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Article

An Investigative, Cooperative Learning Approach to the General Microbiology Laboratory

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Investigative- and cooperative-based learning strategies have been used effectively in a variety of classrooms to enhance student learning and engagement. In the General Microbiology laboratory for juniors and seniors at James Madison University, these strategies were combined to make a semester-long, investigative, cooperative learning experience involving culture and identification of microbial isolates that the students obtained from various environments. To assess whether this strategy was successful, students were asked to complete a survey at the beginning and at the end of the semester regarding their comfort level with a variety of topics. For most of the topics queried, the students reported that their comfort had increased significantly during the semester. Furthermore, this group of students thought that the quality of this investigative lab experience was much better than that of any of their previous lab experiences.

INTRODUCTION

For more than 20 years, science educators have been responding to the call for more emphasis on the process of "doing science" as an effective way for the students to learn, retain, and use scientific information (Chiappetta and Russell, 1982; Narum, 1991; Modell and Michael, 1993; Ertepinar and Geban, 1996; Heppner, 1996; Jarmul and Olson, 1996; National Research Council [NRC], 1996, 1998; Butts and Jackson, 1997; Glasson and McKenzie, 1997; McNeal and D'Avanzo, 1997; Ratcliffe, 1998; Yip, 2005). Learning occurs best when students are actively involved in the construction of their knowledge (Mestre and Cocking, 2002). The practice of science using investigative, discovery-based, open-ended processes, with opportunities for designing experiments built on previous observations, represents an educational tool that effectively demonstrates to students how the scientific process works in the professional world (Switzer and Shriner, 2000).

Frequently, such investigative experiences are performed in cooperative learning situations, teaching methods that encourage students to work together to achieve a common goal, and that result in greater student achievement than traditional didactic methodology (Johnson and Johnson, 1999). In addition to greater student achievement, engaging in cooperative learning leads to the development of higher-level thinking skills, greater intrinsic motivation, improved interpersonal skills, positive attitudes toward learning, and heightened self-esteem (Dornyei, 1997; Slavin, 2000). According to Johnson *et al*. (1998), five conditions must be met to promote effective cooperative learning.

1. Students need to experience clearly perceived positive interdependence. Students must be made to feel that they cannot succeed by themselves and need the entire group to achieve the desired goals. Without positive interdependence, the learning becomes either competitive or individualistic.
2. Students must experience promotive interaction (face to face). This occurs when students provide feedback to others in the group.
3. Students should exchange necessary resources as well as challenge assumptions and encourage one another to achieve their goals. It is imperative to structure the learning situation so that there is individual accountability to achieve the group's goals.
4. Students need to frequently use relevant interpersonal and small group skills to allow for effective cooperative learning. It is likely that students will need some guid-

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ance developing the social skills necessary when working in a group. Development of these skills by all members of the group will ensure that the group does not depend entirely on the more socially skilled members of the group.

5. Regular group processing must occur to determine what member actions were helpful, to determine what member actions were unhelpful, and to foster working together to make decisions on how to proceed.

One type of cooperative learning method, group investigation, lends itself well to the type of design we wanted for the microbiology lab. The lab had been a typical "cookbook" lab, with a series of metabolic tests on known organisms, followed by testing for a standard set of unknowns near the end of the semester. We were interested in making the lab more student-centered and investigative, with the students working in teams. Group investigation is a cooperative learning method and has as its hallmark students working in small groups, actively constructing their knowledge, with the outcome of the enhancement of student learning and of student satisfaction (Marlowe and Page, 2005). The group investigation method has four elements that function simultaneously to distinguish it from other types of cooperative learning (Pedersen and Digby, 1995). These elements are investigation, interaction, interpretation, and intrinsic motivation. In this particular microbiology experience, small groups of students, determined by seating arrangement, decide on where to collect bacterial samples (e.g., water, cat, feces), and each member of the group is responsible for finding information on the site selected to sample. Interaction occurs when group members exchange information regarding their research. The group members then analyze and interpret the information presented by all group members and plan how to carry out the investigation. Finally, because the students choose the environment to sample and plan the investigation, and because of the curiosity of the students to determine the identity of their unknown organism, they are intrinsically motivated to learn.

