Implementing Inquiry-Based Learning in a General Microbiology Laboratory

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ABSTRACT

In recent years there has been an increased interest in inquiry-based learning, also known as experiential learning or problem-based learning, as a more appropriate model of teaching science. The purpose of this study was to incorporate inquiry-based learning in a college sophomore-level General Microbiology Laboratory. The goal of this laboratory course is to introduce students to basic techniques and procedures necessary for the study of microorganisms. Laboratory sections were randomly assigned to an experimental group or a control/reference group. The experimental group was taught the concept of serial dilutions using an inquiry-based learning approach whereas the control group was taught using traditional teaching methods. Analysis of the data generated from the students' involvement in the investigation during the fall semester indicated that the experimental group had a slightly greater improvement in their knowledge of serial dilution. The study continued in the spring semester and involved close to 300 students. During the spring semester both the experimental and the control groups had similar attitudes about their learning experience as evaluated by a Lickert Scale survey. However, a statistical analysis of the quiz scores of the students with values within the interquartiles indicated the experimental classes' quiz scores were significantly higher on

quiz 2 taken at the midpoint in the study. Thus an inquiry-based learning approach was found to be beneficial to the middle 50% of the class.

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CHAPTER ONE

Literature Review

Educational Reform

Colleges and universities strive for excellence in education in their science departments. However, the methods of instruction used in implementing science courses, particularly the laboratory experience, are undergoing a change in philosophy, incorporating teaching strategies such as inquiry-based learning, to correct weaknesses of science laboratory programs. One of the most important weaknesses is that the instructors of laboratory courses are often not equipped with the knowledge to conduct a successful investigative/inquiry-based laboratory experience. The goal of an inquiry-based laboratory experience is not only to provide hands-on application of materials, but also to include a higher level thinking process. Science laboratory classes become less effective when they focus on demonstration rather than investigation.

Second, colleges and universities frequently rely on graduate teaching assistants to instruct a majority of their laboratory courses and they often have no pedagogical background nor support from their research oriented faculty advisors to excel at teaching (Paulsen et. al, 1995). Teaching assistant training is limited and teacher assistants are often left unsupervised. It is naïve to believe that just because an individual has mastered content knowledge that it makes them capable of being effective facilitators of learning (Keig and Waggoner, 1994). Teaching assistants must possess other necessary competencies as stated by Yarbough: “1) subject- matter content knowledge, 2) subject-matter pedagogical knowledge, 3) curricular knowledge, 4) general pedagogical knowledge, 5) knowledge of learner characteristics and 6) knowledge of communication techniques” (Kreig and Wagonner, 1994). Due to a lack of training and background, teaching assistants will often model their teaching style after those instructors they have encountered throughout their educational history. How people were educated in the past is not necessarily appropriate for meeting the demands of the future (Senge, 2000).

In order to be effective contemporary educators, the teaching assistants must be educated in pedagogy. The National Research Council has adopted specific initiatives that should be met in science education for teachers. These standards are as follows (1996):

“1. Teachers of science plan an inquiry-based science program for their students.

2. Teachers of science guide and facilitate learning.

3. Teachers of science engage in ongoing assessment of their teaching and of student learning.

4. Teachers of science design and manage learning environments that provide students with the time, space, and resources needed for learning science.

5. Teachers of science develop communities of science learners that reflect the intellectual rigor of scientific inquiry and the attitudes and social values conducive to science learning.

6. Teachers of science actively participate in the ongoing planning and development of the school science program.”

These standards set the overall goal of constructing a laboratory curriculum that engages the student’s mind through hands-on activity. A hands-on activity has been defined as a science lab activity that allows the student to handle, manipulate or observe a scientific process (Lumpe et .al., 1991). However, a minds-on activity involves problem solving thinking, a process not always utilized during a hands-on activity. Science education reform involves bridging the gap between minds-on and hands-on activity. Investigative laboratory exercises can bridge this gap.

Last, too often teaching in a science laboratory is teacher focused and involves demonstration/observation. Students go through a set of procedures within a set period of time with little to no critical thinking involved (Glasson and McKenzie, 2001). An investigative approach such as inquiry-based learning places the responsibility for learning on the student, not the instructor.

Inquiry-Based Learning

Inquiry-based learning is a teaching model directed towards a more investigative approach and is very appropriate for science laboratories. It is believed that students can gain the most understanding in science by using the same approaches that real scientists use (Lumpe et. al., 1991). Scientists begin research with a question followed by a series of procedures that lead them to possible answers. Inquiry-based learning follows the same format. The students begin with an unclear concept and follow the procedures of the activity which leads them to discovery of the key concepts (Lumpe et. al., 1991). The ultimate goal is to improve the standards of student learning by gaining scientific knowledge and an appreciation of how scientists work (National Research Council, 2000).

The National Research Council has outlined key features of classroom inquiry (2000):

"1. Learners are engaged by scientifically oriented questions.

2. Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions.

3. Learners formulate explanations from evidence to address scientifically oriented questions.

4. Learners evaluate their explanations in light of alternative explanations, particularly ones reflecting scientific explanations.

5. Learners communicate and justify their proposed explanations."

Inquiry-based learning has been researched and proven to be a successful model of teaching because it takes into account how individuals learn (National Research Council, 2000). New knowledge can be constructed from pre-existing knowledge, helping individuals to form associations (Hoover, 1996; Bransford, 1999). Constructed knowledge is rooted in two ideas: learners gained new understanding from building upon what they already know and learning is an active process (Hoover, 1996). Jean Piaget's theories in developmental psychology support constructivism (Bransford, 1999).

Implementing Inquiry-Based Learning in Secondary Education

There are numerous empirical studies that have researched the effects of an inquiry-based learning method as opposed to a traditional learning method (i.e. Roth and Bowen, 1995;White and Frederiksen, 1998). Many of these studies have taken place on the secondary education level; two examples are described here.

A study by White and Frederiksen was conducted with middle school students (grades 7-9) in an urban school setting and focused on inquiry-based learning in physics education (White and Frederiksen, 1998). It involved three middle school teachers with a total of 12 classes. In this study, researchers examined the effectiveness of the ThinkTool

Inquiry Curriculum as a tool to implement inquiry-based learning. ThinkTools is software that allows students to interactively apply Newton's models of force and motion. The ThinkTool Curriculum allows teachers to utilize the five steps of the Inquiry Cycle to create a research community within the classroom. The five steps of the Inquiry Cycle include: question, predict, experiment, model, and apply. Students were given two tests: the *Conceptual Model Test* and the *Applied Physics Test.* The *Conceptual Model Test* is a test that measures the expected conceptual model students were to develop as they progressed though their experimental activities. Middle school students who were participants in the ThinkTools Curriculum scored better than 40 high school students who were in a traditional physics course. The *Applied Physics Test* is a test that applies knowledge of physics to real world problems. It was given as a pre-test and a post-test. The results of this test again were compared between the middle school students in the experimental curriculum and high school students enrolled in a traditional physics course. It was found that out of six items assessed, students who learned through the ThinkTools Curriculum performed better than those students in the traditional curriculum on all six items. Researchers in this study determined that inquiry-based learning proved to be a successful model for learning. Middle school students were able to acquire physics knowledge though the practice of inquiry skills, which enabled them to conceptualize the principles of physics better then older high school students who were taught the same information in a traditional classroom.

This study possessed some limitations (White and Frederiksen, 1998). Students, in some cases, developed misconceptions about Newton's concept model of force and law. When comparing the computer-based experience and the real world experience, students had a difficult time putting the model in perspective. It was suggested by the authors that inquiry-based learning is best if initiated in the earlier stages of education. In addition, the researchers who organized the study had a difficult time developing an experience that would be meaningful and would motivate the students to engage in inquiry-based learning.

Another example of inquiry-based learning took place in a private school in central Canada that was modeled after traditional British private schools (Roth and Bowen, 1995). Participants in this study were 65 eighth grade students in three sections of science. It should be noted that in the three sections there were significantly more males than females because the school was in its initial year of co-education. Researchers examined an open-inquiry curriculum where students had to generate their own research questions, design investigations to solve those questions and report their findings. Researchers focused on 10 weeks of the curriculum during which students conducted an ecological investigation of the school's campus. Data collected included videotapes, audiotapes, laboratory reports, and students' answers to word problems. Students were given the *Constructivist Learning Environmental Scale* (CLES) that assessed them in the areas of autonomy, negotiation, prior knowledge, and student centeredness. The study highlighted the achievement of five students who represented the range of students in the course and how they performed on the CLES. Student achievement was associated with three of the four assessed areas, autonomy was excluded. In addition to the data collected from the featured students, the study showed overall students had an interest in making sense of what was learned as opposed to in a traditional laboratory where a majority of the students complete the exercise without an understanding of what they are doing or the purpose for doing it. Students' understanding went further than what was instructed and students began applying information beyond the confines of the assignment.

Researchers were faced with a few limitations in the study. It was found that students when working in an open-inquiry curriculum worked at a slower pace than those students who engaged in a more teacher-centered setting. Also, researchers were unsure as to what impact their presence in the classroom had on the study.

Implementing Inquiry Based Learning in Higher Education

In recent years the use of investigative approaches has gained popularity in teaching laboratories not only in secondary education but in higher education. The following are a few examples of the implementation of inquiry-based learning at this level. These examples are not empirical studies. However, they demonstrate an increase interest in the application of inquiry-based learning in colleges and universities.

The first example was conducted at Denison University where authors set out to revamp the general microbiology courses, incorporating more investigative learning (Stuckus and Lennox, 2001). The laboratory was designed around the following principles: 1) students should be involved in the process of designing the investigative laboratory experience (Wilson and Stensvold 1991), 2) the scientific environment should provide the elements of the nature of science and evoke scientific thought process (Gottfried et al., 1993), 3) there should be a link between the process of science and student's successful achievement of basic techniques (Deutch, 1994), 4) students should be able to communicate the results of their research both written and orally (Seago, 1992), 5) students should have knowledge of library research tools (Seago, 1992) and 6) research takes time therefore students should be given enough time to successfully complete their project (Lawson 1992; Leonard 1988).

The goal was to challenge students while giving them realistic examples of research projects (Stuckus and Lennox, 2001). The research project required students to work alone or in teams in which they designed their own experiment aimed at isolating microorganisms from the environment. The project is broken into weeks with an objective for each week and deadlines to prevent students from procrastinating. Students are assigned an organism to isolate and given one reference relevant to their organism. Throughout the semester students expand their literature review of the organism and create their own protocol for the isolation of their organism. At the end of the semester students submit a paper on their results. The specific guidelines of the paper are those used for authors submitting to the journal, *Applied and Environmental Microbiology* . This program has been successful as gauged by the opinions of the authors of the study.

The next example of inquiry-based learning was a project conducted at Winthrop University. The professors there have designed three investigative science courses which have similar formats but address the very different needs of three distinct groups: nonscience majors, elementary education majors, and biology majors (Dimaculangan et al, 2001). In all three classes, students learn the methods and practices of scientists and engage in the critical thinking process. The three courses cover: “1) fundamentals of scientific method, hypothesis formation, and experimental design; 2) data collection, statistical analysis, and interpretation of results; and 3) dissemination of scientific information through written and oral communication.” All three courses use the textbook, *A Handbook of Biological Investigation*.

The three courses share a unique design. Students begin the semester working together in small groups but end the semester working on an individual project (Dimaculangan et al, 2001). At the beginning of the semester the professor gives the students a question and they work in groups on these “mini investigations”. Students have to develop their own hypothesis and then design an experiment to test that hypothesis. At the end of their findings, each group writes a scientific report. Students within each team break up the writing responsibility and individual grades are given based upon the section he or she was responsible for writing.

After completing the initial investigation at the beginning of the semester, the students move on to “team investigations” (Dimaculangan et al, 2001). This time the students work in groups but come up with their own question. The professor allows the freedom for students to develop their own investigation and students are encouraged to use their creativity and decision making skills. This exercise prepares students for the final investigative experience.

At the end of the semester students complete a project without any partners and it is called the “independent project” (Dimaculangan et al, 2001). This project, performed individually, is a large portion of the student’s final grade and is the sole responsibility of the student. The student is required to write a formal proposal, a written report, give an oral presentation, and display a poster available to the university community.

The last example of inquiry-based learning comes from Oklahoma State University (Harker, 2001). Harker discussed his lack of training as an educator as compared to his experience as a researcher. He emphasized his role as a researcher was of more important than his role as a teacher. After his first year of employment, he had completed what he thought to be a successful year. The next year he found many of his undergraduate students were now in his graduate course. He was startled to find that the students had not conceptualized a lot of the information learned from the previous year. He realized he had forgotten to implement the scientific practices used in successful research. This prompted Harker to rethink the design of his course.

Harker redesigned his class around his own research interest, application of bacterial metabolism to the degradation of environmental pollutants (Harker, 2001). Each group had an unique investigative experience because there were no set instructions or guidelines. The students' assignment involved choosing a microorganism and illustrating its role in bioremediation. The students worked in groups to submit their research proposal. This proposal was to be well researched, thereby familiarizing the students with environmental literature. In the end the students presented their work in written format and in a seminar. Harker found the students' work to be of a quality which showed critical thinking. Despite a large drop in class size after the initial class meeting those students who continued through the course finished with feelings of enjoyment and accomplishment.

