Investigating How Streptococcus Responds to Their Environment: Bringing Together Current Research, a Case Study and Laboratory Investigation †

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Understanding the link between course work and unanswered authentic research questions being explored in the research lab is an important goal in undergraduate science teaching. The activity presented here focuses on current research regarding the virulence characteristics of Streptococcus pyogenes particularly targeting the control of sugar uptake regulated via catabolite repression. Students were challenged to formulate a research question and use higher-order thinking skills to analyze data, work collaboratively to solve problems, and pose and test a hypothesis in the laboratory setting. The activity employed an interrupted case study approach using both online and face-to-face settings. The case story and problems were distributed online and were followed by in-class discussions and lab work. Aspects of the activity required independent thinking, as well as collaborative work. Student learning gains were demonstrated via comparison of pre- and post-scores on the Host Pathogen Interactions (HPI) concept inventory, results from an end of semester Student Perception Survey, and from analysis of students’ work.

INTRODUCTION

The proposed activity, “The Bikini Wax Disaster,” addressed two fundamental concepts that all microbiology students need to understand: How microbes adapt/respond to the environment, and how the environment affects the pathogenicity of a bacterium. The activity integrated research-oriented learning into the undergraduate curriculum through student’s engagement in the process of science. The activity required student’s prior knowledge of a basic understanding of catabolite repression and familiarity with the general characteristics of the bacterial genera Streptococcus and Staphylococcus. “The Bikini Wax Disaster” activity (BWD activity) was composed of a two-part interrupted case study (5, 6) linked to a laboratory investigation, and was based on research that connected carbon catabolite repression (CCR) to the hemolytic activity of Streptococcus pyogenes (S. pyogenes) through the transcriptional repressor CcpA (9). The case study employed a fictitious story about a diabetic patient with necrotizing fasciitis to engage students in the discussion of bacterial genetics (the sag operon which contains the genes required for the production of streptolysin S) and bacterial physiology (sugar availability and blood hemolysis). The case study also required students to critically analyze the research article “CcpA-Mediated Repression of Streptolysin S Expression and Virulence in the Group A Streptococcus” (9). In addition to the case study, the linked lab investigation engaged students in testing student-generated predictions about the effects of sugar on the hemolytic pattern of S. pyogenes. The lab investigation was designed to expose students to the experience of testing a hypothesis using clinical samples, but it employed strategies that made the process accessible to a teaching laboratory (use of a mock patient sample and a guided discussion that leads students toward a hypothesis that can be tested with available supplies, time, and equipment). Participation in the activity allowed students in a novel yet simple way to learn fundamental microbiology concepts, through the analysis of primary research findings.

Intended audience

The research oriented learning activity (ROLA) “The Bikini Wax Disaster” was designed for an upper-level Pathogenic Microbiology course targeted to junior and senior level Biology majors. It is expected that the students will have the sophistication and knowledge required to read primary scientific literature.

Learning time and instructor preparation

Learning time

The BWD activity included an interrupted case study followed by a two-part lab investigation (Fig. 1). The BWD activity required three class periods:

Class meeting 1: Discussion of Case Study Part 1 (20–30 minutes in class); Class meeting 2: Discussion of Case Study Part 2 and laboratory investigation (110 minutes);
Class meeting 3: Laboratory observations and discussion of lab results (90 minutes).

Time between class periods was required to allow students to complete reading, research, and composition of responses related to case study Part 1 and Part 2, and for incubation of cultures related to the lab investigation. The time ranged from two to seven days because of lab meeting days (a minimum of 48 hours between each class meeting is recommended).

Instructor preparation

Graduate Teaching Assistants (TAs) served as lab instructors for our course. TAs participated in training sessions related to the science material and the pedagogy approaches of this activity. Prior to working with students, TAs read and generated responses to the case study questions which they were given 3–5 days to complete. This was followed by a meeting with the faculty lab instructor where the methods to teach Case Study Part 1, Case Study Part 2, and the Lab Investigation were modeled and discussed. The training experience required two meetings. The discussion of the lab investigation included observation and review of lab data using a process similar to that to be used with the students.

Laboratory preparation

TAs were responsible for preparation of lab materials, testing of strains, and setting up for lab. Preparation of sugar solutions required approximately one hour; testing of strains required one hour followed by a 24-hour incubation period; preparing cultures for and set up of student labs required two hours.