The goal of our new approach to a General Microbiology laboratory was to combine cooperative learning with an investigative lab experience to enhance student learning and satisfaction. The concept that we have developed works to give the students ownership of a project very early on in the semester so that this motivation and curiosity carries throughout the course.

METHODS

Participants

All General Microbiology students (72, consisting of 48 seniors, 23, juniors, and 1 sophomore) had previously completed the James Madison University (JMU) Biology Department's 2-yr core curriculum that covers all biology subfields by using an integrated approach, and at a minimum, had four biology classes with mandatory laboratory experiences. Many of these students had taken other classes (such as inorganic chemistry, organic chemistry, physics, or other biology courses) with laboratories as well. Students worked on the investigative project throughout the semester, meeting during assigned class times twice a week (2 h/lab period) and also frequently outside of formal lab times but still contained within a typical school day. During these out-of-class lab visits, students had ready access to lab support personnel. At various times throughout the semester, progress reports, in the form of sections of what would become the final lab reports, were due for instructor feedback. Group poster presentations were made at the end of the semester and represented 15% of their total lab grade. In total, approximately 30–35% of the student's lab grade was due to group work. The overall lab grade was 40% of the total grade for the class. Although this lab has been taught for eight semesters, our results are reported primarily from academic year 2007–2008.

The Cooperative Learning Project

This cooperative, investigative learning project was based on Slavin's six-stage model of group investigation (Slavin, 2000; Table 1). The focus of this investigative lab exercise was to isolate various types of organisms from two different environments and then use the tools and techniques learned throughout the semester to identify these organisms.

Stage 1: Identify the Topic and Form Groups. Although heterogeneity among group members nourishes cooperative learning (Johnson and Johnson, 1999), students were organized into cooperative learning groups of four students based solely on their seating arrangement, which was determined by their choice of seats on the first day of class. Each group of four students worked at its own bench, which was physically separated from other benches. Groups were instructed to identify two locations from which to collect microbiological samples. One sample was to be an environmental sample that could be from, e.g., water, soil, or food; and the other sample was to be a "body" sample that could include the mouth, throat, nose, or gastrointestinal tract from any animal.

Stage 2: Plan the Learning Task. Once it was determined which environment they would be investigating, groups were assigned the task of researching their particular environment. They were required to find and read journal articles to determine what was already known about bacteria that could be isolated from their

Table 1. Slavin's six-stage model of group investigation adapted for use in the General Microbiology lab (Slavin, 2000)

1. Identify topics and form groups
   - Form groups based on seating arrangement
   - Identify environments to sample
2. Plan the learning task
   - Research microbial environments in scientific journals
   - Plan sample collection and isolation
3. Carry out the investigation
   - Prepare experiments—simple and Gram stains, agar deeps, thioglycollate tubes, mannitol salt agar, eosin methylene blue agar, blood agar, sulfur-indole-motility medium, triple-sugar iron agar, methyl-red—Vogues Proskauer, catalase, oxidase, nitrate reduction, ornithine decarboxylase, coagulase
   - Record and interpret data
   - Reach conclusions as to probable genus and species
4. Prepare the group presentation
   - Determine format and content for poster presentation
   - Coordinate plans for presenting
   - Incorporate work from all group members into the final paper
5. Present the group project
   - Poster session similar to American Society for Microbiology
   - Submit group paper similar to scientific journal article
6. Evaluate achievement
   - Group grades: poster presentation and group paper
   - Individual grades: lab notebook, quizzes, assignments, lab practical, peer reviews

environment and to make predictions on what they could potentially isolate based on this knowledge. This background work on their environments was given as a written assignment that each person completed individually.