The 5 E Model

These examples of inquiry-based learning set the stage for the research project described in this thesis, which focused on a 2000 level General Microbiology laboratory exercise that was changed to incorporate inquiry-based learning. The changes to the Serial Dilution laboratory were based on the 5 E Model (Bybee, 1993). The 5 E's stand for: engagement, exploration, explanation, elaboration, and evaluation (Figure 1). Engagement is the initial activity which creates curiosity and connects students' prior

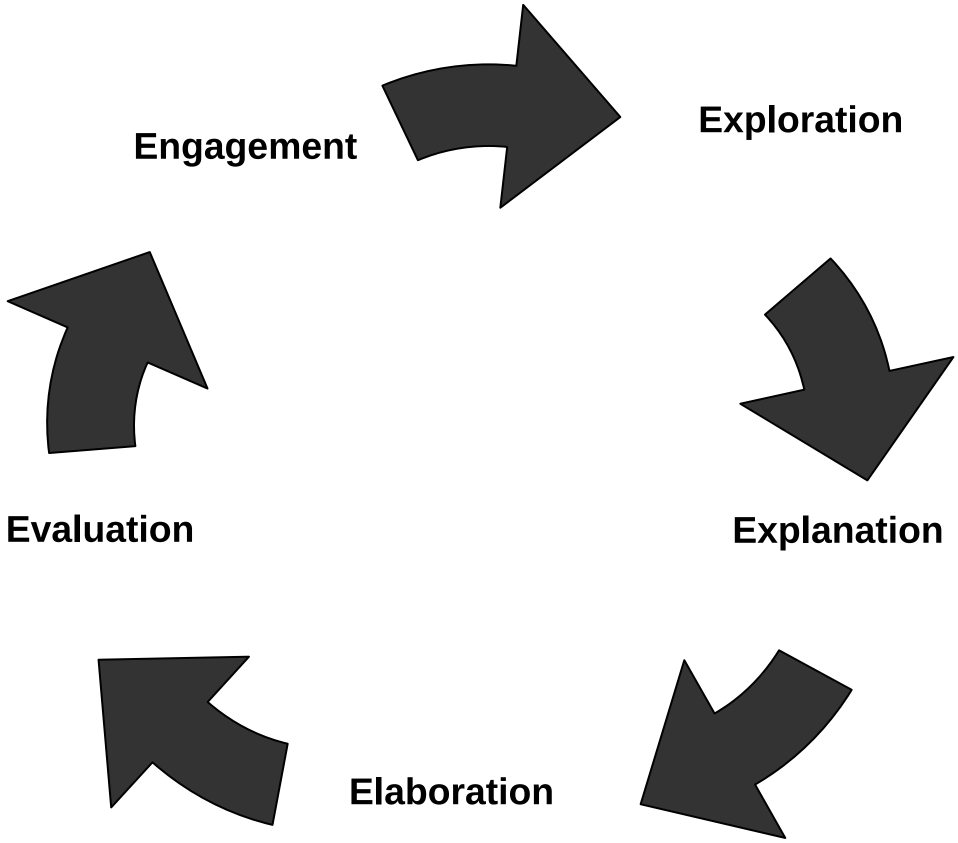


Figure 1: The 5E Model
The diagram above depicts the 5E Model which stands for: Engagement, Exploration, Explanation, Elaboration, and Evaluation (Bybee, 1993). See the text for further details.

knowledge to the new information about to be learned. During exploration students begin working together to try and put together pieces of the concept being learned. Explanation occurs when students are able give their own explanation of the concept and it is backed by creditable evidence. During the elaboration step students are able to extend the concept to other different situations. Finally, during the evaluation stage application of the concept or skill occurs.

Purpose

The laboratory exercise of interest in this study was Exercise 20: Counting Viable Cells: Serial Dilution and Spread Plates or Pour Plates from the laboratory manual, *Understanding Microbes: A Laboratory Textbook for Microbiology* (Claus, 1989). This exercise was is a good candidate for inquiry-based learning because there are techniques described that are no longer taught in the course and the laboratory exercise write up is quite lengthy and complicated. In addition, the exercise did not involve critical thinking. The goal of this research was to incorporate inquiry-based learning into the serial dilution exercise to increase student academic achievement.

Research Questions

Is there a difference between the academic achievement between students learning about serial dilutions through traditional instruction and those learning through inquiry-based instruction?

Is there a difference between students' attitudes towards inquiry-based learning instruction and traditional instruction?

CHAPTER TWO

Materials and Methods

Original Design of the Laboratory (Control Group)

The laboratory exercise on serial dilutions covers an important tool used in laboratory research. Serial dilutions are "the method of sequentially diluting a culture through a series of sterile dilution blanks" (Claus, 1989). This research tool is most commonly used in the fields of microbiology, biotechnology, toxicology, and chemistry (Hilten and Saunders, 1993). In microbiology laboratories, serial dilutions have many applications but in the context of this exercise, it is used to obtain a viable cell number. The original design of the laboratory will serve as the control class and will represent traditional instruction.

The Serial Dilutions laboratory exercise, in its present format, is a teacher-centered lesson. Students are assigned readings a week prior to conducting the exercise. After reading the assigned text the students are expected to complete a series of serial dilution problems. However, they are not held accountable for this assignment. Therefore, it can be assumed many students come to class the day the exercise is to be completed without the appropriate background knowledge. The teaching assistant, using the chalkboard, demonstrates the concept of serial dilutions while students observe. The teaching assistant then repeats the demonstration of serial dilutions using laboratory equipment. He or she explains to the students the proper technique for using pipettes and plating. The students are then allowed to work individually and are given the remainder of the class period to complete the serial dilution exercise. This exercise is a step-by-step process where students begin with a 1 ml culture and perform a series of dilutions to obtain a final dilution of 10^{-6}. After the point where student have diluted the culture to 10^{-4}, 10^{-5}, and 10^{-6}, students perform spread plates at those concentrations. Student then incubate their plated cultures overnight. The students come back the next class period and count colonies to find the viable cell number.

Students are assigned the questions at the end of the exercise. They complete these questions individually and the teacher assistant at the next class period gives the students the correct answers. Teacher assistants make themselves available to answer any questions the students have concerning their understanding of the problems. Students are also given additional serial dilution questions for more practice. These assignments are collected and graded for completion rather than accuracy. Once the teacher feels the students have been given enough practice an announced dilution quiz is administered to the students.

Serial dilution is a concept revisited throughout the semester in laboratory exercises completed after the initial exposure. Those exercises include: Bacteria in Milk, Enumeration of Lytic Bacteriophage and Microbiology of Wine (Claus, 1989). There is little emphasis on the connection between these laboratories and prior learning of serial dilutions. These laboratories could possibly be used to assess student's understanding of serial dilutions, but they are not.

New Design of the Laboratory (Experimental Group)

The newly designed exercise began with an Engagement/Exploration exercise unlike the teacher-centered instruction the control classes received (Table 1).

Table 1: Comparison of the Control and Experimental Classes

Time	Control	Experimental
Day 1	Teaching assistant led example of serial dilutions using the board.	Engagement/Exploratory inquiry-based activity conducted by the students.
Day 2	Exercise 20: Counting Viable Cells: Serial Dilution and Spread Plates or Pour Plates	Exercise 20: Counting Viable Cells: Serial Dilution and Spread Plates or Pour Plates
5 Weeks	Wine Making Exercise in groups of 4[a]	Wine Making Exercise in groups of 4[a] * Emphasis on exercises done as a unit.

[a]The Wine Making Exercise had traditionally been completed as a class demonstration.

During this exercise students were given a handout (Figure 2) prior to class. On this handout students were asked to complete a Pre-Class exercise that instructed them to read text from their lab manual on serial dilutions and define the following vocabulary: viable number, colony forming units, dilution factor, TNTC, and TLTC. Once students got to class the instructor went over the definitions with the students.

Students were then directed to complete the remainder of the exercise. Students worked in groups of four. During Part A, each group of four students was given four colored water tubes serially diluted using a four fold dilution factor. While working in groups, students had to determine the dilution pattern of the four colored water tubes by taking spectrophotometer readings. Once students had determined the pattern, the students were asked a series of critical thinking questions. Students continued Part A by recreating the four observation tubes. Students were given the following supplies: concentrated stock solution, spectrophotometer set at 650 nm, water, Kim Wipes, screw cap tubes, pipettes, pipette aid, and water blanks. Students were to write out their procedure step by step and complete the dilution scheme provided to them.

The Exploration segment involved the students observing serial dilutions and bacterial cultures. The students continued to work in groups of four while making observations about four plates which contained a bacterial culture plated out using a ten fold dilution factor. Students recorded the number of pre-counted bacterial colonies. Using the final numbers of colonies on each plate, students determined the dilution factor and how many colony forming units were in the original culture. Finally, students were able to write out their own definition of serial dilution.

Serial Dilutions Exercise

Dilutions are used to diminish the strength of solutions. Dilutions are an important tool utilized in a microbiology laboratory. In this exercise you will determine the definition of serial dilutions and investigate how dilutions can be used to obtain a viable cell count. For additional background information please refer to Exercise 20 in your text, *Understanding Microbes*, and the handout, Calculating Serial Dilutions.

Pre-Class Exercise
Prior to class in one sentence define the following vocabulary:

Viable number-

Colony-forming units (CFU)-

Dilution factor-

TNTC-

TLTC-

Part A.
Instructions: You will be given 4 control test tubes with various colored water samples labeled A, B, C and D and a water blank. Each test tube contains 3 ml of solution. Please observe these test tubes.

1. a. What observations regarding color intensity can you make about the various water samples?

b. Use the spectrophotometer to record the absorbance of the 4 test tubes. Read the spectrophotometer on a wavelength of 650 nm. Remember to use the water blank for accurate spectrophotometer readings. Read the test tubes from dark to light.

c. Based upon the recorded absorbance readings, the dilution pattern is

___________________ fold.

Figure 2. Serial Dilution Engagement/Exploration Exercise

2. If you were placed in a laboratory and asked to dilute a concentrated stock solution, describe two methods that could be used to obtain concentrations equivalent to the 4 control tubes. **(Pour plate and spread plate are not the two methods.**)

a.

b.

3. Cost can be a factor when working in a laboratory. The method chosen to perform the dilution should take into account the amount of materials and supplies used. If it does not, and material and supplies are not used efficiently, that would be a disadvantage of the method. This is just one example. Below please describe 1 to 2 other advantages and disadvantages for each method described in question 2 that have an impact on the methodology of the technique.

a.
Advantages-

Disadvantages-

b.
Advantages-

Disadvantages-

Figure 2. Serial Dilution Engagement/Exploration Exercise cont.

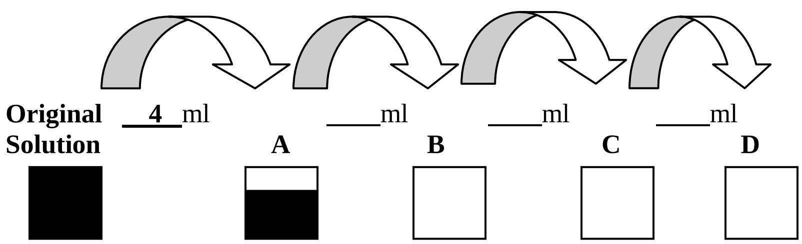
4. Of the two dilution methods described in question 2, which method is the best method to use when the initial stock concentration is in small quantity?

5. Complete the dilution scheme below. After drawing the dilution scheme, perform the dilutions that will recreate the four test tubes observed in question 1. Remember to use the water blank for accurate spectrophotometer readings. Space is provided for you to describe the steps you are taking to recreate the four test tubes. Be specific and provide clear details in a way that someone else could re-create this dilution scheme.

The following materials are made available for performing the dilution:

Concentrated stock solution	Screw Cap Tubes
Spectrophotometer set at 650 nm	Pipettes
Water	Pipette Aids
Kim Wipes	Water Blank

Remember your answer from question 1c is the dilution pattern.

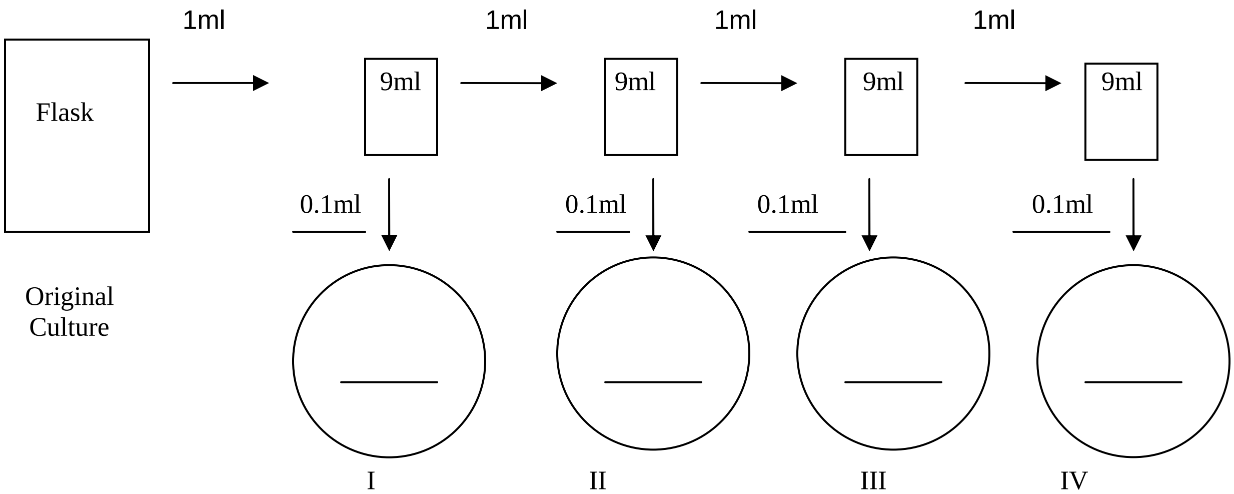


	B	C	D
Blank Volume	_____	_____	_____
Total Test Tube Volume Before Transfer	_____	_____	_____
Dilution from stock	______	______	______
Dilution Factor From Stock	______	______	______

Figure 2. Serial Dilution Engagement/Exploration Exercise cont.

Part B.
You will be given four plates labeled I- IV. On each plate a bacterial culture is growing.
Countable plates are those plates that contain between 30- 300 colonies. For more information refer to your textbook, *Understanding Microbes*, pages 185-186.

1. Count the colonies and write the number of colonies of the **countable plates** on the line provided.



2. What observations can be made about the four plates in regards to colony numbers?

3. All of the dilution steps, designated by the arrows, use the same dilution factor. The

Dilution factor is _____________ fold.

