform the project in a cooperative manner sharing their observations, data, and thoughts. Students within each group agreed to monitor each others methodology to ensure that the correct steps were being taken and all data observed were collected. The students also felt that it would be important for the three groups to interact with each other to comment on experimental procedures, observations, and data collection to ensure uniformity while conducting the project, for statistical validity. Finally, all three groups agreed to share their data with each other to arrive at a consensus with the instructor moderating the discussions.

Based on their learning of typical microbiological principles and methods during the semester, students reasoned that they would be able to investigate four important aspects in their microbiological evaluation, namely:

i. quantitate levels of bacterial contamination using the standard plate count (SPC) and coliform count methods.

ii. isolate and identify the bacteria using selective/differential culture plates, wet mount analysis, and Gram staining.

iii. determine if the contaminating bacteria form spores.

iv. antimicrobial testing to determine the effectiveness of selected typical antibiotics on the recovered contaminating bacteria.

C. Pre-project Evaluation Design and Assessment

In order to incorporate an investigative cooperative learning approach in an introductory microbiology lab course, it was essential to ensure that students had acquired skills in: performance of microbiological techniques and experiments using appropriate scientific controls; collection and organization of results; drawing conclusions; and, in interacting with fellow students. Students were assessed for the following important learning components prior to embarking on the project:

i. Student Learning of Microbiological Techniques: Students learnt a set of seven standard microbiological techniques that are required for analyzing the contamination levels of food. The techniques are: (a) light microscopy analysis using wet mounts; (b) Gram staining; (c) aseptic & pure culture techniques & culturing

methods; (d) spore analysis test; (e) antimicrobial sensitivity testing (Kirby Bauer method); (f) standard plate count method (SPC); and, (g) identification of unknown bacteria using selective/differential culture media. Students also learnt general microbiology safety guidelines and universal precautions as described in their microbiology lab manual (Brown, 2009).

ii. Laboratory Notebook: Students were required to maintain a logbook of their lab class activities. The log book notes of all students were inspected, and comments provided on the format of journal entry.

iii. Data Collection & Organization: Students were required to organize all data obtained from the experiments that they had performed in the lab class, in the form of tables and graphs. The students also learnt the importance of statistical validity and therefore tested three sushi samples of the same variety, essentially to obtain results in triplicate.

iv. Collaboration with Peers: Students were familiarized with the cooperative learning approach by requiring all students to share their data with the rest of the class. This was achieved by drawing data tables on the blackboard. Each student recorded his or her data on the blackboard followed by an interactive discussion on the observations. This exercise taught the students how to arrive at conclusions by consensus, taking into account all the pros and cons.

v. Theoretical Knowledge: An exam was conducted to test the student's basic theoretical knowledge associated with the microbiological techniques to be used, as well as familiarity with lab equipment, culture media, and reagents. A post-exam review ensured that all students learnt the concepts forming the basis of each microbiological procedure.

vi. Laboratory Report: Earlier in the semester, the students were required to present their results for the "bacterial unknown identification" experiment in a concise and well-organized laboratory report. This exercise prepared the students for writing lab reports that would form the final part of the investigative project.

D. Pre-project Questionnaire - Evaluating Student Preparedness for Undertaking Project

In the first ten weeks of the semester, students had completed a series of microbiological experiments acquiring skills that would be required for successfully completing the food analysis project and attended lecture classes on essential microbiological concepts. Students were provided a questionnaire to determine their comfort level with microbiological concepts and skills. The questions and response data are provided in Table 1. The results indicated that all students in the class had acquired fundamental microbiological skills and had gained the confidence in continuing with the project.

E. Learning outcomes

The main student learning outcomes of the inquiry-based investigative project in the Introductory Microbiology course are specified below:

1. Enhancement of student's curiosity levels and thinking ability.
2. Application of microbiology techniques and approaches in investigating a scientific question, relevant to public health.
3. Designing experiments, collecting and organizing data in the form of tables & figures, photo documentation, and preparation of scientific reports.
4. Development of collaborative and communication skills.
5. Inculcate awareness and enthusiasm for the scientific discovery process.

F. Project performance assessment

At every step of the multi-stage investigative project, each student groups methodology was monitored to ensure that the correct microbiological procedures were being used. The groups were advised not to proceed to the next stage until clearance was obtained, ensuring harmonious group activity and transition through the various stages of the project.