Grading

TAs were responsible for grading student responses to case study Part 1 and Part 2, as well as for the laboratory investigation questions from the two lab sections (36 students total). Using specifically designed rubrics (see Materials), grading required 2–3 hours for each set of student responses.

Prerequisite student knowledge

It was expected that students had completed a one-semester general microbiology course with laboratory and

FIG. 1. Activity overview. The activity was designed using an interrupted case study released to students in two parts followed by a lab investigation. Top: timeline for the activity; bottom: explanation of elements of the activity followed by Bloom level (BL) where 4 through 6 are higher-order cognitive skills, as described by Crowe et al. (3).
had been trained in safety precautions required for handling BSL2 organisms. The BWD activity built upon prior knowledge of microbiology. Specifically:

• basic understanding of catabolite repression
• basic knowledge of characteristics of Genera Streptococcus and Staphylococcus
• basic microbiology laboratory skills (aseptic techniques, streaking plates, and pipetting)
• basic understanding of alpha, beta, and gamma hemolysis as observed on blood agar plates

The BWD activity followed course lectures that provided basic concepts related to characteristics of Genera Streptococcus and Staphylococcus, virulence factors, pathogenesis, and a lab activity where students learned the phenotypic characteristics of the two genera.

Learning objectives

The BWD activity was created as part of a larger project to develop research-oriented learning activities (ROLA) in Host Pathogen Interaction (HPI) undergraduate courses (NSF DUE 0837515). For each ROLA, faculty research was used as the inspiration or model system for the design. Development was approached using the Backward Design method (3, 4, 15, 16) (see Table 1) where learning goals and assessments were first established and then activities developed to meet the goals. Each activity targeted at least one HPI concept (7, 12), and was designed to help students develop higher-order thinking skills (1, 13) as defined by attaining upper levels of Bloom’s taxonomy (1), and a meaningful understanding of the process and relevance of science (17). To accomplish this mission, the following learning goals were established. At the completion of the BWD activity students will:

1. Understand connections between HPI research and concepts learned in class/lab.
2. Understand how microbes respond to the environment.
3. Understand how the environment affects the pathogenicity of a bacterium.
4. Be able to apply the scientific research process to a specific microbiological question.

Learning outcomes to allow students to meet each of these goals are presented in Table 1.

PROCEDURE

Materials to support student learning

Handouts
Case Study Student Version, Laboratory Investigation Student Handout (Appendix 1 and 2).

Instructor information
Case Study Instructor Version, Laboratory Investigation Instructor Information (Appendix 3 and 4).

PowerPoint presentations
Case Study Part 1 Discussion PowerPoint, Case Study Part 2 Discussion PowerPoint (Appendix 5 and 6).

Assessment documents
Rubric Case Study part 1 Questions, Rubric Case Study part 2 Questions, Rubric Lab Questions, Rubric Case Study Discussion, Student Perceptions Survey (Appendix 7, 8, 9, 10 and 11).

Materials for the laboratory investigation

Strains and safety issues
All strains tested in the laboratory investigation were obtained from Dr. Kevin McIver (wild type S. pyogenes and ΔccpA S. pyogenes; contact information: kmciver@umd.edu; 3124 Bioscience Research Building, University of Maryland, College Park, MD 20742-4451; phone: +1 301 405 4136) (9). These samples were appropriate for use within student teaching labs rated BSL-2 and for students who have been trained in proper aseptic technique. Patient samples were not appropriate for use in the teaching lab. To create an authentic research oriented learning experience mock samples were used for the laboratory investigation. For the mock patient sample ΔccpA S. pyogenes was used.

Materials and equipment
• Pipettes (100-1000 μl and 20-200 μl range) and corresponding pipette tips (Thermo Fisher Scientific, Ottawa ON, Canada)
• 1.5 ml sterile microfuge tubes, 3 per group (Fisher)
• Plate spreaders
• Inoculating loops (Fisher)
• 37°C CO₂ incubator

Media and solutions
• BHI slants for student cultures, one culture of each of the three strains per two groups of students (Remel Products, Lenexa, KS)
• Blood agar plates (Remel) to test for hemolytic properties, 7 plates per group stored at 4°C
• 2 ml autoclaved distilled water per group
• 1 ml aliquots of each: 1M Glucose, 1M Fructose, 1M Maltose, (Sigma- Aldrich, St. Louis, MO) stored at room temperature, one set of sugars per student lab group

Student Instructions
See Appendix for handouts: Case Study Student Version, Laboratory Investigation Student Handout (Appendix 1 and 2).
An overview of the design of the activity is presented in Fig. 1.