4. Using the dilution factor:
   a. Calculate the total dilution factor between the original culture and plate III.

   b. Calculate the CFU/ml in the original culture.

Part C. Based upon your observations in Parts A and B, determine and write a definition of "serial dilution."

Figure 2. Serial Dilution Engagement/Exploration Exercise cont.

In this research set up the explanation phase occurs throughout all of the other phases of instruction. The instructor circulates around the room providing assistance and reassurance. Student interaction within the smaller group setting also provided the students an opportunity among themselves to discuss and analyze the concept of serial dilutions.

The fourth phase of the 5E Model is Elaboration. During this phase students completed Exercise 20 in their textbook on a separate day. This exercise allowed students to perform a serial dilution of a bacteria culture individually. Students completed a dilution scheme on paper and then physically performed the dilutions.

Lastly, the final stage of the 5E Model is the Evaluation. During the evaluation students applied the serial dilution concept by engaging in wine making. The wine making exercise was a five week assignment where students designed a dilution scheme and carried out serial dilutions using a yeast culture. A successful wine product at the end of the wine making process was indicative of proper serial dilution. In addition, students were also evaluated with a paper format quiz.

Graduate Teaching Assistant Workshop

A workshop was organized for those graduate teaching assistants (GTA) who would be teaching the experimental classes. Normally, GTAs meet on Fridays with the laboratory coordinator to review the exercises to be done the following week. The Friday prior to the serial dilution exercise, teaching assistants from both the experimental and control classes met with the lab coordinator for their regular weekly meeting. At this meeting the lab coordinator went over the serial dilution exercise. The GTAs for the experimental sections were separated from the control teaching assistants. The experimental GTAs attended a separate workshop organized by the researcher on this project where they received instruction on how to conduct the new design of the serial dilution exercise.

During the workshop the researcher discussed inquiry-based learning and how it was incorporated into the serial dilution exercise. All the laboratory materials that would be available to the students the day of the exercise were set up for the workshop so that the teaching assistants had an understanding of how the classroom would be set up for the exercise. The researcher provided the teaching assistants with the exercise and they were asked to look over it. A formal document on how to conduct the workshop (Figure 3) was prepared. These instructions were to be used as a guide for conducting future workshops on how to teach the inquiry-based serial dilution exercise and as a reference for the laboratory coordinator.

Participants

Participants in this study included students and GTAs. The study was approved by the Human Subjects Committee with an expedited review and all participants were asked to consent to participating at the completion of the study (Appendix I). The students involved in the study had enrolled in the General Microbiology course and almost all were life science majors. Students were taking this course to fulfill a requirement towards their graduation. There were three levels of participation in this study, involvement in the study during the summer school session, fall semester (Table 2), and spring semester (Table 3). The classes were already pre-existing as assigned by the registration process. Excluding the summer school session I, students were selected to be in the control or experimental population based upon the prior teaching experience(s) of their teaching assistant.

Serial Dilutions TA Workshop Instructions

Prior to the workshop:
Send out an e-mail to the teaching assistant with the following information.

1. Provide the teaching assistant with a copy of the Serial Dilutions Exercise that should be read prior to attending the workshop.
2. Teaching assistant will need to read Exercise 20 pages 175-193 prior to attending the workshop.
3. Instruct the teaching assistants to bring a pen and pencil and be prepared to take notes.

Prepare a demonstration set of the 4 colored water tubes for observation and the 4 plates containing the bacterial culture.

The day of the workshop:
Part A
Set up the 4 colored water observation tubes and well as the following materials:

Concentrated stock solution	Screw Cap Tubes
Spectrophotometer set at 650 nm	Pipettes
Water	Pipette Aids
Kim Wipes	Water Blank

Part B
Set up the 4 plates on which a bacterial culture is growing for observation.

During the TA workshop:
Run through the exercise as if the TAs were the students.
Discuss proper use of the spectrophotometer and proper pipette techniques.
Proper use of the spectrophotometer:
Turn the spectrophotometer on at least 15 minutes prior to class.
Set the spectrophotometer to 650 nm.
Students should blank the machine with the water blank first before taking their colored water readings.
Before inserting the colored water tubes into the spectrophotometer, have the students rock the tube gently back and forth to ensure even color distribution and use a Kim Wipe to remove any finger prints from the tube.
Students should read tube A first, B, C, and D last.
Students will record the absorbance for each colored water tube.
Proper technique for disposable serological pipette use:
Open the disposable serological pipette from the end that has the cotton tip.
Obtain a pipette aid and insert the pipette tip into the pipette aid while the pipette is still in its outer covering to maintain sterility.
When handling the tip use sterile technique.
Make sure the pipette is handled at the top leaving the part of the tip to be placed in the solution sterile. Hold the pipette aid and insert the pipette tip into the solution to be measured.
The amount of solution measure is control by rolling the knob up and down.
Notify teaching assistants where in the classroom they can find the materials needed to perform the laboratory.
Have teaching assistants work in a group and complete the Serial Dilutions Exercise.

After the teaching assistants have finished the exercise, hand out the instructor’s copy and go over each section of the exercise.

Answer any questions the TAs have at the end of the workshop.

Figure 3: Teaching Assistant Serial Dilution Exercise Workshop Instructions

Table 2: Number of Students Participating in the Study and the Times[a] of the Classes During the Fall Semester

Teaching Assistant	Control	Experimental
TA 1	MW 8:00- 23 students MW 10:00- 23 students	
TA 2		MW 8:00- 24 students MW 10:00- 25 students
TA 3		TR 12:00- 23 students TR 2:00- 22 students
TA 4	MW 12:00- 23 students MW 2:00- 25 students	

[a]Classes were 1 hour and fifty minutes in length; M=Monday; T= Tuesday; W= Wednesday; R= Thursday

Table 3: Number of Students Participating in the Study and the Times[a] of the Classes During the Spring Semester

Teaching Assistant	Control	Experimental
TA 1	MW 8:00- 10 students MW 10:00- 23 students	
TA 2	MW 8:00- 19 students MW 10:00- 24 students	
TA 3		MW 12:00- 21 students MW 2:00- 20 students
TA 4		MW 12:00- 21 students MW 2:00- 22 students
TA 5		TR 8:00- 15 students TR 10:00- 14 students
TA 6	TR 8:00- 8 students TR 10:00- 14 students	
TA 7		TR 12:00- 15 students TR 2:00- 21 students
TA 8	TR 12:00- 22 students TR 2:00- 21 students	

[a]Classes were 1 hour and fifty minutes in length; M=Monday; T= Tuesday; W= Wednesday; R= Thursday

During the summer school session there were two small classes (Monday/Wednesday- 23 students and Tuesday/Thursday- 11 students) and both classes received the experimental exercise with one teaching assistant involved as a pilot exercise. After several modifications, the study was expanded in the fall semester to include about 200 students and four teaching assistants (Table 2). There were eight teaching assistants involved in the study during the spring semester with close to 300 students participating (Table 3). All teaching assistants involved in the project were graduate level students. A majority of the GTAs had little previous teaching experience. Teaching assistants were assigned to the experimental or control classes based upon their previous exposure to the study. In the fall semester, all four GTAs were teaching for the first time. During the spring semester, those teaching assistants who were involved in the study in the fall semester were assigned to the experimental classes; while teaching assistants with no prior involvement were assigned the control classes.

Assessment

Students from both the control and experimental classes were given three quizzes (Figure 4) throughout the study as a method of evaluation. Each of the three quizzes administered were in the same format with different numerical values used from quiz to quiz. The students received an unannounced pre-quiz the second week of the semester. The pre-quiz was given to assess what pre-existing knowledge of serial dilutions the students had prior to instruction. Students were told this quiz would not impact their grade after completing it. The mid-quiz was given the fifth week of the semester and was administered shortly after completing Exercise 20: Counting Viable Cells: Serial Dilution

Name: Id#:

1. Calculate the number of colonies you would expect to get on a T-soy agar plate if you spread **0.1 ml** of the following dilutions from an original broth culture that has a density of 6.5 x 10^6 cfu/ml.

(a) 10^{-3} __________

(b) 10^{-4} __________

(c) 10^{-5} __________

2. Show a dilution scheme that would allow you to get a countable number of colonies if the original culture has a density of 4.3 x 10^7 cfu/ml. Make sure to include final dilution, dilution factor, and number of colonies.

Final Dilution=_________ Dilution Factor=_________ Number of Colonies=_______

Dilution Scheme:

3. What is the final dilution?

a) 1:100, 1:10, 1:100, 10^{-1} _____________

b) 10^{-3}, 10^{-2}, 1:100 _____________

c) 1:100, 1:10, 1:100, 1:10, 1:10 _____________

4. Calculate cfu/ml:

Number of colonies	final plate dilution	cfu/ml
a) 35	10^{-6}	_______
b) 189	10^{-7}	_______
c) 225	10^{-5}	_______

5. Which of the cultures in question 4 (a, b, or c) would be the most turbid? (Assuming that each culture is pure and contains the same species of bacteria).

Figure 4: Quiz Format Used for Assessment
Students from both the experimental and control classes were given three serial dilution quizzes throughout the semester. This is one variation of the three quizzes administered. Quiz was designed by Brad Joyce.

and Spread Plates or Pour Plates. This quiz was an announced/scheduled quiz and counted for credit towards the students' final grade. The last quiz was the post-quiz. This quiz was also unannounced and was given two weeks after the completion of the wine making exercise. The post-quiz was used to assess students' retention of the serial dilution concept. During the fall semester students were told this quiz would not count towards their grade after completing it, but in the spring they were told prior to taking it. Each quiz was graded out of a maximum of fourteen points. Answers were graded for complete correctness or were counted wrong; there was no partial credit awarded.

Attitudinal Surveys

After the completion of the wine making exercise and post-quiz all of the students in the General Microbiology Laboratory were given a survey (Figure 5) where they could provide feedback on their experiences related to serial dilutions. The survey consisted of six questions, most of which were set to a seven point Lickert Scale. In addition to their Lickert scale response, students were prompted to elaborate on their responses in the form of short answers. During the study four students had been randomly chosen from an experimental class and a control class and these two groups of students served as focus groups who were videotaped during the duration in which they were performing serial dilutions. The students from the focus groups were given a brief exit interview one-on-one with the researcher at the end of the study, where they were asked to freely express their opinion about the instruction they received on serial dilutions.

The teaching assistants were also surveyed at the end of the study in the form of a questionnaire (Figure 6). However, the questionnaire was administered as an interview.

Student Questionnaire

The brief questionnaire below uses a Likert scale that gives you a range of choices. Please circle the number on the scale that best reflects your response. Also, after many questions there is a place for you to explain why you chose the response that you did (please continue on back if necessary).

1. Have you been exposed to the concept of serial dilution before this class? (please circle)

YES NO

When (what year) were you exposed to this concept?

Where were you exposed to this concept? (please circle or fill in the blank, e.g., biology or chemistry)

_____________ class job student research

2. Do you think the lesson on serial dilution was clearly presented?

1 2 3 4 5 6 7

very well — neutral — very confusing

Please specify reasons why you chose this response.

3. How effective was this exercise in promoting your understanding of serial dilution?

1 2 3 4 5 6 7

very effective — neutral — very ineffective

Please specify reasons why you chose this response.

4. How effective was this exercise in helping you learn and retain the concept of serial dilution?

1 2 3 4 5 6 7

very effective — neutral — very ineffective

Please specify reasons why you chose this response.

5. What is your overall evaluation of the serial dilution exercise?

1 2 3 4 5 6 7

excellent — neutral — poor

Please specify reasons why you chose this response.

6. Are there any other comments that you would like to add related to the serial dilution exercise? (please continue on back if necessary).

Thank you for participating in this research.

Figure 5: Student Questionnaire

Teaching Assistants Questionnaire

The brief questionnaire below uses a Likert scale that gives you a range of choices. Please circle the number on the scale that best reflects your response. Also, after many questions there is a place for you to explain why you chose the response that you did (please continue on back if necessary).

1. When were you first exposed to the concept of serial dilution? (please circle)

1 2 3 4 5 6 7 or more years

2. How does this experience compare to your experience with serial dilutions? (please circle)

1	2	3	4	5	6	7
much better			neutral			much worse

3. How many semesters have you taught before or was this your first experience? (please circle)

1st experience 1 2 3 4 5 or more semesters

4. How would you rate your current teaching experience? (please circle)

1	2	3	4	5	6	7
very positive			neutral			very negative

Please specify reasons why you chose this response.

5. How do you think the class as a whole responded to the lesson on serial dilution? (please circle)

1	2	3	4	5	6	7
very positive			neutral			very negative

Please specify reasons why you chose this response.

6. As the GTA, how well do you think the students understood serial dilution after the exercise? (please circle)

1	2	3	4	5	6	7
understood it well			neutral			did not understand

Please specify reasons why you chose this response.

7. When the class as a whole was working on the serial dilution exercise did they rely more on their peers or on the instructor? (please circle)

1	2	3	4	5	6	7
relied solely on peers			relied equally on peers and GTA			relied solely on GTA

Please specify reasons why you chose this response.

Figure 6: Teaching Assistant Questionnaire

8. How would you rate the training you received for the exercise on serial dilution?

1	2	3	4	5	6	7
excellent			neutral			very poor

Please specify reasons why you chose this response.

9. Are there any other comments that you would like to add related to the serial dilution exercise? (please continue on back if necessary).

Thank you for participating in this research.

Figure 6: Teaching Assistant Questionnaire cont.

The researcher read the nine questions from the questionnaire but also asked additional questions in response to the teaching assistants’ answers.

Statistical Methods Used

A statistical analysis of the quiz scores and questionnaires was performed using Minitab™. The specific statistics tests used were a probability plot, descriptive statistics, Mann Whitney Test, Mood Median Test, and the Analysis of Variables (ANOVA) Test. The on-campus Test Scoring Center was used to score and tabulate the Lickert responses from the student questionnaires.