Students also had to plan the sample collection. Students were encouraged to "be creative" with their sampling environments. Although they had to decide to sample from particular environmental categories, they had virtually limitless possible environments from which to sample within those categories. For example, a group that decided to get its sample from "water" could select practically any water source from which to sample, as long as the group could conduct the sampling within a week. The groups each had to submit, in writing, their sampling and initial isolation protocol to the instructor as well as present their plan orally. This communication with the instructor allowed for the identification of any experimental design flaws or any other problems that the group might encounter after its collection or isolation protocol. Individual assignments relating to the sampling and isolation were determined so that each member of a group was involved in the process.

Stage 3: Carry Out the Investigation. The majority of the work during the semester was devoted to completing the identification of the bacterial unknowns. This lab used *Microbiology Theory and Application* (Leboffe and Pierce, 2006) as its laboratory manual for almost all procedures. A typical schedule for a semester is given in Supplemental Material A. Once several isolated colonies were collected from the various environments, groups were instructed to select four colonies, preferably two from each environment, to work with for the remainder of the semester. Students were encouraged to select as many morphologically different colonies for identification as possible to increase diversity of unknowns within a group.

Each class period was dedicated to initiating or completing a specific task or experiment. Instructors would introduce the topic and procedure for the day as well as discuss the previous day's experiment(s). Experiments were ordered based on what would be the most beneficial to the students according to the way that *Bergey's Manual of Determinative Bacteriology* (Bergey and Holt, 2000) prioritizes various characteristics.

Many biochemical analyses were conducted throughout the next weeks (Table 1). Students were given the freedom to determine on their own whether any of the biochemical tests would aid in the identification and could elect not to conduct a particular test. This decision-making process conveys to the student the importance of resource management in the laboratory. Because budget constraints are always a consideration in any scientific setting, students are able to understand that only beneficial tests should be conducted, and they must choose the tests they conduct with forethought and purpose. Students also were encouraged to research additional biochemical tests that they felt would help with a particular identification. If they could convince the instructor that an additional test was necessary for proper identification, and if the medium or test was easily made or purchased, the students were allowed to conduct the test. Finally, students were encouraged to repeat experiments, if necessary, and to further analyze any conflicting test results.

During the first third of the semester, DNA was isolated from each of the unknowns and used as a template for polymerase chain reaction (PCR) in an attempt to amplify a partial sequence of the 16S rRNA gene. The primers used are described in Fierer and Jackson (2006). All PCR products were sent to Elim Biopharmaceuticals (Hayward, CA) for DNA sequencing, and useful results were typically obtained for 75–80% of isolates. These sequences were used in BLAST analysis (Altschul *et al.*, 1990) to help to confirm the identity of the organism. The sequences were released to the students after most biochemical tests were done, so that this single test would only be another piece of the puzzle, not the entire answer. After all these analyses had been conducted, the groups were able to identify their organism with confidence, at least to the genus level.

For at least two of the organisms identified, the students were required to find a primary research article that described some aspect of the organism. These articles ranged from medical and industrial applications to species identification and microbial ecology. Information gleaned from these articles was reported in both the poster and final paper.

Stage 4: Prepare the Group Poster Presentation. For one of the final group projects, students were to make and present a poster for the rest of the class. Students were advised that the format for the poster presentation would be similar to poster presentations at scientific meetings. Students were given instructions for the preferred format for posters from the American Society for Microbiology (www.asm.org/MTGSRC/pdfs/slide.pdf). The time was divided in half so that two students would present the poster and the other two members were looking at other groups' posters. This way, each group member would be involved as presenter and audience member. When presenting their posters, the group members were to engage the other students by guiding the audience through their project. They were to focus on the main themes of the topic including: environment chosen for study, sampling protocol, definitive stains or biochemical tests, other relevant information, and ultimately, their identification of the unknown organisms. When acting in the capacity as audience members, the students were to ask relevant questions of the other groups. In addition, audience members were required to evaluate the other posters in their session, and ultimately, to assign a grade. This was used as a way to increase interest and participation and also to force peers to evaluate critically the work of their peers.