Case study part 1

Prior to class period 1

Case Study Student Version Part 1 of BWD activity was distributed to students. The Case Study began with a clinical emphasis and then transitioned to a research focus. Case Study Part 1 opened with a story about Trudi, a fictional patient presenting symptoms of necrotizing fasciitis and included images, patient information, and test results. As the story in Part 1 continued, students were guided toward the reading of the review article “Streptococcal β-hemolysins: genetics and role in disease pathogenesis” (14) to encourage thinking about the connections between disease symptoms, bacterial virulence, and the factors that control bacterial virulence. Students worked independently to read and critically assess the case study material and determine the relevance of the case content to the Case Study Part 1 questions (included in Case Study Part 1). The case was intentionally written so as to omit some details necessary to respond to Case Study Questions and to include relevant and irrelevant information. Presenting students with case studies that contain incomplete or excessive information has been recommended as an avenue to promote critical thinking and problem-solving skills.

Distribution of student handouts

For distribution of student handouts (Case Study Student Version and Laboratory Investigation Student Handout), we used the online University Learning Management System. Alternatively, these could be e-mailed to students or distributed on paper in class.

<table>
<thead>
<tr>
<th>Learning Outcomes Students Will Be Able To:</th>
<th>Learning Objectives Addressed</th>
<th>Activity to Achieve Learning Outcome</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaluate a patient history and laboratory results to determine the causative agent. (BL 5)</td>
<td>3,4</td>
<td>Case Study Part 1</td>
<td>Case study part 1 questions</td>
</tr>
<tr>
<td>Design a treatment plan for a diabetic patient with S. pyogenes necrotizing fasciitis. (BL 6)</td>
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<td>Case Study Part 1 Discussion</td>
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<td>Define and state the action of streptolysins. (BL 1)</td>
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<tr>
<td>Identify the product of the Sag operon and describe how it is analyzed using the mouse model organism. (BL 2)</td>
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<td>Based on the evidence presented, predict if the strain of S. pyogenes from Trudi’s blister is producing streptolysin S. (BL 2)</td>
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<tr>
<td>Analyze a primary research article and interpret graphical data presented in a primary research article. (BL 4)</td>
<td>1,2,3,4</td>
<td>Case Study Part 2</td>
<td>Case study part 2 questions</td>
</tr>
<tr>
<td>Based on data presented in a primary research article formulate a testable hypothesis. (BL 6)</td>
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<tr>
<td>Propose how the Sag operon in S. pyogenes might affect disease progression in a diabetic patient. (BL 5)</td>
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<tr>
<td>Apply analysis to a new situation. (BL 3)</td>
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<td>Use aseptic techniques and blood agar plates to test the effects of various sugars on the hemolytic pattern of wild-type S. pyogenes and strains of S. pyogenes defective in carbon catabolite repression. (BL 3)</td>
<td>1,3,4</td>
<td>Laboratory Investigation</td>
<td>Lab investigation questions</td>
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<tr>
<td>Record and interpret data. (BL 4)</td>
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<tr>
<td>Evaluate data obtained in comparison to published research findings. (BL 2 and 5)</td>
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<tr>
<td>Propose how catabolite repression in S. pyogenes might affect disease progression in a diabetic patient. (BL 5)</td>
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to engage students in thinking critically (5, 6). After reading the case, students were guided to determine what additional information or insights were needed to address the Case Study Part 1 questions, and were then asked to complete the research and compose responses to the case study questions. Students were allowed sufficient time to complete their work. Students submitted their responses to Case Study Part 1 questions (see Case Study Student Version Part 1) to the instructor at the beginning of class meeting 11, prior to the class discussion (Fig. 1).

**Class meeting 1: Case study part 1 class discussion**

During class meeting 1, a 20–30 minute guided class discussion of Case Study Part 1 was conducted (see in Appendix 5 for PowerPoint presentation slides with notes utilized in leading the whole class in discussion). The instructor determined from student responses during discussion the level of understanding and the readiness to proceed to Case Study Part 2. Students also received individual feedback via grading of their Case Study Part 1 question responses.