CHAPTER THREE

Results and Discussion

Evolution of the Exercise

The serial dilution exercise was initially piloted during summer school session I in 2004. The General Microbiology Laboratory class sizes were small and the laboratory met twice a week for three hours and fifty minutes. The summer school session gave the researcher the opportunity to refine the serial dilution exercise. During summer school students were taking up to two hours to complete Part A alone. In the initial version of the exercise in Part A (not shown) the critical thinking questions were very open ended. The summer school students struggled to answer the questions. They either relied heavily on their textbook for the answers (in most cases the answers could not be found in the textbook) or they relied on the instructor. The instructor had to step in and guide the students. Also in the initial version of the exercise in Part B (not shown), students were asked to count the colonies, unlike the final version in which the colonies were pre-counted. If the students got to Part B then they endured the time consuming process of counting hundreds of colonies. During the summer school session the first version of the exercise was very time consuming and the wording of the questions were confusing for students. For the fall semester, the questions were rewritten to narrow down the possible answers and eliminate the textbook as a reference for the critical thinking questions. Students were also provided vocabulary to define, which exposed them to the textbook and alleviated in-class reading. In Part B, colonies were pre-counted to maintain the visual concept but eliminated the time spent on counting colonies. The amount of time the exercise took had to be decreased because during the fall and spring semester each class period is only one hour and fifty minutes.

During the fall semester the study was again piloted but the changes made after the summer school session were incorporated. In the fall, the participants included four teaching assistants and approximately two hundred students. There were two teaching assistants teaching the four control classes and two teaching assistants teaching the four experimental classes. Control and experimental classes were matched up by time of day, therefore if there was an eight o'clock control class then there was also an eight o'clock experimental class. This set up would later have to be abandoned in the spring semester due to scheduling constraints. During the fall pilot, on the day the experimental classes received the serial dilutions exercise, the control classes received no instruction on serial dilutions. This was also later changed during the spring semester to allow both groups to receive equal instruction time. Students in the control class were given a teacher led example of serial dilutions using the chalkboard.

Results from the fall semester were encouraging. Therefore after again incorporating some minor changes to the exercise, the study continued to the spring semester where the participants included eight teaching assistants, four who had previously participated in the fall semester, and approximately three hundred students. The changes that were made between the fall and spring semesters were focused primarily on further refining the wording of the exercise to help guide the students and better instruct the GTAs on time management in the classroom so that time limitation would not negatively impact the spring study. In addition, students were informed prior to taking quiz 3 that this was part of an educational study and that their score would not impact their grade to illicit their full participation. In the spring semester, the control and experimental classes could not be matched up according to times. Those teaching assistants with prior participation with the study were given the responsibility to teach using the inquiry-based learning instruction and those teaching assistants new to the study were assigned to teach using traditional instruction. GTAs were divided this way to prevent teaching assistants with previous exposure to the inquiry-based learning methods from having possible bias if placed in the control group.

Quizzes

Preliminary quiz data from the fall semester pilot was collected (Table 4). During the fall semester participants took the unannounced pre-quiz, the announced mid-quiz and the unannounced post-quiz. The primary statistical data gathered were the mean values of the quiz scores. After analyzing the data, it was seen that students in the experimental class achieved a higher net gain on their mean scores from quiz 1 to quiz 2. The net loss between quiz 2 and quiz 3 was equal indicating the two groups lost about the same knowledge. These findings suggested that the students who participated in the inquiry-based learning strategy had benefited from it academically.

In the spring semester, in order to perform a more in-depth statistical analysis, students were asked to provide identification on the quizzes so that individual student achievement on all three quizzes could be tracked. This had not been previously done in the fall semester. Researchers initially checked for normality amongst the range of the quiz scores for the control and experimental quizzes for all three quizzes (not shown). It was found that the range was not normal therefore the quiz scores for the control and experimental groups could not be compared based upon mean scores. The quiz scores had

Table 4: Summary of Quiz Means from the Fall Semester

Group	Quiz 1	Quiz 2	Quiz 3
Control	1.800	10.500	8.900
Experimental	0.700	10.800	9.100

to be compared based upon median values so the Mood Median test was preformed to compare the quiz scores of the three quizzes. Initially, the population was analyzed as a whole and all participants of the control classes were compared to all participants in the experimental classes. On quiz 1 when the Mood Median test was performed the control group had a median of 1.000 and the experimental group had a median of 1.000 (Figure 7). The test used a 95% confidence interval and found a p-value of 0.133. Therefore, statistically both classes had the same median value, meaning both groups went into the study with an equal foundation of knowledge about serial dilutions. On quiz 2 when the Mood Median test was performed the control group had a median of 11.000 and the experimental group had a median of 11.000 (Figure 8). The test used a 95% confidence interval and found a p-value of 0.394. These values were proven to statistically be the same. On quiz 3 when the Mood Median test was performed the control group and the experimental group both had a median value of 10.000 using a 95% confidence interval with a p-value of 0.940 (Figure 9). Therefore, academic performance between both the control and experimental groups were again statistically the same.

Additional statistical analyses were performed to identify if individual teaching assistants were outliers as shown by quiz scores using an analysis of variance (ANOVA) test. Quiz scores based upon teaching assistants were compared to each other within the control and experimental groups. The results from the comparison of scores for quiz two showed that the mean values all fell within the confidence interval (Figure 10). The results from the comparison of the quiz scores for quiz three showed that all of the mean values for quiz scores by individual teaching assistant fell within the confidence

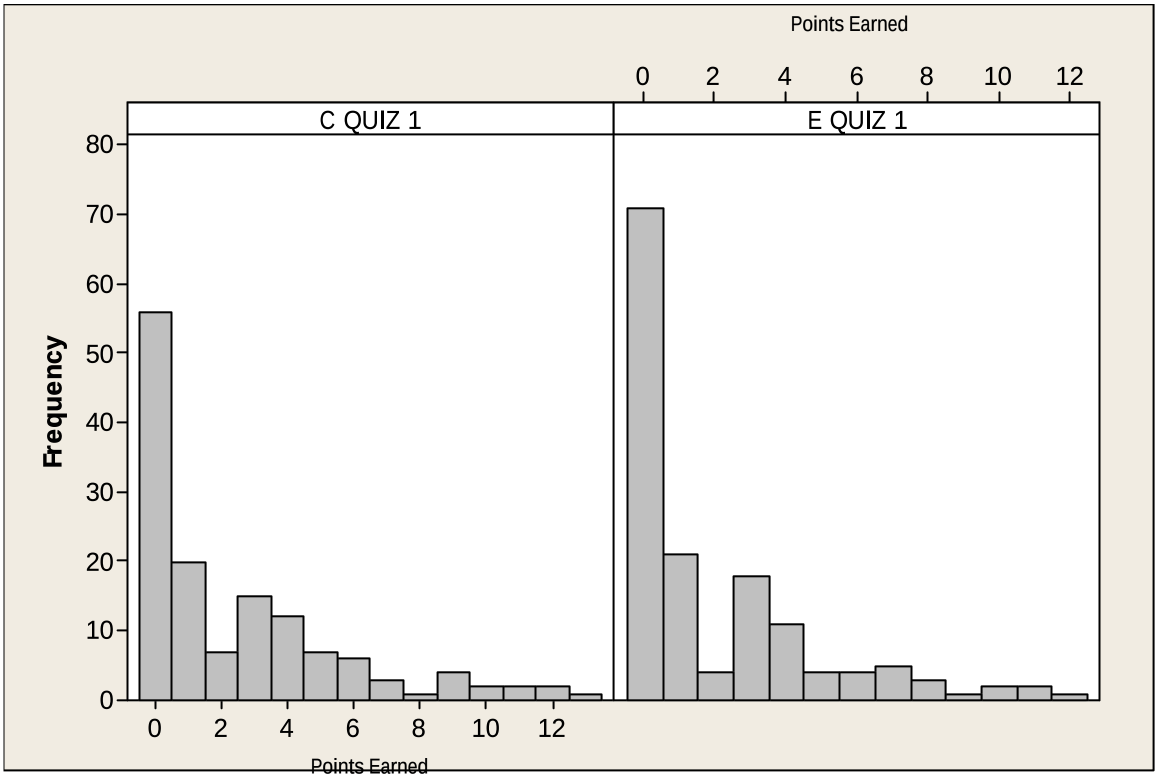


Figure 7: Histogram of Control vs. Experimental Classes Quiz 1 (Pre-quiz) Spring Semester The control class (C) had a mean of 2.478 and a median of 1.000. The experimental class (E) had a mean of 1.993 and a median of 1.000.

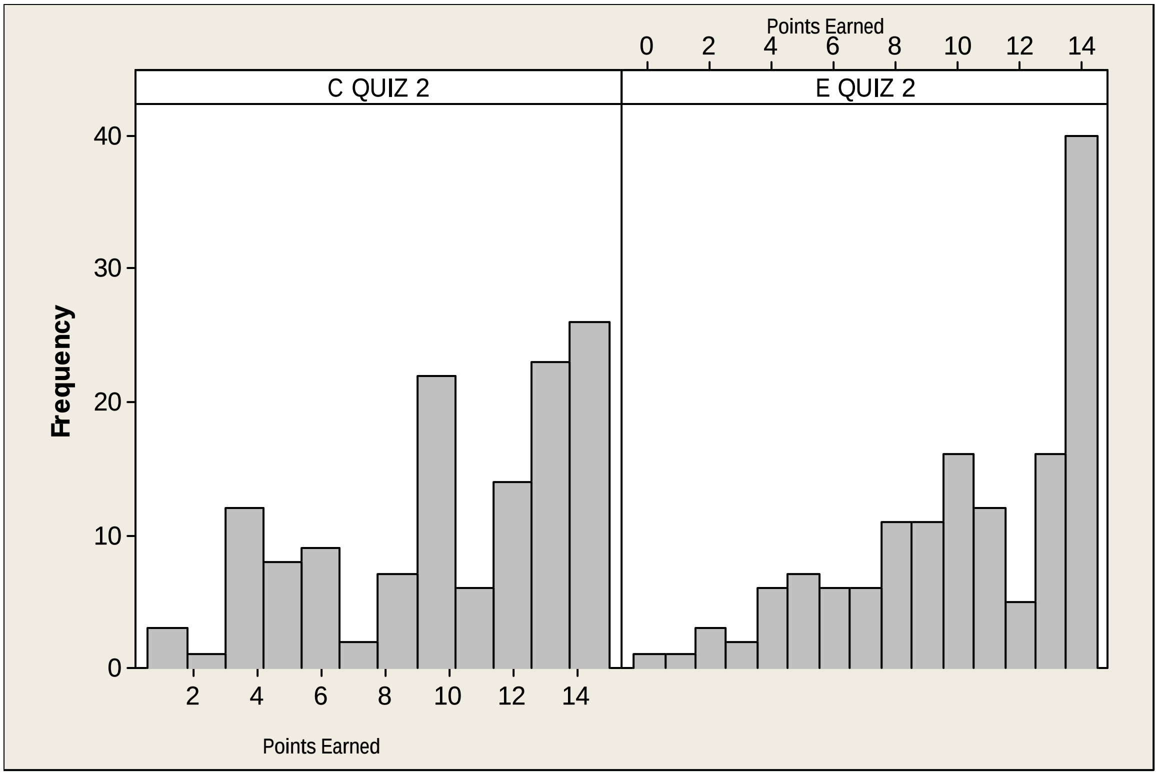


Figure 8: Histogram of Control vs. Experimental Classes Quiz 2 (Mid-quiz) Spring Semester The control class (C) had a mean of 9.947 and a median of 11.000. The experimental class (E) had a mean of 10.189 and a median of 11.000.

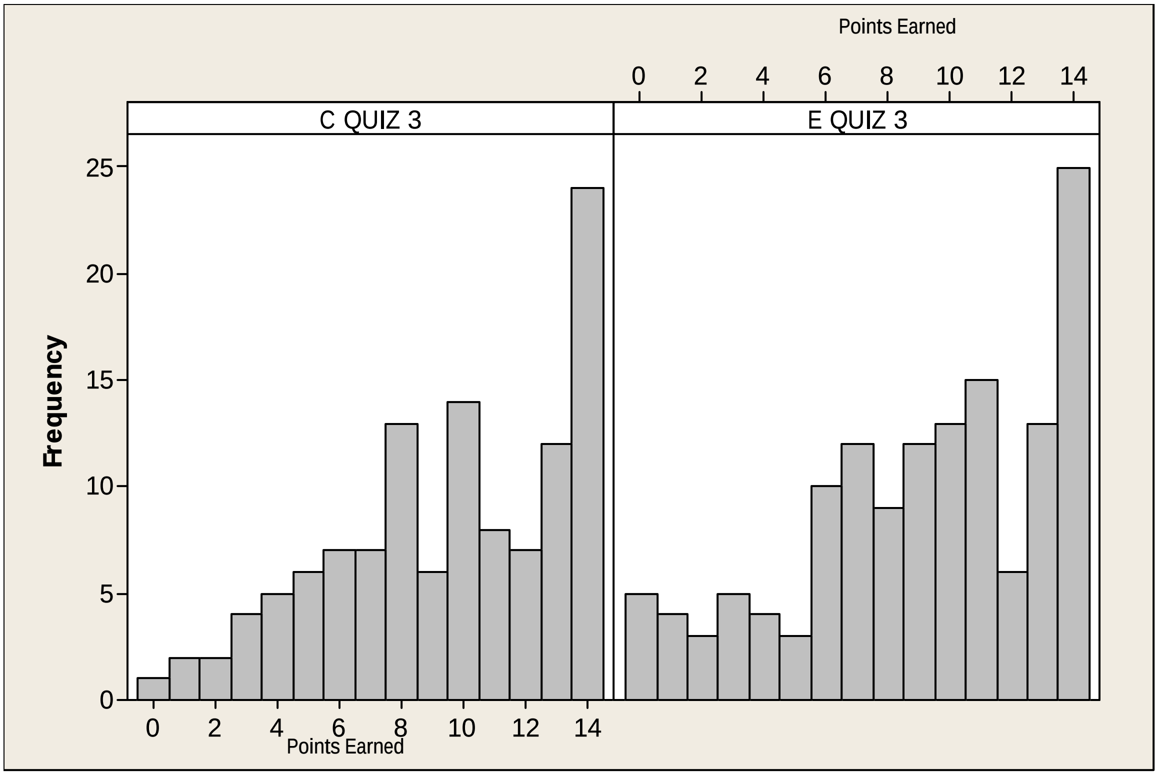


Figure 9: Histogram of Control vs. Experimental Classes Quiz 3 (Post-Quiz) Spring Semester The control class (C) had a mean of 9.424 and a median of 10.000. The experimental class (E) had a mean of and 9.081 a median of 10.000.