For the other part of the final group project, students were to assemble a group paper, incorporating writing done by all of the group members. At various points during the semester, individual students submitted drafts of sections of what would become the final lab report. In this class, a draft of the introduction was due a few weeks into the semester, a draft of the methods and results sections was due approximately halfway through the semester, and a draft of the discussion section was due 2–3 wk before the final report was due. Guidelines for each of these sections were given to the students, and individual feedback and grades were provided as well. This method of writing the final paper individually in separate parts allowed the students to use the writing from all individuals as well as the feedback for their final group paper. Students were able to learn from each other as well as from the instructor.

Stage 5: Present the Group Project. The poster session was conducted similarly to poster sessions at national meetings such as the American Society for Microbiology. The 2-h lab period was divided in half so that each student could visit all of the other posters. Two students from each group were required to present the poster, and the other students looked at and evaluated the other posters. After the first hour, the groups switched responsibilities.

The poster was submitted as a group assignment at the end of the semester and was graded by the instructor based on a rubric given to the students at the beginning of the semester. Examples of posters prepared by the students can be seen in Supplemental Material B.

Stage 6: Evaluate Achievement. Several measures were used in evaluating student achievement. Individual accountability and group goals have been identified as factors that contribute to the achievement effects of cooperative learning (Slavin, 2000). Therefore, students were given a combination of individual and group grades. The individual grades included tasks such as a lab notebook, various quizzes and writing assignments, a peer review of the other group members, and the lab practical. Group scores were determined for the poster presentation and the final paper by the instructor, according to the rubric. Grade breakdown is itemized in Table 2.

Individual Grades

Lab Notebooks. One requirement of all students was to maintain a detailed lab notebook. Students were instructed to keep careful record of everything that they did in lab each day, from various protocols and experimental procedures, to observed results and their conclusions based on their results. Lab notebooks were collected three to four times throughout the semester and graded on content, organization, completeness, and quality for individual experiments and for the entire notebook The grading rubric can be found in Supplemental Material C. Notebook grades accounted for 20% of the final lab grade.

Peer and Instructor Review of Effort. Individuals submitted peer evaluations of their group members in three different areas, which accounted for 10% of the final lab grade. They were asked to comment on each group member's contribution to the poster presentation, the lab report, and overall participation for the entire semester. These peer reviews were confidential and submitted directly to the instructor. For each of these evaluations, students were asked to assign a total of 15 points to the remaining three group members, so that each member would receive 5 points if they each contributed equally. If a group had fewer than four members, the grading structure was altered accordingly. Students also were asked to give additional comments about the group dynamic for each of the three evaluations. This method of peer evaluation was adapted from Fourtner *et al*. (2008) (Supplemental Material D).

Lab Practical. At the conclusion of the semester, students also took a lab practical exam, which accounted for 20% of the lab grade. This exam was a traditional lab practical, with students rotating to various stations. Students were asked a variety of questions designed to test not only content knowledge but also their ability to interpret results and make conclusions based on their interpretation.

Quizzes. Throughout the semester, students took weekly quizzes that covered the material that they learned that week. Usually, these quizzes focused on tasks such as stains or biochemical tests that were directly related to identification of the bacteria. Students were not only responsible for knowing the procedure to follow for these tasks but also for the theory behind the test and for interpretation of various results, if appropriate. Quizzes were worth 10% of the lab grade.

Individual Assignments and Lab Reports. Individual assignments and lab reports were worth 25% of the lab grade. During the semester, students were required to complete individual exercises, including sections of lab reports. Students completed these sections individually and then compiled them for the final group paper. This 25% of the lab grade also included the final lab report, which was a group grade (see below).

Group Grades

Poster Presentation. Students also critiqued and graded the other groups' posters, and their comments and grades were used by the instructor to determine the final poster presentation grade, which was 15% of the total grade for the lab. Up to 5 points were awarded in six different areas: 1) Overall appearance, organization, and clarity; 2) Introductory and background material; 3) Presentation and clarity of results; 4) Figures and tables; 5) Extra effort (information provided beyond the expected); and 6) Verbal explanations. In addition, 10 points were given for overall quality. This rubric gave a grand total of 40 points for the poster (Supplemental Material E). Instructors used the same criteria for grading. All student grades for their peers were averaged and counted as 50% of the grade; the other 50% was from the instructor's assessment.