To enhance the cooperative approach, the three groups were asked to share their experiences at the end of every stage of the investigative project. This allowed each group to comment on and critique each other and ensure that all three groups were maintaining uniformity in their experimental methods for statistical validity. The strategy of monitoring the students themselves allowed detection of any unexpected mistakes that were made and to correct them or to account for them while drawing conclusions from the results obtained. For example, at the very first stage of the project the three groups blended their sushi sample in a sterile blender, prepared appropriate dilutions and plated on a rich nutrient medium for culturing bacteria. During the discussions, the students found that one of the groups had peeled the sushi wrapping and the rice away from the raw fish contents and did not include them in the blender while preparing food dilutions. A dialogue ensued, and the students discussed the consequences and the results that they could expect for the three food samples. The students agreed that not including the rice and wrapping would mean that they essentially would be performing duplicates instead of in triplicates as originally planned. However, the students reasoned that this mistake could be used to their advantage. They hypothesized that the major source of bacterial contamination would come from

Table 1. Student's comfort level with microbiological concepts and skills required to perform a microbiological evaluation of raw fish containing ready-to-eat food preparations ("sushi".)

Concepts & Skills	Average Score*
General Microbiological Principles	4.62 ± 0.62
Light Microscopy analysis using wet mounts	4.81 ± 0.40
Staining and observation of microorganisms	4.75 ± 0.45
Aseptic & Pure culture techniques and culturing methods	4.62 ± 0.62
Spores and spore analysis test	4.37 ± 0.62
Antimicrobial sensitivity testing (Kirby Baeur Method)	4.56 ± 0.63
Standard Plate Count Method (SPC Method)	3.56 ± 0.89
Identification of unknown bacteria using selective/differential culture plates	4.68 ± 0.48
Writing lab reports and presentation of data in clear and succinct format	4.37 ± 0.80

*Students were asked to indicate their comfort level in nine areas, on a scale of 1-5 (1, Not at all; 2, Very Little; 3, Somewhat; 4, Quite a bit; 5, Very much). n =16

the raw fish content of the sushi sample and not from the cooked rice and wrapping. They reasoned that if indeed this were true, then the level of bacterial contamination for all the three samples would be similar. If the contamination levels for the sample where the rice and wrapping were not included were lower, then that would indicate that the cooked rice and wrapping also were contaminated. During the observations and collection of data, the students found lower levels of contamination when the rice and wrapping were not included. The students concluded that the rice and wrapping used were also contaminated. The students found significant contamination of Staphylococcus aureus and Staphylococcus epidermidis based on selective/differential culture plate test. Both these species are present abundantly on the surface of the human skin. The students concluded that the sushi samples were prepared under unhygienic conditions, where the food preparer probably did not wear gloves and rolled the sushi with bare hands. However, some students argued that the contaminants could very easily have been introduced by the students themselves during the food analysis project. The interaction between the three groups at every stage of the project allowed students to build consensus regarding conclusions. This exercise would play a very important part in the end stage of the project when students came together to arrive at a summary conclusion regarding the safety of sushi.

An important element of involving students in cooperative discussions is the fact that students spontaneously start thinking critically. This was evident during the identification of yeast contaminants using selective culture plates - the chloramphenicol antibiotic in the plate prevents the growth of bacteria, thus any colonies detected would be that of yeast. The students did not observe growth of any colonies on the plates for the three food samples and concluded that the sushi samples did not contain any yeast contamination. However, on one of the plates, one colony was found growing at the edge of the plate and the students of the group after discussion among themselves remarked that the colony may be a bacterial contaminant that is resistant to the chloramphenicol antibiotic. This raised concern among students about the potential for spreading of antibiotic resistant strains of bacteria through sushi. However, students counter-argued that the contaminant could very well have come from the teaching lab while analyzing the food sample. It was evident that the students were able to utilize the important microbiological concepts that they had learnt in the lecture and laboratory class for their investigative project.

During the final discussion session, it was evident that students were actively engaged and had realized the significance of the investigative project. The students debated the conclusions to be arrived at regarding the contamination levels of the sushi samples. Students agreed that that the precise rules of food safety testing, including statistical analysis, was not performed. Some students argued that the bacterial contaminants they recovered may have very well come from a breach of aseptic procedures in the lab while evaluating the sushi samples. Others commented that there is a possibility that sushi sold at stores may exhibit some levels of non-pathogenic bacterial contamination which did not pose a serious threat to humans, especially since no case of food poisoning was reported from any of the food outlets. The students also reasoned that if indeed the sushi samples exhibited some levels of contaminating bacteria, then the presence of these contaminants did not indicate that the food was spoiled, rather there may be a potential for rapid spoilage of food. Coliform counts

using the selective culture plate did not reveal any fecal contamination of the food samples – the students heaved a sigh of relief! The colonies found on the plates were non-lactose fermenting species and students commented that these bacteria may potentially be pathogenic since gram negative bacteria are known to secrete toxins (Tortora et al., 2009). The students expressed their concern that the gram-negative bacteria contaminating the sushi samples that did not respond to any of the antibiotics tested in their antimicrobial testing analysis, could potentially be harmful if ingested. The students reasoned that these bacteria might represent resistant strains whose genome codes for enzymes responsible for inactivating the effects of the antibiotics tested as learnt from their microbiology textbook (Tortora et al., 2009).