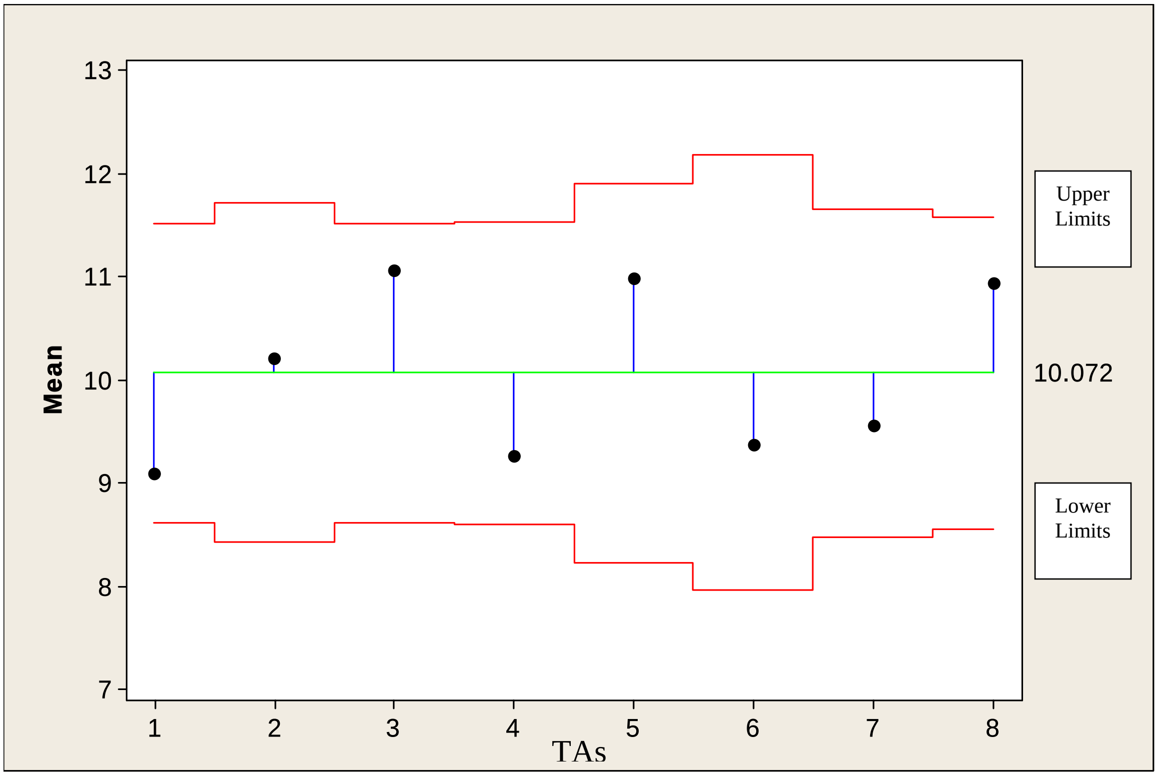


Figure 10: Comparison of Means by Teaching Assistant for Quiz 2 (Mid-quiz) Spring Semester This diagram displays the confidence interval (red line), overall mean (green line) and compares the mean quiz scores from quiz 2 for each teaching assistant using the analysis of variance (ANOVA) test. Teaching Assistants are as follows:
1- Control, 2- Control, 3-Experimental, 4- Experimental, 5- Experimental, 6- Control, 7- Experimental, 8- Control.

interval (Figure 11). It should be noted that teaching assistant 2 from the control group, had the highest individual mean value. This could be accounted for by the fact that of all the teaching assistants, this teaching assistant had the most teaching experience, having taught the course seven previous semesters. Calculation of the median value for quiz 3 without the quiz scores of TA 2 using the Mood Median test was done (not shown). It was found that removing those scores did not have an impact on the overall median of the control group.

After the initial statistical analysis of the quiz scores appeared to show no apparent difference between the control and experimental groups, the groups were then compared based upon the values that are contained within the interquartiles (Johnson, R., 2005). The interquartile range was found using the percentiles provided using Minitab™ Separate statistical analysis of the top and bottom quartiles generated no significant statistical differences on any of the quiz scores between the experimental and control groups (data not shown). However, similar analysis of the two interquartiles yielded interesting results. The interquartiles are those quiz scores that lie within the middle 50% of the pool of quiz scores. Using the Mood Median test it was found that the median score of the interquartiles of the control group was an 11.500 and 13.000 for the experimental group with a 95% confidence interval and a p-value of 0.009 (Figure 12). Since the p-value 0.009 is less than alpha (0.05) this indicates a statistical difference between the two median values. Students in the experimental class within the interquartiles scored significantly higher than those students in the control group. Therefore it can be concluded that the inquiry-based learning strategy employed in this

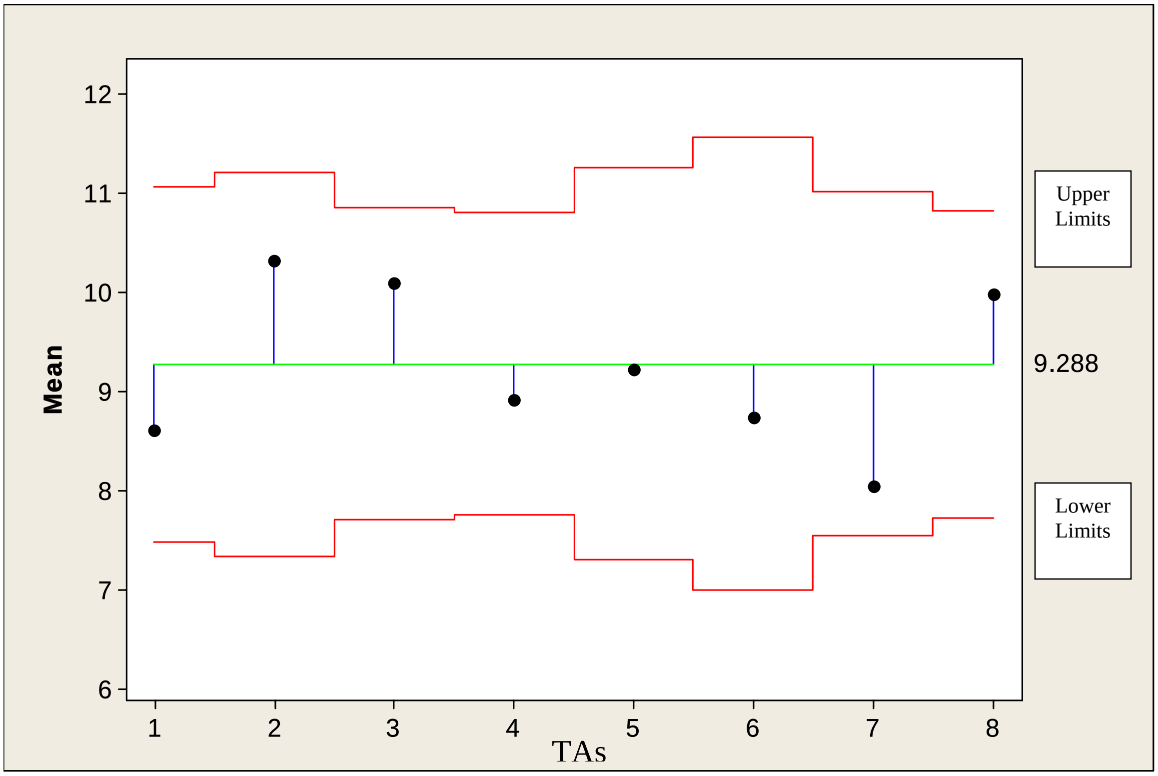


Figure 11: Comparison of Means by Teaching Assistant for Quiz 3 (Post-quiz) Spring Semester This diagram displays the confidence interval (red line), overall mean (green line) and compares the mean quiz scores from quiz 3 for each teaching assistant using the analysis of variance (ANOVA) test. Teaching Assistants are as follows:
1- Control, 2- Control, 3-Experimental, 4- Experimental, 5- Experimental, 6- Control, 7- Experimental, 8- Control.

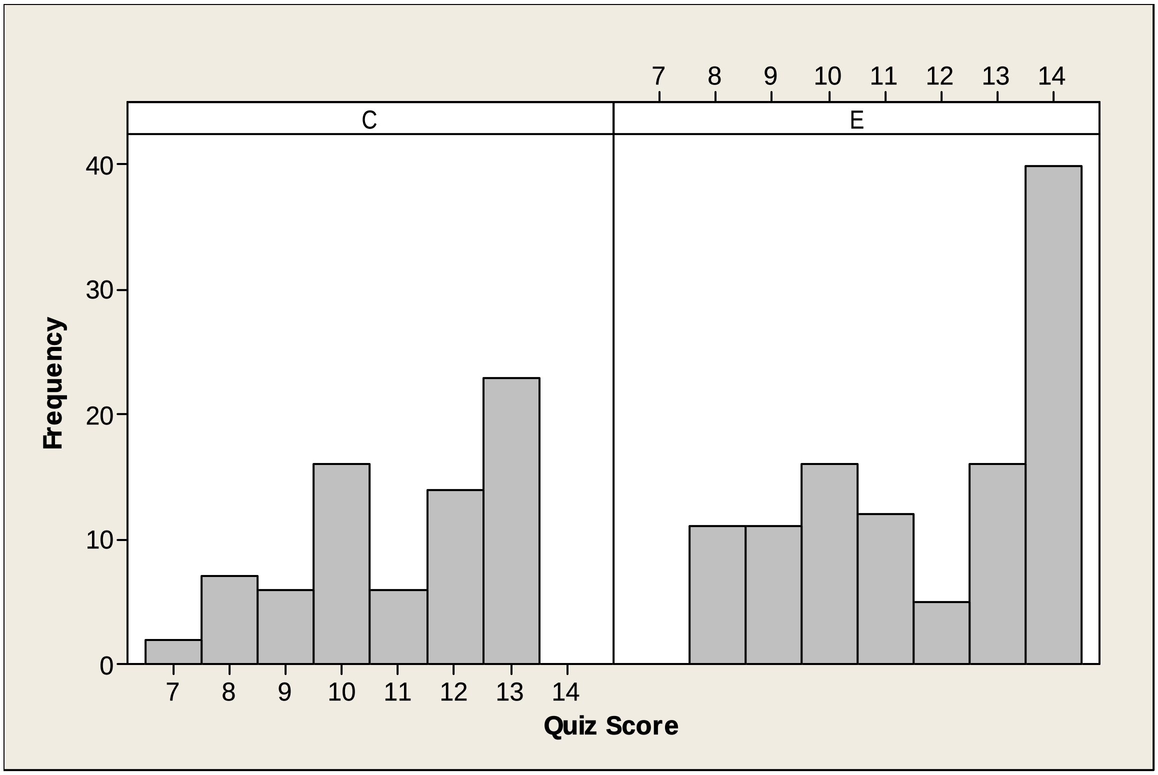


Figure 12: Comparison of Quiz 2 Scores Contained Within the Interquartiles of the Control and Experimental Classes Spring Semester The median score for the middle 50% of the control (C) classes was 11.500 and the median score for the middle 50% of the experimental (E) classes was 13.000. The Mood Median test was preformed to compare the medians of the two groups and the following was found: A 95.0% confidence interval for median(1) - median(2): (-3.00,1.00) and p-value=0.009.

study increased the academic achievement of the “average” students in the class on quiz 2.

The interquartiles of the control and experimental groups were then compared for quiz 3. Using the Mood Median test it was found that the median score of the interquartiles of the control group and the experimental groups were both 10.000 with a 95% confidence interval and a p-value of 0.787 was found (Figure 13). This p-value indicates the values are statistically no different. There are a few factors that can justify why the control group scored identical to the experimental group on quiz 3. By the time the third quiz was administered both classes had received many weeks of practice with serial dilutions from the wine making exercise. It is hypothesized that from this repetitive learning the control group gained their understanding of serial dilutions. Conversion of the wine making exercise to a group activity versus a demonstration was a change made to both the control and experimental groups from the traditional way this had been taught. Also, the third quiz was given the week after spring break and class attendance was lower than for the previous two quizzes resulting in a population that was not representative of the population tested at the mid-quiz.