Final Lab Report. The guidelines for the format of the final report and the rubric that was to be used for grading were given to the students at the beginning of the semester (Supplemental Material F). This group grade was part of the 25% assigned to assignments and lab reports.

In total, approximately 65–70% of the lab grade was from individual work and 30–35% was from group work.

Questionnaires

Questionnaires assessing the students' perceived knowledge or "comfort" with the process of experimentation and communication while conducting scientific inquiry and working with microorganisms were given to the students during the first week of class and again at the end of the semester. This self-reporting instrument was used to evaluate their level of comfort with a variety of topics. Students were asked to evaluate their level of comfort (1, not comfortable at all; 3, somewhat comfortable; and 5, extremely comfortable). Seventy (of 72 possible) students completed the prequestionnaire, and 63 students completed the postquestionnaire. Statistical analyses were done using SPSS software (SPSS, Chicago, IL) and the chi-squared test.

Additionally, at the end of the semester, students were asked to compare this lab experience to those that they have had previously in several areas (1, much worse than previous, 3, the same; and 5, much better than previous), ranging from overall experience in the lab to their feeling of ownership in this lab compared with others. Fifty-four students completed this questionnaire. Participation in all questionnaires was strictly voluntary, thus the discrepancy in numbers.

Finally, students were given an opportunity to give more detailed feedback about the course, particularly what they felt worked with this lab experience, what didn't work for this lab experience, and suggestions for improvement. The specific questions are listed in Table 3. Institutional review board approval was obtained to conduct the research, and waivers were signed by each individual participating in the study.

Table 2. Laboratory grading percentages

	Grading %
Lab notebooks	20
Peer and instructor review of effort	10
Lab practical	20
Quizzes	10
Poster presentation	15
Lab reports and assignments	25

Table 3. Specific questions asked regarding the lab experience

1. How does this kind of lab experience compare with other advanced biology classes you have had?
2. Do you like the way the process of experimentation was handled in the lab?
3. Would you prefer a more structured lab experience? If so, why?
4. Do you think that you have a better learning experience when things "work" more predictably?
5. There were two of three experiences that were not directly involved in bacterial identification. Do you think those were valuable experiences, or should all procedures point toward the identification?
6. Do you have suggestions on how to get more communication going amongst the groups?
7. Please share any other ideas for making this a good learning experience.

Table 4. Students' comfort levels with various topics at the beginning and end of the semester

Topic	Prequestionnaire avg.	Postquestionnaire avg.	Net change
1. The scientific method	4.4	4.65	+0.25
2. Hypothesis formulation	4.36	4.48	+0.12
3. Experimental design	3.94	4.46	+0.52*
4. Interpreting results of experiments	4.03	4.60	+0.57*
5. Integrating results of previous experiments	3.57	4.41	+0.84*
6. Planning future experiments based on previously obtained data	3.44	4.29	+0.85*
7. Drawing conclusions based on the data	4.09	4.56	+0.47*
8. Writing scientifically	3.83	4.40	+0.57*
9. Communicating scientific information to peers	3.77	4.30	+0.53*
10. Conducting literature searches for background information	3.59	4.17	+0.58*
11. Understanding scientific literature	3.26	4.03	+0.77*
12. Performing techniques required for bacterial growth	3.33	4.83	+1.50*
13. Performing biochemical tests with bacteria	2.67	4.76	+2.09*
14. General microbiology knowledge	2.76	4.46	+1.70*

Self-reporting questionnaires assessing the students' perceived knowledge or "comfort" with the processes or experiences were taken at the beginning and end of the semester. Students were asked to evaluate their level of comfort (1, not comfortable at all; 3, somewhat comfortable; 5, extremely comfortable).

* $p < 0.05$, n = 70.