**Case study part 2**

**Prior to class meeting 2**

Case Study Student Version Part 2 was distributed to students in the same manner as Case Study Student Version Part 1. Students followed the same approach to reading Case Study Part 2, individually reflecting on questions, researching necessary information, and composing responses to questions. Case Study Part 2 was written to transition student thinking away from the interesting clinical observation discussed in Part 1 to a basic research question introduced in Part 2. The case involved a fictional conversation between Trudi’s physician and University of Maryland (UMD) researcher Kevin McIver. Dr. McIver is an expert in Streptococcal pathogenesis and author of the article “CcpA-mediated repression of Streptolysin S expression and virulence in the group A Streptococcus” (9) that served as the basis for Case Study Part 2 and the following lab investigation. The case study required students to make a prediction, based on the research presented in the article, about how the addition of glucose to blood agar plates would affect the hemolytic pattern of *S. pyogenes*. After a period of brainstorming, the class was guided towards the following hypothesis: increased glucose on blood agar plates will activate CcpA and repress the Sag operon; this will result in a decreased production of streptolysin S (SLS) and thus produce less efficient hemolysis.

After the discussion of Case Study Part 2, students worked in groups to complete session one of the laboratory investigation (see Lab Investigation Student Handout and Lab Investigation Instructor Handout). Lab groups were provided with a set of materials and followed a guide (Lab Investigation Student Handout) to complete the lab investigation. Students completed an experiment to observe the impact of glucose on hemolytic activity of *S. pyogenes*. This experiment was designed to test the hypothesis the students were guided to develop during the class discussion, and presented a novel way to confirm the results presented in the research article.

**Class meeting 3: Observation and interpretation of lab results and class discussion**

Students worked in groups to observe results from the lab investigation conducted in class meeting 2. Students observed and interpreted data using the questions provided in the Lab Investigation Student Handout as a guide. Following this, the groups discussed their findings and the relevance to the published work of Kinkel and McIver (9). Students within their groups came to consensus, and then reported their findings and conclusions to the class as a whole by recording group results in a table on the classroom chalkboard. The TA then lead a whole-class discussion related to the implications of the student results to the findings of Kinkel and McIver (9) and the impact on the progression of the disease in the patient from the case study. Students worked in groups to compose their final responses to the Laboratory Investigation Questions and submitted them to the instructor before leaving class. Student responses were assessed according to the Rubric for Case Study Part 2 Questions (Appendix 8) and returned to students at the next lab period.

**Pre- and postassessment**

Prior to starting this activity, students completed the HPI Concept Inventory (II), an assessment tool developed
by the HPI teaching team at UMD to assess the development of concept knowledge in host pathogen interactions. Following the activity, students again completed the HPI Concept Inventory and responded to the Post-project Student Perception Survey that was distributed via paper in class (Appendix 11). After completion of the activity, the TAs who conducted the activity were interviewed as a focus group, and were asked to provide feedback on the activity. The interview protocol was semi-constructed and included questions about the benefits for using the case study and the relevant research study, possible difficulties students encountered, and suggested changes.

Suggestions for determining student learning

Student learning was assessed through: (1) responses to questions found in Case Study Student Version and the Lab Investigation Student Handout, (2) instructor’s assessment of participation in class discussions of Case Study Part 1, Part 2, and the Lab Investigation, and (3) scores on the pre- and post-HPI concept inventory.

DISCUSSION

Field testing

The activity was piloted in fall 2009 offering of BSCI 424: Pathogenic Microbiology course at the University of Maryland. The course consisted of 65 seniors, three juniors and two graduate students, of which 34 were males and 37 females; 65 were majoring in the College of Life Sciences, two in the College of Engineering, two in graduate school, one in the College of Agriculture, one in Letters and Sciences. In fall 2010, following a revision, the activity was implemented into two sections of BSCI 424. The 2010 course consisted of 32 seniors and four juniors of whom 11 were males and 25 females; 34 majoring in the College of Life Sciences, one in the College of Agriculture, and one in the college of Behavioral and Social Sciences.

Evidence of student learning: Analysis of students’ answers to Case Study questions

Student learning was assessed via analysis of responses to case study questions based on the rubrics available in Supplementary Materials (Rubric for Case Study Part 1 and Rubric for Case Study Part 2). Seventy students completed the activity in fall 2009 and the class average grade for the case study was an 8.7 out of 10. Thirty-three students completed the activity in fall 2010 with a class average of 8.5 out of 10. These consistently high scores indicated that students were able to meet the learning goals for this portion of the activity (see Table 1 and Rubric for Case Study Part 1 and Rubric for Case Study Part 2).