Student Questionnaires/Interviews

Results from the student questionnaires showed that students from both the control and experimental group had similar attitudes towards the two types of instruction as judged by their responses to the Lickert scale questions. The students recorded their responses on scantrons which were sent to an on campus test scoring center. The results showed for each question in both the control and experimental classes the mean was

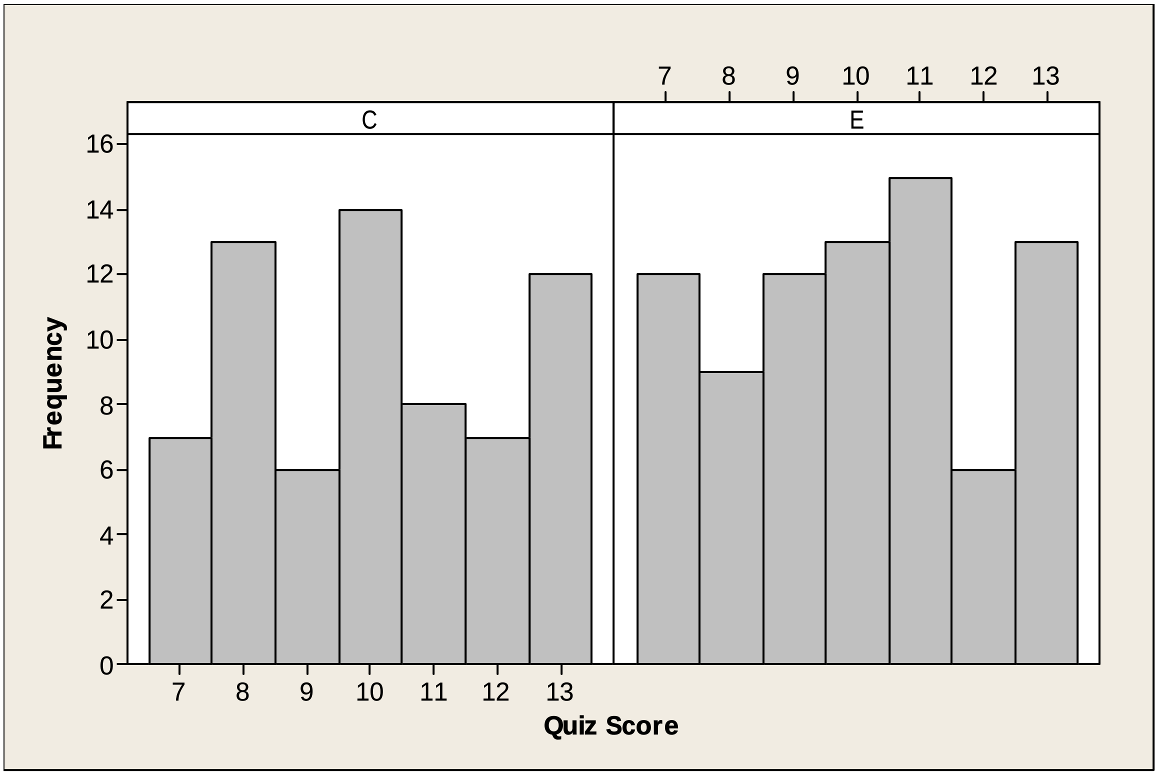


Figure 13: Comparison of Quiz 3 Scores Contained Within the Interquartiles of the Control and Experimental Classes Spring Semester The median score for the middle 50% of the control (C) classes was 10.000 and the median score for the middle 50% of the experimental (E) classes was 10.000. The Mood Median test was preformed to compare the medians of the two groups and the following was found: A 95% confidence interval for median (1) – median (2): (-0.38,0.00) and p-value=0.787.

about a three which is slightly better than neutral (Appendix E). In addition to the Lickert response the students had the opportunity to write additional comments after each question (Appendix F). Many students in both the control and experimental groups felt that hands-on activities were beneficial. For example students said, "hands-on [experience] and repetition helped" and "very hands-on, a great way to learn."

Both groups appreciated the repetition of the wine making exercise and felt additional examples of serial dilution were needed. Also, written responses from the student questionnaires revealed many of the students within the experimental class initially felt negatively towards the first serial dilution exercise because we "had to teach ourselves" and the "teaching assistants need to be more involved in teaching it". Despite the negativity towards the inquiry-based instruction students still benefited academically from it (Figure 12). When interviewed, students in the experimental focus group explained that after overcoming the shock of receiving no instruction on serial dilutions, they appreciated the thought process behind determining what a serial dilution was. One student stated,

> "The group exercise where we worked on the actual problem solving idea where we had to develop a dilution like this using two separate methods. I thought that really kind of put it in perspective what we were really trying to do with the exercises."

Students also commented being able to see the serial dilution with the visual aid of the colored water tubes was beneficial to them. One student stated that, "The fact that we used colored water we could actually see the dilutions too …".

Teaching Assistant Questionnaires/Interviews

The teaching assistants from both the control and experimental groups were interviewed at the conclusion of the study. Teaching assistants from both the control and the experimental groups felt the repetition of the wine making exercise was beneficial. TA 7 had been a TA in the control group in the fall and then was moved to the experimental group in the spring. This TA commented that there appeared to be a difference in the students understanding from the fall to the spring semester. The TA felt students from the spring semester had a better understanding of serial dilutions because of the inquiry-based learning method. She stated:

> "There was a huge difference. [The experimental] group definitely learned it a lot better and they had more experience with it. They understood it especially with the first experiment when they didn't know what they were doing. The last one the wine or the milk they really knew what they were doing. They understood it completely. I definitely see a more positive result this semester than I did last semester."

Limitations

There were several limitations faced in this study. The mere fact that the study involved humans was the biggest limitation. Working with humans incorporates varying attitudes and people's own biases. This particular studied relied heavily on the ability of the teaching assistants to carry out the instruction assigned to them. Both groups of teaching assistant were given appropriate preparation for them to provide the required instruction to their classes. However, their individual teaching style, experience, and attitude could have played a role in determining how effective the instruction was, using either the inquiry-based method or the traditional method. For example, TA 1 was initially reluctant to willingly participate in the study due to a concern that student frustration with inquiry-based learning might negatively impact the overall teaching evaluation score this TA earned. After these concerns were addressed, this TA fully cooperated with the study. In the case of another GTA (TA 3) it was very apparent as determined through interviews and student questionnaires, that this individual's approach towards teaching was less than adequate. However, upon analyzing the quiz scores from students taught by TA 3, it was found that they were consistent with the overall experimental groups' scores. Therefore, this teaching assistant's attitude did not have an impact on students' academic achievement.

The lack of random assignment is another limitation involving the teaching assistants. During the spring semester teaching assistants were assigned to the control or experimental group based upon their prior experience in the study. Those teaching assistants who had participated during the fall semester were assigned to the experimental group and those teaching assistant with no prior exposure were assigned to the control group. The study could have been impacted by this lack of random assignment, resulting in teacher effect. However, analysis of the mean quiz scores of individual GTAs (Figure 10 and Figure 11) suggested this factor did not significantly impact the study.

As human beings, the students participating in the study also brought their personal experiences and biases into it. The attitude each student took towards being a part of the study undoubtedly had an impact on the research. Therefore, every effort was made to limit students' knowledge that they were involved in a research project. The classroom environment was kept normal, but as time progressed it was apparent to the student participants that they were part of an experimental study. It is possible some students may have altered their behavior once they realized they were part of a study by either over compensating on the questionnaire or doing the opposite and not putting forth the effort.

Finally, a limitation involved the time constraint placed on the exercise. Inquiry-based learning is a time consuming process and the essence of inquiry requires taking the time to explore and investigate. The General Microbiology laboratories run for an hour and fifty minutes and students must complete several exercises in one class period. A lot of the time needed for the inquiry process to take place was lost because the exercise was restricted to a one hour time frame. Nevertheless even with these constraints and limitations, this research project had yielded some exciting results.

Conclusions

- When the control and experimental classes are compared as a whole there is no apparent statistical difference in the scores of the pre-quiz, mid-quiz, and post-quiz when comparing the median and mean values.
- When comparing the interquartiles of the control and experimental classes there was a significant statistical difference between the classes for the mid-quiz. The experimental class had a higher median, therefore indicating the inquiry-based method had an impact on student's understanding.
- The responses from the questionnaire indicated students from both the control and experimental classes had similar attitudes towards traditional instruction and inquiry-based instruction.
- After comparing the students' comments from the questionnaires, quiz performance, and teaching assistants comments about their attitude towards teaching, it was found that GTAs experience level or attitude does not have a significant effect on student performance in comparison to the class overall.

CHAPTER FOUR

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LIST OF APPENCICES

Appendix A

Quiz Scores From Fall Semester

M= Monday, W= Wednesday
T= Tuesday, R= Thursday
Experimental= 4, 5
Control= 4, 7

Teaching Assistant 4 MW 8 Quiz 2	Teaching Assistant 4 MW 10 Quiz 2	Teaching Assistant 3 MW 8 Quiz 2	Teaching Assistant 3 MW 10 Quiz 2	Teaching Assistant 5 TR 12 Quiz 2	Teaching Assistant 5 TR 12 Quiz 2	Teaching Assistant 7 TR 12 Quiz 2	Teaching Assistant 7 TR 2 Quiz 2
10	0	12	10	11	13	13	2
0	13	14	10	14	14	4	13
6	3	14	10	6	13	13	13
13	7	14	14	10	9	14	9
14	14	11	8	8	9	9	9
11	14	14	11	13	10	8	13
13	12	7	11	14	10	12	13
12	12	13	12	14	14	13	13
3	7	7	6	14	8	11	14
3	14	14	14	14	9	7	14
11	12	14	13	7	5	9	13
13	3	14	8	4	13	7	9
6	13	13	10	6	11	9	12
12	14	11	13	14	12	9	2
14	12	13	11	13	7	6	10
12	6	11	13	9	14	12	14
9	10	7	13	14	10	9	11
13	9	5	11	11	9	12	2
9	14	14	9	12	13	11	14
	11	13	7	14	13	9	10
	4	7	10	7	10	14	13
	9	9	9	11	13	12	8
			5	10	14	9	
					11	8	
					7		

M= Monday, W= Wednesday
T= Tuesday, R= Thursday
Experimental= 4, 5
Control= 4, 7

Teaching Assistant 4 MW 8 Quiz 3	Teaching Assistant 4 MW 10 Quiz 3	Teaching Assistant 3 MW 8 Quiz 3	Teaching Assistant 3 MW 10 Quiz 3	Teaching Assistant 5 TR 12 Quiz 3	Teaching Assistant 5 TR 12 Quiz 3	Teaching Assistant 7 TR 12 Quiz 3	Teaching Assistant 7 TR 2 Quiz 3
1	12	13	14	11	8	7	13
12	3	8	14	12	9	6	12
4	6	9	14	5	13	3	7
9	5	11	10	7	10	5	14
10	11	14	8	14	8	12	0
9	1	4	10	5	9	9	8
9	14	4	10	14	14	9	13
3	14	9	5	7	9	8	3
5	10	12	11	14	14	4	5
3	6	13	12	3	6	8	4
14	11	11	13	11	11	4	4
11	13	13	5	4	11	4	8
9	14	10	3	7	14	12	13
10	2	14	5	4	13	14	7
13	14	14	8	14	3	12	9
6	0	10	8	8	5	13	7
6	14	3	13	10	11	13	3
7	4	5	12	10	8	13	12
1	1	4	4	10	12	7	12
10	11	9	6	11	4	5	9
6		11		13	4	8	9
				14	14	11	9
				13	10	13	
				14	13		
				11			

Appendix B

Quiz Scores from Spring Semester

*Indicates student did not provide an identification number
M=Monday, W= Wednesday
T= Tuesday, R= Thursday
Control TA= 1, 2, 6, 8
Experimental= 3, 4, 5, 7

TA 1 MW 8:00

Student Number	Quiz 1	Quiz 2	Quiz 3
1	9	14	14
2	0	9	8
3	0	7	8
4	1	12	8
5	0	6	
6	0	5	
7	4	4	
8	0	1	0
9	2	14	14
10	0	8	11

TA 1 MW 10:00

Student Number	Quiz 1	Quiz 2	Quiz 3
11	3	14	10
12	13	14	12
13	0	4	13
14	0	12	13
15	1	10	14
16	0	9	14
17	5	6	5
18	4	13	13
19	1	6	4
20	1	11	11
21	2	13	8
22	3	10	
23	6	14	14
24	0	12	
25	3	13	
26	0	13	11
27	1	5	
28	0	9	
29	2	14	10
30	0	14	
31	6	13	14
32	6	14	14
33	3	14	14
			*10
			*2
			*10

TA 2 MW 8:00

Student Number	Quiz 1	Quiz 2	Quiz 3
34	3	10	9
35	1	1	
36	1	13	11
37	9	13	6
38	0	13	
39	4	13	8
40	0	5	
41	4	9	8
42	0	13	9
43	1	4	11
44	7	9	3
45	7	13	8
46	1	4	5
47	0	8	
48	0	3	
49	0	2	
50	0	7	
51	6	10	8
52	0	3	
	*4		

TA 2 MW 10:00

Student Number	Quiz 1	Quiz 2	Quiz 3
53	0		
54	5	11	13
55	1	9	10
56	0	8	5
57	0	12	12
58	3	12	12
59	1	8	9
60	4	14	7
61	0	13	14
62	1	13	10
63	3	10	11
64	1	10	8
65	3	1	
66	0	5	7
67	0	5	
68	0	10	12
69	4	14	10
70	8	12	13
71	4	13	14
72	0	10	7
73	12	12	
74	0	8	1
75	0	10	2
76			4

TA 3 12:00 MW

Student Number	Quiz 1	Quiz 2	Quiz 3
77	3	14	14
78	3	12	9
79	3	14	11
80	0	13	12
81	3	9	10
82	12	14	13
83	0	11	4
84	0	14	11
85	4	8	11
86	1	4	1
87	3	10	7
88	0	8	10
89	0	7	8
90	0	14	10
91	1	9	
92	0	10	7
93	6	11	5
94	1	12	12
95	7	14	11
96	0	5	8
97	0	14	

TA 3 MW 2:00

Student Number	Quiz 1	Quiz 2	Quiz 3
98	0	5	6
99	2	9	8
100	3	14	14
101	3	12	14
102	8	13	14
103	1	11	1
104	10	14	14
105	0	14	14
106	0	11	10
107	1	9	11
108	0	14	11
109	8	14	14
110	1	10	7
111	3	14	14
112	0	13	8
113	5	11	10
114	9	13	13
115	0	6	13
116	4	10	14
117	3	10	10

TA 4 MW 12:00

Student Number	Quiz 1	Quiz 2	Quiz 3
118	4	14	14
119	0		8
120	0	14	11
121	0	6	0
122	1	4	0
123	1	2	2
124	0	10	7
125	0		11
126	0	13	13
127	1	14	14
128	0	8	11
129	0	13	9
130	0	6	13
131	0	10	7
132	0	10	9
133	0	14	9
134	0	7	13
135	0	2	13
136	7	14	14
137	4	14	9
138	0	10	