RESULTS AND DISCUSSION

In this study, we used an investigative approach together with cooperative learning to enhance the learning experience of biology majors and increase their satisfaction with the advanced microbiology laboratory. For each of the topics on the questionnaire, feelings of comfort improved (Table 4). Except for the two topics on scientific method and hypothesis formulation, this increase was statistically significant ($p < 0.05$). The biggest improvements were regarding the topics specific to microbiology. Smaller increases were determined for more general topics. There were no decreases determined for any of the topics. This indicated that the students felt they had a significantly better understanding of the "process of doing science" after completing this lab experience. Due to the sequence of lab courses that students must follow before entering this class, all students had multiple experiences with the other topics surveyed. Interestingly, increases in comfort were measured for all topics, most of them significant, even though prequestionnaire values were >3, and several of them were >4. With 5 as a maximal score, recording significant increases in almost every area was unexpected. In the two topics in which a significant increase was not observed (scientific method and hypothesis formulation), initial values were both >4.35. These were the two highest initial values for all topics, and reaching a significant increase for these topics would be difficult. It is important to note that the questionnaires used were self-reporting instruments and not true indicators of actual proficiency in any specific area. Alternate methods or instruments would be necessary to determine this directly.

When comparing this lab experience with others, students rated this lab experience as much better than others at a statistically significant p value of <0.05 (Table 5). In every topic surveyed, average scores were well above 4, with 3 being the equivalent to the same as other lab experiences. It was clear from these results that students felt more responsibility for their learning, felt freedom to pursue lines of inquiry as needed, and felt that this style of laboratory experience would lead to better retention of the skills. This is especially surprising considering the student demographics. Almost all students (71/72) were either juniors and seniors. By the time biology majors enter their junior year, they have experienced, at a minimum, four biology classes with associated labs and two to three chemistry classes with labs. Most seniors also would have experience in other biology classes with labs and probably physics with lab. Considering the number of lab experiences that most students would have by the time they took this class, having scores drastically higher compared with all other lab experiences is exceptional.

To improve the lab experience each subsequent semester, we asked students to respond to several questions. The responses were consistent throughout the 3 years of course development (which is still ongoing); implementation of

Table 5. Students' comparison of this laboratory experience with other lab experiences

Topic	Avg. score
1. The opportunity to repeat experiments as many times as necessary	4.57
2. Mastery of techniques needed to complete lab exercises	4.54
3. Freedom to pursue lines of experimentation as needed	4.48
4. Overall satisfaction	4.35
5. Feeling of ownership for my learning	4.35
6. Anticipated retention of skills, concepts, and content	4.20

At the end of the semester, students were asked to compare this lab experience with previous labs in six areas, on a scale of 1–5 (1, much worse than previous; 3, the same; 5, much better than previous). n = 54 students; $p < 0.05$ for all topics, compared with an expected value of 3.0, the average score.

student ideas has improved the lab considerably. The timing of certain tests, the lab manual chosen, better organization and storage, and a "real" poster session with deliverables from each student were some of the responses that resulted in better flow and more positive student feedback. One of the key questions asked whether students preferred a more "structured" laboratory experience in which the outcomes were predictable. Some students considered this experience to be more structured, because we were working toward the same goal all semester. Overwhelmingly, they preferred the "real-world" approach, felt that not knowing the outcome was more like being a "real" scientist, and appreciated the opportunity to repeat tests. A majority of respondents described the experience as "fun," but also challenging to feel the responsibility of being in charge, rather than simply following instructions. Many students noted that this was the first time that the teacher did not know the answer; some students were frustrated by that, but most found it (in the end) exciting and personally gratifying to act like a real scientist. Personal responsibility, freedom to plan their own activities, and having to apply results to future experiments were common answers to questions of why the experience was valuable. Although these are not quantitative data, the summary above represents inclusive and highly representative student feedback.

Some suggestions for improvement from the students included having more interaction between groups. As the groups get more and more involved in their own projects, many people felt isolated or distant from other groups and their results. For those students who did reach out to other groups, many commented on how they were able to learn something that they would not have been able to had they not communicated with others.