Case study discussions and TA feedback

In the interview, the TAs reported on several benefits for using the case study and the relevant research study: (1) case study discussions were lively, since the case study story elicited student participation; (2) students seemed to enjoy connecting the disease symptoms described in the Case Study to a causative agent and then discussing potential treatments and their effectiveness; (3) students were able to easily transition from the discussion of the clinical aspects of the case to the discussion of the research problem related to streptococcal pathogenesis and the relevance of this research to the patient and her disease; (4) students enjoyed class discussions regarding data from the research article, which helped them to understand the relevance of basic concepts in microbiology and in science in general, especially the use of experimental controls and significance of data. Overall the TAs reported that “The Bikini Wax Disaster” was a successful activity that challenged and stimulated the students to think critically and introduce them to current and authentic research related to host pathogen interactions.

Graded laboratory report

In fall 2010, 35 students completed the revised version of the laboratory investigation. All students stated that their results supported the observations in Dr. McIver’s article (9). The majority of students (80%) gave an appropriate explanation of how their results supported the paper’s conclusions, which addresses the learning outcome: “students will be able evaluate data obtained in comparison to published research findings” (Table 1). For example, one student reported, “These results did support the results observed by Dr. McIver’s lab in that the wild-type showed a lesser degree of hemolysis with increasing concentrations of glucose, but ΔccpA remained beta hemolytic throughout. This correlates with figure 3 of the article that shows ΔccpA constantly remaining highly hemolytic and the WT complement ΔccpA starting off with little hemolysis.”

To assess the learning outcome: “students will be able to propose how catobolite repression in S. pyogenes might affect disease progression in a diabetic patient,” students were asked to answer the question, “From your results, what can you predict about the strain isolated from Trudi’s (the mock patient from the case study) blister? How do these results relate to Trudi’s poor outcome?” The majority of students indicated that the sample from the patient’s blister reacted similar to the ΔccpA mutant strain in the experiments conducted; however, they often sighted it as being the exact same strain. Although this could count as technically correct (in the lab it is the same strain), the lab results did not definitively show that it is the same strain. Instead, a more accurate answer would be as one student wrote, “She must have a mutant S. pyogenes that has the Sog operon always expressed and producing streptolysin. Trudi’s
severe symptoms indicate an extremely virulent strain, producing much SLS toxin with lots of beta hemolytic activity.”

Overall, the students’ answers to the laboratory activity questions indicated that they were able to interpret their results appropriately, relate them to the HPI research article, and make predictions about the strain isolated from the patient based on those results.

Students’ perceptions survey

In fall 2010, thirty-five students completed a postsurvey in which they were asked to give feedback related to the “Bikini Wax Disaster” activity by responding to six Likert scale questions (0 = Strongly disagree, 1 = Disagree, or 2 = Agree, 3 = Strongly agree), and were prompted to comment on the activity stating what they liked or did not like about the activity (see Appendix 11 for complete survey). They were also asked to make suggestions about how the activity might be improved. Ninety-four percent of students agreed or strongly agreed with the statement: “I found the case study intellectually challenging.”

One goal of this activity was to introduce students to research occurring in host pathogenic interactions (Learning goal 1) at the University of Maryland. This activity was developed around Dr. Kevin McIver’s research on the molecular mechanisms by which pathogenic streptococci regulate their virulence repertoire in response to host signals. After completing this activity, 91% of students agreed or strongly agreed with the statement: “I learned about research related to host pathogen interactions occurring at UMD through completing the case study and lab activity.”

These results indicated that the activity met our first broad goal that students make connections between HPI research and concepts learned in class/lab.

To determine how students perceived their improved understanding of the scientific research process (goal 4), they were asked to respond to the statement, “The case study and lab activity gave me a better understanding of the scientific research process.” Ninety-one percent of the students agreed or strongly agreed. Twenty-seven students wrote comments, 22 of them were positive and three gave suggestions regarding the need for some more background information or links to sites to help with answering the case study questions. One student did not like having to read a research article, and another student felt that the questions were too easy. Positive student comments on the activity included: “The case study provided a real-life example of what we were performing in lab, that allowed me to better relate/understand the principles being described.” “I really liked trying to figure out Trudi’s case by looking at her test results and symptoms, and then testing her ‘sample’ in lab.” “I liked seeing that the results from the paper were actually true instead of just reading about it.” These self-reporting data suggest that, overall, the students had a positive experience with the activity and that the activity implementation met the learning goals set forth by the HPI teaching team.