The scientific argumentation and data analysis by all three groups provided strong evidence that student's curiosity, thinking ability, and enthusiasm were enhanced as a result of collaborative project participation. The classroom discussions generated among students, collection of quantitative and qualitative data, organization of data in the form of tables & figures, nature of the conclusions arrived at by consensus among the students, and preparation of final report, provides strong evidence that the main student learning outcomes were achieved in the inquiry-based project in the introductory microbiology course.

G. Post-project Student Feedback and Student's Experience of the Investigative Project

Post-project feedback from the students was obtained via: questionnaire, spontaneous student comments made verbally during the progress of the project in the classroom to each other, verbal comments provided by some students to the Instructor outside of the classroom, and, official course and instructor evaluation by students.

a. Post-project Questionnaire:

Sixteen of the eighteen students present during the last laboratory class for the semester provided feedback on the investigative project – the students were asked to not include their names in their responses to the questionnaire. The questions that were asked of the students are given below:

i. Did you find the investigative project interesting and important?
ii. Do you think that being able to apply microbiological techniques learned in the lab class to an investigative project enhances the lab experience of students?
iii. Did you feel comfortable performing the project using the microbiological techniques that you learnt earlier in the semester?
iv. Do you think that it is important to learn to work collaboratively with your fellow students?
v. Do you feel that performing an investigative project enhances your ability to think and analyze data compared to performing experiments directly from the lab manual?
vi. Do you feel that an investigative project should be included as an important component of the microbiology lab course conducted at the university?

The students unanimously answered in the affirmative for all six questions. One student further commented that this cooperative approach was good training that would help them prepare for a career in nursing. The positive feedback from the students was further borne out by the spontaneous student comments as described in the next section. In official student evaluations, only one of fourteen students commented that the investigative project performed in the laboratory was a distraction with regards to preparation for the final examination for the microbiology course. Since the sample size of the class was small (eighteen students), it is conceivable that not all students taking an introductory microbiology course would be in favor of an inquiry-based project as part of laboratory course work. However, the largely favorable response from students indicate that the investigative project indeed helped students learn the real-world applications of microbiology.

b. Spontaneous Student Comments:

A very strong indication that the investigative project was viewed favorably by the class is the spontaneous comments on the project made by the students to each other during the performance of the lab work, and verbally to the Instructor outside the classroom. Six students informed the Instructor that they enjoyed the investigative project commenting that they had been used to "learning chapter by chapter straight from the lab manual". One student remarked "You should introduce it as a regular part of the lab course work in future micro lab classes". Another student went on to comment "We never realized that biology can be so interesting. If we had known, we would have become biology majors".

In the final project report submitted by group # 3, the following comment was included: "This project has enlightened our group and put many questions on our table. The project conducted has many implications as to how exactly food is handled and what steps food handlers are taking to minimize food contamination. The project can serve as a helpful resource and educate the food industry as to approximately how many microbes can contaminate food if the proper techniques are not practiced."

c. Official Student Evaluations and Student Performance in Final Exams:

Only one of fourteen students who participated did not favor the idea of an investigative project in an introductory course, citing that it distracted from preparing for the final exam. There was no significant difference in student ratings of the Instructor received for the project-based microbiology course and the scores that were received in earlier microbiology courses. The students of the project-based microbiology course did not perform better on their end-of-course final exam compared to students in earlier Microbiology courses. There seems to be no correlation between participation in an investigative project and increased success in the final exam on microbiology.

Discussion

Here, is reported the outcomes of an inquiry-based project performed cooperatively by pre-nursing students in an introductory microbiology laboratory class. These students had a limited background in the sciences and none of them had participated in a research type project for any of the earlier courses that they had taken. It was indeed remarkable to observe the collaborative nature of the students in undertaking a project. The intensity of the classroom discussions reflected the ability of the students to think and integrate concepts learnt in the microbiology lecture and laboratory class. The overall impression was that such an investigative project enhanced the learning experience of pre-nursing students and created a general sense of confidence in their academic work. Students felt much more aware of their capabilities, which would be very important in their future careers in the health professions. Students felt quite thrilled that they were able to interact with each other in a critical yet harmonious manner and accomplish the goals set for the project.