Some students (<10%) really disliked the notion of a group project or group grades. They would rather be left to complete all tasks on their own and do not like having to depend on others for work to be completed. These students are fairly easy to identify, and it is important to stress the value of completing group work and participating in the group dynamic. Individual meetings with these students were very effective in lessening the fears of the student with regard to group dynamics. It is also important to stress that there are very few careers that do not have some aspect of a "group," and that learning within this type of environment is beneficial in and out of the laboratory.

For instructors, this type of investigative lab certainly has its advantages. For the first two-thirds of the semester, the workload is decreased in comparison with more traditional labs. Students are required to complete random assignments and write sections of their paper rather than completing exercises for every lab period. In addition, by providing individuals feedback on their writing, the final group lab paper was easier to read and grade. By receiving instructor feedback regarding their writing, students also benefit by knowing how to correct their mistakes before submitting their final paper. Additionally, the students' evaluation of posters during the poster session can be used by the instructor to help determine grades. Because of the work by both students and instructors throughout the semester, the workload at the end was no more, and conceivably less, than in a traditional lab. The cost difference per student between this and traditional labs is insignificant. Although we did not previously perform PCR and get DNA sequences in this lab, we had traditionally used Enterotube and the BBL CRYSTAL identification systems Gram-positive identification kit to illustrate clinical lab identifications. These kits and the associated expense were eliminated because we do not typically isolate clinically relevant organisms; thus, the kits were not helpful and in fact were often confusing. In fact, the more standard (one might say "old-fashioned") tests tend to use inexpensive media and chemicals. We lowered expense, also, by using very inexpensive agar plates (tryptic soy agar) for the initial isolation, thus limiting our population of unknowns to those that would grow readily on this medium.

One of the aspects of this type of experience that would normally go unreported by the instructors is the feeling of excitement of the unknown. Students, when given the freedom, can be very creative when determining where to acquire samples. Some of the environments that have been sampled include camel and turtle feces, a dog's mouth, soil and water taken from various places on campus, the air in a hospital emergency room, and bark and leaves from various trees and shrubs. With such diversity of samples, it is easy for both students and instructors to stay invested in the process of identification for the entire semester.

Although the lab experience was structured to make it imperative that all individuals of a group participate and contribute throughout the semester, there were a few groups where individuals did not participate nearly as much as the others. For these students, it did not seem that contributing to the group was important. It was in these situations where the peer evaluations became very important. If it was obvious that certain members of the group did not do their share of the workload, particularly on group assignments, and this was supported by the peer evaluations, individual grades on the group work were adjusted up or down to correct for this discrepancy.

Previously published microbiology laboratories of this type include Deutch (1994), who reported the use of soil unknowns for a similar experience. The advantages of our laboratory are 1) exposure of students to a wider variety of organisms and 2) more connection of the laboratory experience with the lecture material. Wagner and Stewart (2000) also reported a similar experience; however, our laboratory focuses more on the cooperative learning experience and includes more research about the organisms on the part of individual students.

Based on quantitative data and written student feedback, the organization and execution of this lab experience were preferred by both students and instructors over other laboratory experiences. Many students commented that although sometimes having experiments "work" is preferable, they actually learned more when they didn't work, and they had to not only re-examine the data but also re-examine their assumptions for the experiment.

The specific objectives of this modified laboratory experience were to teach the basic techniques used in the microbiology laboratory and to use these techniques in the identification of unknown species of bacteria in a cooperative learning group environment. This experience emphasizes the process associated with scientific discovery and ensures student engagement by offering ownership of the project. Furthermore, students learn to communicate scientific data effectively, through both written and oral presentations. It has been said that science, technology, engineering, and mathematics are defined “as much by what they do and how they do it as they are by the results they achieve” (Rutherford and Ahlgren, 1989). This laboratory experience embraces that definition and uses a combination of active and cooperative learning. We find this experience was overwhelmingly preferred by students and instructors and improved the teaching and learning environment.

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