HPI Concept Inventory (10) results from 2009

The HPI Concept Inventory assesses students understanding of 13 concepts developed by the HPI teaching group (6, 11), including the two HPI concepts addressed in this activity. Forty-one students completed both the pre- and post-HPI survey. The average score on the post-survey (52.53 ± 16.49) was significantly higher ($p > 0.001$) than the average score on the presurvey (40.58 ± 15.35), demonstrating that students improved their understanding of important concepts in host pathogen interactions (Learning goal 3).

Possible modifications

The case study could be used alone without the laboratory investigation portion of the activity. Although we did not require students to reference sources used in answering the case study questions, we plan to in the future as a method to engage students in critical evaluation of resources and to teach students the proper use and referencing of researched information. The lab, as presented here, is very directed; however, it could easily be manipulated in a variety of ways to give students more flexibility. For example, students could propose which sugars to test, as well as calculate the concentrations to analyze.

One of the aims of this activity was to engage students in an in-depth discussion of a patient. To achieve this, the patient (Trudi) is the touchstone of the entire activity. Trudi has diabetes, which directly relates to the research on carbon catabolite repression presented in the article and connects the microbiology concepts, “microbes respond to the environment changes in glucose levels” (addressing Learning goal 2) and “the environment/glucose levels affects the pathogenicity of a bacterium” (addressing Learning goal 3), to patient outcome. To integrate the patient story into the lab investigation, a mock patient sample was introduced. The mock patient sample was the ΔccpA strain; however, the wild-type strain could also be provided as the mock patient sample to allow for a discussion about how Trudi’s poorly managed diabetes (fluctuating blood glucose levels) would affect the pathogenicity of $S. pyogenes$ and result in her poor outcome.

The idea for the student laboratory investigation portion of this activity came about from discussion of this research in a Host Pathogen Interactions Research and Teaching Summer Workshop held at UMD in June of 2009 (www.clfs.umd.edu/hpi/workshop.html). The lab investigation was set up to test the hypothesis set forth and investigated by Dr. McIver and colleagues in their article (9) that the hemolytic activity of $S. pyogenes$ is regulated through catabolite repression mechanisms (Fig. 3, Kinkel and McIver, 2008) and that glucose leads to catabolite repression (Fig. 4, Kinkel and McIver, 2008). Integrating the results of these two assays, students tested the strains obtained from the McIver laboratory using the simpler...
hemolytic assay, growth, and hemolytic pattern on blood agar plates supplemented with glucose. In addition, they tested the strains on plates supplemented with maltose and fructose. None of these blood agar plate assays had ever been performed in the McIver laboratory; thus, the data obtained from the student work were novel and further supported reported findings while also raising additional questions to be tested. The activity as presented here allowed students to develop an initial prediction (Case Study part 2 done individually) and to share their ideas with the class followed by instructor guided brainstorming (class discussion), which led students to the hypotheses tested in the structured lab activity. A potential modification would be to open the lab investigation for testing of other hypotheses by providing a set of materials and allowing each group to test their own ideas using only materials provided. This methodology would add another level of inquiry while limiting the supplies required. Some potential possibilities would be to: (1) test other sugars, (2) test more points of sugar concentration to determine the exact concentration of glucose that shifts the hemolytic pattern, or (3) test other beta hemolytic gram-positive bacteria to determine if this is a common regulatory mechanism for all gram-positive bacteria.

For the laboratory investigation portion of the activity, groups of two would work well, but groups should remain no larger than three so that all students in the group have the opportunity to fully participate in the hands-on laboratory work. (We chose to have groups of three mainly based on the seating arrangement in the teaching labs.)

SUPPLEMENTAL MATERIALS

Appendix 1: Case Study Student Version
Appendix 2: Laboratory Investigation Student Handout
Appendix 3: Case Study Instructor Version
Appendix 4: Laboratory Investigation Instructor Information
Appendix 5: Case Study Part 1 Discussion PowerPoint
Appendix 6: Case Study Part 2 Discussion PowerPoint
Appendix 7: Rubric for Case Study Part 1 Questions
Appendix 8: Rubric for Case Study Part 2 Questions
Appendix 9: Rubric for Lab Investigation Questions
Appendix 10: Rubric for Case Study Discussion
Appendix 11: Student Perceptions Survey

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