The main aim of this inquiry-based project was to test if pre-nursing students of an introductory microbiology course were able to utilize and integrate microbiological concepts and experimental skills; to test the collaborative capability of the students; and ability to communicate effectively and arrive at conclusions by consensus. The success of the students in fulfilling these aims clearly shows that inquiry-based projects using a cooperative learning approach can be effectively utilized in an introductory microbiology lab course to enhance student learning in a limited time and budget format.

Acknowledgments

The author thanks the Division of Natural Sciences Laboratory Staff of the University of Guam for preparation of bacterial culture media and reagents.

References

American Association for the Advancement of Science. 2011. Vision and change in undergraduate biology education: A call to action. Washington, DC.

Brown, A. 2009. Microbiological Applications by Bensons, 11th Edition. McGraw Hill Publishers, New York.

Goldberg, H.R. and Dintzis, R. 2007. The positive impact of team-based virtual microscopy on student learning in physiology and histology. Adv. Physiol. Educ. 31, 261-265.

Goyette, S.R. and DeLuca, J. 2007. A Semester-long student-directed research project involving enzyme immunoassay: Appropriate for Immunology, Endocrinology, or Neuroscience Courses. CBE Life Sci. Educ. 6, 332-342.

Hurd, D.D. 2008. A Microcosm of the biomedical research experience for upper-level undergraduates. CBE Life Sci. Educ. 7, 210-219.

Lu, F., Eliceiri, K.W., Squirrell, J.M., White, J.G., and Stewart, J. 2008. Student learning of early embryonic development via the utilization of research resources from the nematode Caenorhabditis elegans. CBE Life Sci. Educ. 7, 64-73.

Madhuri, M. and Broussard, C. 2008. "Do I need to know this for the exam?" Using popular media, inquiry-based laboratories, and a community of scientific practice to motivate students to learn developmental biology. CBE Life Sci. Educ. 7, 36-44.

Marshall, P.A. 2007. Using Saccharomyces cerevisae to test the mutagenicity of household compounds: an open-ended hypothesis-driven teaching lab. CBE Life Sci. Educ. 6, 307-315.

Mitchell, B.F., and Garziano, M.R. 2006. From organelles to protein gel: a 6-wk laboratory period on flagellar proteins. CBE Life Sci. Educ. 5, 239-246.

National Academies of Sciences, Engineering, and Medicine. 2015. Integrating discovery-based research into the undergraduate curriculum: Report of a convocation. Washington, DC: National Academies Press.

National Academies of Sciences, Engineering, and Medicine. 2017. Undergraduate research experiences for STEM students: Successes, challenges, and opportunities. Washington, DC: National Academies Press.

Premo, J, Cavagnetto, A, and Davis W. B. 2018. Promoting collaborative classrooms: The impacts of interdependent cooperative learning on undergraduate interactions and achievement. CBE—Life Sciences Education, 17:ar32, 1–1.

Seifert, K., Fenster, A., Dilts, J.A., and Temple, L. 2009. An investigative, cooperative learning approach to the general microbiology laboratory. CBE Life Sci. Educ. 8, 147-153.

Somres, B., and Ham, B. 2009. Experts urge bold new undergrad biology courses for the 21st century. Science, Vol 325, 1637.

Spiro, M.D. and Knisely, K.I. 2008. Alternation of Generations and Experimental Design: A guided-inquiry lab exploring the nature of the her1 developmental mutant of Ceratopteris richardii (C-Fern). CBE Life Sci. Educ. 7, 82-88.

Tortora, J.G., Funke, B.R., & Case, C.L. 2009. Microbiology, 10th Edition. Pearson Benjamin Cummings Publishers.

Walker, D.E., Lutz, G. P., and Alvarez, C.J. 2008. Development of a cross-disciplinary investigative model for the introduction of microarray techniques at non-R1 undergraduate institutions. CBE Life Sci. Educ. 7, 118-131.

Wieman, C. 2009. Galvanizing sciences departments. Science, Vol 325, 1181.

Weisman, D. 2010. Incorporating a collaborative web-based virtual laboratory in an undergraduate bioinformatics course. Biochem. Mol. Biol. Educ. 38, 4-9.

Zhang, S. 2008. A research project-based and self-determined teaching system of molecular biology techniques for undergraduates. Biochem. Mol. Bio. Educ. 36, 181-188.