TA 4 MW 2:00

Student Number	Quiz 1	Quiz 2	Quiz 3
139	6	14	9
140	0	13	12
141	5	10	13
142	4	11	14
143	0	4	9
144	0	6	5
145	0	7	10
146	0	5	0
147	0	5	7
148	0	10	7
149	4	14	14
150	0	10	14
151	4	14	14
152	0	9	4
153	0	1	1
154	3	14	9
155	0	8	9
156	0	7	
157	1	4	4
158	0		6
159	0	6	7
160	0	14	11

TA 5 TR 8:00

Student Number	Quiz 1	Quiz 2	Quiz 3
161	0	14	13
162	4		
163	0	12	
164	0	5	1
165	3	10	7
166	5	13	6
167	3	6	8
168	0	9	
169	4	14	10
170	3	11	8
171	10	13	13
172	0	14	7
173	3	5	11
174	1	13	14
175	7	14	14
			*10

TA 5 TR 10:00

Student Number	Quiz 1	Quiz 2	Quiz 3
176	1	14	14
177	0	8	5
178	0		
179	1	9	3
180	1	14	12
181	0	14	8
182	2	13	9
183	0	12	12
184	1	9	6
185	0	3	0
186	1	9	8
187	8	14	14
188	6	14	14
189	6	11	13

TA 6 TR 8:00

Student Number	Quiz 1	Quiz 2	Quiz 3
190	0	6	6
191	0	10	6
192	2	5	8
193	0	8	6
194	0	4	6
195	0	6	5
196	0	11	9
197	0	12	7

TA 6 TR 10:00

Student Number	Quiz 1	Quiz 2	Quiz 3
198	3	11	11
199	3	11	4
200	6	13	10
201	0	12	
202	0	3	
203	0		10
204	0	6	5
205	0	10	14
206	3	4	
207	3	14	14
208	6	13	13
209	4	13	13
210	0	12	14
211		13	10
			*4

TA 7 TR 12:00

Student Number	Quiz 1	Quiz 2	Quiz 3
212	3	11	4
213	3		10
214	11	13	10
215	7	13	13
216	0	4	3
217	0	10	3
218	0	4	
219	3	14	9
220	2	14	14
221	0	7	
222	1	11	
223	0	8	7
224	0	2	
225	1	7	11
226		8	11
			*6

TA 7 TR 2:00

Student Number	Quiz 1	Quiz 2	Quiz 3
227	7	8	6
228	1	13	10
229	0	0	3
230	4	14	9
231	3	14	14
232	0	3	2
233	0	14	11
234	2	10	13
235	0	8	3
236	5	11	6
237	1	8	6
238	4	13	14
239	1	9	6
240	0	8	2
241	0	10	11
242	0	14	10
243	0	13	7
244	0	5	0
245	0	9	6
246	11	11	12
247		14	14

TA 8 TR 12:00

Student Number	Quiz 1	Quiz 2	Quiz 3
248	12	14	13
249	5		
250	0	5	7
251	2	5	1
252	3	10	12
253	9	13	14
254	0	6	7
255	1	10	6
256	3	13	8
257	0	14	14
258	0	14	8
259	0	6	9
260	9	12	12
261	0	8	4
262	0	12	11
263	7	14	7
264	3	12	14
265	5	10	10
266	0	14	14
267	11	14	14
268	1	14	14
269	1	14	13

TA 8 TR 2:00

Student Number	Quiz 1	Quiz 2	Quiz 3
270	4	14	14
271	0	6	3
272	5	14	14
273	10	11	14
274	1	14	8
275	4	3	6
276	1	10	3
277	0	4	3
278	10	12	13
279	0	14	10
280	5	13	10
289	4	13	13
290	11	13	13
291	1	3	5
292	5		10
293	0	14	9
294	2	10	14
295	1	14	12
296	2		14

Appendix C

Three Forms of Quizzes from Spring Semester

Quiz 1

Name: Id#:

1. What is the final dilution?

a) 1:10, 1:10, 1:100, 10^{-2} ______________

b) 10^{-3}, 10^{-2}, 1:10 ______________

c) 1:100, 1:10, 1:10, 1:10, 1:10 ______________

2. Calculate the number of colonies you would expect to get on a T-soy agar plate if you spread **0.1 ml** of the following dilutions from an original broth culture that has a density of 4.6×10^{7} cfu/ml.

(a) 10^{-3} __________

(b) 10^{-4} __________

(c) 10^{-5} __________

3. Show a dilution scheme that would allow you to get a countable number of colonies if the original culture has a density of 5.5×10^{6} cfu/ml. Make sure to include final dilution, dilution factor, and number of colonies.

Final Dilution=_________ Dilution Factor=_________ Number of Colonies=_______

Dilution Scheme:

4. Calculate cfu/ml:

Number of colonies	final plate dilution	cfu/ml
a) 54	10^{-6}	_______
b) 173	10^{-7}	_______
c) 207	10^{-5}	_______

5. Which of the cultures in question 4 (a, b, or c) would be the most turbid? (Assuming that each culture is pure and contains the same species of bacteria).

Quiz 2

Name: Id#:

1. Calculate the number of colonies you would expect to get on a T-soy agar plate if you spread **0.1 ml** of the following dilutions from an original broth culture that has a density of 6.5×10^6 cfu/ml.

   (a) 10^{-3} __________

   (b) 10^{-4} __________

   (c) 10^{-5} __________

2. Show a dilution scheme that would allow you to get a countable number of colonies if the original culture has a density of 4.3×10^7 cfu/ml. Make sure to include final dilution, dilution factor, and number of colonies.

Final Dilution=_________ Dilution Factor=_________ Number of Colonies=_______

Dilution Scheme:

3. What is the final dilution?

   a) 1:100, 1:10, 1:100, 10^{-1} ______________

   b) 10^{-3}, 10^{-2}, 1:100 ______________

   c) 1:100, 1:10, 1:100, 1:10, 1:10 ______________

4. Calculate cfu/ml:

Number of colonies	final plate dilution	cfu/ml
a) 35	10^{-6}	_______
b) 189	10^{-7}	_______
c) 225	10^{-5}	_______

5. Which of the cultures in question 4 (a, b, or c) would be the most turbid? (Assuming that each culture is pure and contains the same species of bacteria).

Quiz 3

Name: Id#:

1. Calculate the number of colonies you would expect to get on a T-soy agar plate if you spread **0.1 ml** of the following dilutions from an original broth culture that has a density of 3.9 x 10^6 cfu/ml.

   (a) 10^{-3} __________

   (b) 10^{-4} __________

   (c) 10^{-5} __________

2. Show a dilution scheme that would allow you to get a countable number of colonies if the original culture has a density of 4.7 x 10^5 cfu/ml. Make sure to include final dilution, dilution factor, and number of colonies.

Final Dilution=_________ Dilution Factor=_________ Number of Colonies=_______

Dilution Scheme:

3. What is the final dilution?

   b) 1:10, 1:10, 1:100, 10^{-2} _____________

   b) 10^{-3}, 10^{-2}, 1:100 _____________

   c) 1:100, 1:10, 1:10, 1:10, 1:100 _____________

4. Calculate cfu/ml:

Number of colonies	final plate dilution	cfu/ml
a) 79	10^{-6}	_______
b) 213	10^{-7}	_______
c) 115	10^{-5}	_______

5. Which of the cultures in question 4 (a, b, or c) would be the most turbid? (Assuming that each culture is pure and contains the same species of bacteria).

Appendix D

Statistical Data for Quiz Scores for

Spring Semester

C= Control, E= Experimental
CI= Confidence Interval
N= Number
P= p-value
Tests were performed on entire population unless otherwise indicated.

Descriptive Statistics: C Quiz 1

```
Variable    N  N*   Mean  SE Mean  StDev      Minimum           Q1  Median
C Quiz 1  138   6  2.478    0.267  3.142  0.000000000  0.000000000   1.000

Variable     Q3  Maximum
C Quiz 1  4.000   13.000
```

Descriptive Statistics: C QUIZ 2

```
Variable    N  N*   Mean  SE Mean  StDev  Minimum     Q1  Median      Q3
C QUIZ 2  133  10  9.947    0.328  3.779    1.000  6.500  11.000  13.000

Variable  Maximum
C QUIZ 2   14.000
```

Descriptive Statistics: C QUIZ 3

```
Variable    N  N*   Mean  SE Mean  StDev      Minimum     Q1  Median      Q3
C QUIZ 3  118  26  9.424    0.345  3.752  0.000000000  7.000  10.000  13.000

Variable  Maximum
C QUIZ 3   14.000
```

Descriptive Statistics: E QUIZ 1

```
Variable    N  N*   Mean  SE Mean  StDev      Minimum           Q1  Median
E QUIZ 1  147   3  1.993    0.230  2.793  0.000000000  0.000000000   1.000

Variable     Q3  Maximum
E QUIZ 1  3.000   12.000
```

Descriptive Statistics: E QUIZ 2

```
Variable    N  N*    Mean  SE Mean  StDev      Minimum     Q1  Median      Q3
E QUIZ 2  143   8  10.189    0.304  3.637  0.000000000  8.000  11.000  14.000

Variable  Maximum
E QUIZ 2   14.000
```

Descriptive Statistics: E QUIZ 3

```
Variable    N  N*   Mean  SE Mean  StDev      Minimum     Q1  Median      Q3
E QUIZ 3  139  12  9.081    0.342  4.030  0.000000000  7.000  10.000  13.000

Variable  Maximum
E QUIZ 3   14.000
```

Mann-Whitney Test and CI: C QUIZ 1, E QUIZ 1

```
            N  Median
C QUIZ 1  138   1.000
E QUIZ 1  147   1.000


Point estimate for ETA1-ETA2 is -0.000
95.0 Percent CI for ETA1-ETA2 is (0.000,-0.000)
W = 20679.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.1744
The test is significant at 0.1536 (adjusted for ties)
```

Mann-Whitney Test and CI: C QUIZ 2, E QUIZ 2

```
            N  Median
C QUIZ 2  133  11.000
E QUIZ 2  143  11.000


Point estimate for ETA1-ETA2 is 0.000
95.0 Percent CI for ETA1-ETA2 is (-1.000,-0.001)
W = 17983.5
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.5100
The test is significant at 0.5058 (adjusted for ties)
```

Mann-Whitney Test and CI: C QUIZ 3, E QUIZ 3

```
            N  Median
C QUIZ 3  118  10.000
E QUIZ 3  139  10.000


Point estimate for ETA1-ETA2 is -0.000
95.0 Percent CI for ETA1-ETA2 is (-1.000,0.999)
W = 15593.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.5327
The test is significant at 0.5303 (adjusted for ties)
```

Mood median test for Quiz 1

```
Chi-Square = 2.26    DF = 1    P = 0.133

                               Individual 95.0% CIs
Group  N<=  N>  Median  Q3-Q1  +---------+---------+---------+------
C       76  62    1.00   4.00                   *---------------)
E       79  44    1.00   3.00  (----------------*
                               +---------+---------+---------+------
                             0.00      0.60      1.20      1.80

Overall median = 1.00


A 95.0% CI for median(1) - median(2): (0.00,2.00)
```

Mood median test for Quiz 2

```
Chi-Square = 0.73    DF = 1    P = 0.394

                               Individual 95.0% CIs
Group  N<=  N>  Median  Q3-Q1  ---+---------+---------+---------+---
C       70  63   11.00   6.50  (---------------*----------------)
E       69  50   11.00   6.00  (---------------*----------------)
                               ---+---------+---------+---------+---
                               10.20     10.80     11.40     12.00

Overall median = 11.00


A 95.0% CI for median(1) - median(2): (-1.00,2.00)
```

Mood median test for Quiz 3

```
Chi-Square = 0.01    DF = 1    P = 0.940

                               Individual 95.0% CIs
Group  N<=  N>  Median  Q3-Q1    +---------+---------+---------+------
C       67  51   10.00   6.00    (----------------*---------------)
E       67  50   10.00   7.00    (----------------*---------------)
                                 +---------+---------+---------+------
                               9.00      9.60     10.20     10.80

Overall median = 10.00


A 95.0% CI for median(1) - median(2): (-1.00,1.01)
```

Mood median test for C QUIZ 1

```
Chi-Square = 2.17    DF = 3    P = 0.538

                              Individual 95.0% CIs
C TA  N<=  N>  Median  Q3-Q1    +---------+---------+---------+------
1      26  17    1.00   4.00    (-------*----------------)
2      18  15    1.00   3.50    (-------*----------------)
6      13   8    0.00   3.00    *------------------------)
8      19  22    2.00   5.00            (--------*---------------)
                                +---------+---------+---------+------
                              0.0       1.2       2.4       3.6

Overall median = 1.00
```

Mood median test for C QUIZ 2

```
Chi-Square = 5.50    DF = 3    P = 0.138

                              Individual 95.0% CIs
C TA  N<=  N>  Median  Q3-Q1  ------+---------+---------+---------+
1      26  15   10.00   7.00          (-------*-------)
2      16  17   12.00   7.50              (-----------*---)
6      13   8   11.00   6.50  (--------------------*---)
8      15  23   12.50   4.50                  (---------*-----)
                              ------+---------+---------+---------+
                                  7.5      10.0      12.5      15.0

Overall median = 11.00
```

Mood median test for C QUIZ 3

```
Chi-Square = 5.37    DF = 3    P = 0.147

                              Individual 95.0% CIs
C TA  N<=  N>  Median  Q3-Q1    +---------+---------+---------+------
1      21  10    9.00   4.00            (------*------)
2      12  15   11.00   6.00                        (----*---------)
6      14   6    8.50   6.50    (-----------*-----------)
8      20  20   10.50   7.00                (---------*------------)
                                +---------+---------+---------+------
                              6.0       8.0      10.0      12.0

Overall median = 10.00
```

Mood median test for E QUIZ 1

```
Chi-Square = 7.94    DF = 3    P = 0.047

                              Individual 95.0% CIs
E TA  N<=  N>  Median  Q3-Q1    +---------+---------+---------+------
3      21  20    1.00   3.50    (---------*-------------------)
4      34   9    0.00   1.00    *
5      16  13    1.00   4.00    (---------*-------------------)
7      21  13    1.00   3.00    (---------*----------)
                                +---------+---------+---------+------
                              0.0       1.0       2.0       3.0

Overall median = 1.00
```

Mood median test for E QUIZ 2

```
Chi-Square = 4.43    DF = 3    P = 0.219

                              Individual 95.0% CIs
E TA  N<=  N>  Median  Q3-Q1  -----+---------+---------+---------+-
3      21  20   11.00   5.00                 (----*---------)
4      26  14   10.00   8.00  (--------------*----------)
5      12  15   12.00   5.00            (--------------*---------)
7      23  12   10.00   5.00       (---------*-----------)
                              -----+---------+---------+---------+-
                                 8.0      10.0      12.0      14.0

Overall median = 11.00
```

Mood median test for E QUIZ 3

```
Chi-Square = 2.38    DF = 3    P = 0.497

                              Individual 95.0% CIs
E TA  N<=  N>  Median  Q3-Q1    +---------+---------+---------+------
3      19  20   11.00   5.00                        (----*----)
4      24  17    9.00   6.00             (-----*---------)
5      15  11    9.50   6.25            (--------*--------------)
7      22  11    9.00   6.00    (--------------*-------)
                                +---------+---------+---------+------
                              6.0       8.0      10.0      12.0

Overall median = 10.00
```

Test Means by Control vs. Experiment

One-way ANOVA: Quiz 1 versus Group

```
Source   DF       SS     MS     F      P
Group     1    17.51  17.51  1.97  0.161
Error   259  2297.23   8.87
Total   260  2314.74

S = 2.978   R-Sq = 0.76%   R-Sq(adj) = 0.37%

                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level    N   Mean  StDev  ----+---------+---------+---------+-----
C      138  2.478  3.142               (------------*-----------)
E      123  1.959  2.783  (------------*------------)
                          ----+---------+---------+---------+-----
                            1.60      2.00      2.40      2.80

Pooled StDev = 2.978
```

One-way ANOVA: Quiz 2 versus Group

```
Source   DF      SS    MS     F      P
Factor    1     4.0   4.0  0.29  0.589
Error   274  3762.5  13.7
Total   275  3766.6

S = 3.706   R-Sq = 0.11%   R-Sq(adj) = 0.00%


                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level    N    Mean  StDev  -------+---------+---------+---------+--
q2con  133   9.947  3.779  (---------------*--------------)
q2exp  143  10.189  3.637        (---------------*--------------)
                           -------+---------+---------+---------+--
                                9.60     10.00     10.40     10.80

Pooled StDev = 3.706
```

One-way ANOVA: Quiz 3 versus Group

```
Source   DF      SS    MS     F      P
Group     1     9.7   9.7  0.62  0.433
Error   233  3661.5  15.7
Total   234  3671.1

S = 3.964   R-Sq = 0.26%   R-Sq(adj) = 0.00%


                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level    N   Mean  StDev  ---+---------+---------+---------+------
C      118  9.424  3.752           (-----------*-------------)
E      117  9.081  4.167  (--------------*-------------)
                          ---+---------+---------+---------+------
                           8.50      9.00      9.50     10.00

Pooled StDev = 3.964
```

Test Mean by TA

One-way ANOVA: C QUIZ 1, C TA

```
Source   DF       SS      MS      F      P
Factor    1   172.24  172.24  18.27  0.000
Error   280  2640.18    9.43
Total   281  2812.43

S = 3.071   R-Sq = 6.12%   R-Sq(adj) = 5.79%


                             Individual 95% CIs For Mean Based on
                             Pooled StDev
Level       N   Mean  StDev  --+---------+---------+---------+-------
C QUIZ 1  138  2.478  3.142  (------*-------)
C TA      144  4.042  3.001                        (------*------)
                             --+---------+---------+---------+-------
                             2.10      2.80      3.50      4.20

Pooled StDev = 3.071
```

One-way ANOVA: C QUIZ 2 versus C TA

```
Source   DF      SS    MS     F      P
C TA      3    76.7  25.6  1.82  0.146
Error   129  1808.0  14.0
Total   132  1884.6

S = 3.744   R-Sq = 4.07%   R-Sq(adj) = 1.84%


                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level   N    Mean  StDev  -----+---------+---------+---------+----
1      41   9.098  3.859   (---------*--------)
2      33  10.212  3.822          (----------*----------)
6      21   9.381  3.584  (------------*-------------)
8      38  10.947  3.631                 (---------*---------)
                          -----+---------+---------+---------+----
                             8.4       9.6      10.8      12.0

Pooled StDev = 3.744
```

One-way ANOVA: C QUIZ 3 versus C TA

```
Source   DF      SS    MS     F      P
C TA      3    64.4  21.5  1.55  0.207
Error   114  1583.1  13.9
Total   117  1647.5

S = 3.727   R-Sq = 3.91%   R-Sq(adj) = 1.38%


                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level   N    Mean  StDev   -+---------+---------+---------+--------
1      31   8.613  3.422     (----------*----------)
2      27  10.333  3.922                  (-----------*-----------)
```

```
6      20   8.750  3.522   (-------------*-------------)
8      40  10.000  3.909                  (--------*---------)
                           -+---------+---------+---------+--------
                           7.2       8.4       9.6      10.8

Pooled StDev = 3.727
```

One-way ANOVA: E QUIZ 1 versus E TA

```
Source   DF       SS     MS     F      P
E TA      3    60.66  20.22  2.68  0.049
Error   143  1078.34   7.54
Total   146  1138.99

S = 2.746   R-Sq = 5.33%   R-Sq(adj) = 3.34%


                         Individual 95% CIs For Mean Based on
                         Pooled StDev
Level   N   Mean  StDev  --------+---------+---------+---------+-
3      41  2.634  3.168                 (-------*--------)
4      43  1.047  1.927  (-------*--------)
5      29  2.414  2.797             (---------*---------)
7      34  2.059  3.025          (---------*--------)
                         --------+---------+---------+---------+-
                               1.0       2.0       3.0       4.0

Pooled StDev = 2.746
```

One-way ANOVA: QUIZ 2 versus TA

```
Source   DF      SS    MS     F      P
TAS       7   177.3  25.3  1.89  0.071
Error   268  3589.3  13.4
Total   275  3766.6

S = 3.660   R-Sq = 4.71%   R-Sq(adj) = 2.22%


                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level   N    Mean  StDev  -----+---------+---------+---------+----
1      41   9.098  3.859   (---------*--------)
2      33  10.212  3.822           (---------*----------)
3      41  11.073  2.902                   (--------*---------)
4      40   9.275  4.082     (--------*---------)
5      27  11.000  3.317               (-----------*----------)
6      21   9.381  3.584  (------------*------------)
7      35   9.571  3.868       (---------*---------)
8      38  10.947  3.631                (---------*---------)
                          -----+---------+---------+---------+----
                             8.4       9.6      10.8      12.0

Pooled StDev = 3.660
```

One-way ANOVA: QUIZ 3 versus TA

```
Source   DF      SS    MS     F      P
TAS1      7   150.7  21.5  1.43  0.193
Error   249  3748.0  15.1
Total   256  3898.7

S = 3.880   R-Sq = 3.87%   R-Sq(adj) = 1.16%


                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level   N    Mean  StDev  -----+---------+---------+---------+----
1      31   8.613  3.422     (--------*---------)
2      27  10.333  3.922                (---------*---------)
3      39  10.103  3.508                (-------*--------)
4      41   8.927  4.280         (-------*------)
5      26   9.231  4.112         (---------*---------)
6      20   8.750  3.522    (----------*-----------)
7      33   8.061  4.115  (--------*--------)
8      40  10.000  3.909                (-------*-------)
                          -----+---------+---------+---------+----
                             7.5       9.0      10.5      12.0

Pooled StDev = 3.880
```

Mood median test for Quiz 1 Interquartiles

```
Chi-Square = 2.95    DF = 1    P = 0.086

                               Individual 95.0% CIs
q1c=1  N<=  N>  Median  Q3-Q1    +---------+---------+---------+------
C       56  54    0.00   2.25    *--------------------------------)
E       71  43    0.00   1.00    *
                                 +---------+---------+---------+------
                               0.00      0.30      0.60      0.90

Overall median = 0.00
A 95.0% CI for median(1) - median(2): (0.00,1.00)
```

Mood median test for Quiz 2 Interquartiles

```
Chi-Square = 6.81    DF = 1    P = 0.009
                               Individual 95.0% CIs
q2c=1  N<=  N>  Median  Q3-Q1     +---------+---------+---------+------
1       51  23   11.50   3.00     (--------------*----)
2       55  56   13.00   4.00               (-------------------*
                                  +---------+---------+---------+------
                               10.0      11.0      12.0      13.0

Overall median = 12.00
A 95.0% CI for median(1) - median(2): (-3.00,1.00)
```

Mood median test for Quiz 3 Interquartiles

```
Chi-Square = 0.07    DF = 1    P = 0.787

                               Individual 95.0% CIs
q3c=1  N<=  N>  Median  Q3-Q1    +---------+---------+---------+------
1       40  27   10.00   4.00    (----------------*---------------)
2       46  34   10.00   3.00    (----------------*---------------)
                                 +---------+---------+---------+------
                               9.00      9.60     10.20     10.80

Overall median = 10.00
                     A 95.0% CI for median(1) - median(2):
```

Appendix E

Statistical Data for Questionnaires from

Spring Semester

The FREQ Procedure

TA	Frequency	Percent	Cumulative Frequency	Cumulative Percent
3	40	28.99	40	28.99
4	42	30.43	82	59.42
5	26	18.84	108	78.26
7	30	21.74	138	100.00

Frequency Missing = 1

NClass	Frequency	Percent	Cumulative Frequency	Cumulative Percent
1	63	46.67	63	46.67
2	72	53.33	135	100.00

Frequency Missing = 4

q1	Frequency	Percent	Cumulative Frequency	Cumulative Percent
1	34	25.00	34	25.00
2	102	75.00	136	100.00

Frequency Missing = 3

q2	Frequency	Percent	Cumulative Frequency	Cumulative Percent
1	18	13.04	18	13.04
2	39	28.26	57	41.30
3	27	19.57	84	60.87
4	17	12.32	101	73.19
5	24	17.39	125	90.58
6	9	6.52	134	97.10
7	4	2.90	138	100.00

Frequency Missing = 1

q3	Frequency	Percent	Cumulative Frequency	Cumulative Percent

1	27	19.42	27	19.42
2	31	22.30	58	41.73
3	29	20.86	87	62.59
4	28	20.14	115	82.73
5	14	10.07	129	92.81
6	5	3.60	134	96.40
7	5	3.60	139	100.00

q4	Frequency	Percent	Cumulative Frequency	Cumulative Percent
1	27	19.42	27	19.42
2	27	19.42	54	38.85
3	29	20.86	83	59.71
4	26	18.71	109	78.42
5	13	9.35	122	87.77
6	13	9.35	135	97.12
7	4	2.88	139	100.00

q5	Frequency	Percent	Cumulative Frequency	Cumulative Percent
1	20	14.49	20	14.49
2	38	27.54	58	42.03
3	27	19.57	85	61.59
4	21	15.22	106	76.81
5	19	13.77	125	90.58
6	8	5.80	133	96.38
7	5	3.62	138	100.00

Frequency Missing = 1

The MEANS Procedure

Variable	N	Mean	Std Dev	Minimum	Maximum
q2	138	3.2391304	1.6235239	1.0000000	7.0000000
q3	139	3.0431655	1.5874074	1.0000000	7.0000000
q4	139	3.1870504	1.6792353	1.0000000	7.0000000
q5	138	3.1811594	1.6265835	1.0000000	7.0000000

Control
MicroLab Survey (Control) 3-25-05 3
Overall Frequencies
15:28 Friday, March 25, 2005

The FREQ Procedure

TA	Frequency	Percent	Cumulative Frequency	Cumulative Percent
1	37	29.84	37	29.84
2	32	25.81	69	55.65
6	15	12.10	84	67.74
8	40	32.26	124	100.00

Frequency Missing = 2

NClass	Frequency	Percent	Cumulative Frequency	Cumulative Percent
1	52	41.94	52	41.94
2	72	58.06	124	100.00

Frequency Missing = 2

q1	Frequency	Percent	Cumulative Frequency	Cumulative Percent
1	36	28.57	36	28.57
2	90	71.43	126	100.00

q2	Frequency	Percent	Cumulative Frequency	Cumulative Percent
1	15	11.90	15	11.90
2	39	30.95	54	42.86
3	26	20.63	80	63.49
4	24	19.05	104	82.54
5	15	11.90	119	94.44
6	7	5.56	126	100.00

q3	Frequency	Percent	Cumulative Frequency	Cumulative Percent
1	23	18.25	23	18.25
2	32	25.40	55	43.65
3	37	29.37	92	73.02
4	21	16.67	113	89.68
5	8	6.35	121	96.03
6	5	3.97	126	100.00

q4	Frequency	Percent	Cumulative Frequency	Cumulative Percent
1	21	16.67	21	16.67
2	37	29.37	58	46.03
3	32	25.40	90	71.43
4	17	13.49	107	84.92
5	16	12.70	123	97.62
6	3	2.38	126	100.00

q5	Frequency	Percent	Cumulative Frequency	Cumulative Percent
1	12	10.00	12	10.00
2	37	30.83	49	40.83
3	32	26.67	81	67.50
4	23	19.17	104	86.67
5	11	9.17	115	95.83
6	4	3.33	119	99.17
7	1	0.83	120	100.00

Frequency Missing = 6

MicroLab Survey (Control) 3-25-05 4
Overall Means 15:28 Friday, March 25, 2005

The MEANS Procedure

Variable	N	Mean	Std Dev	Minimum	Maximum
q2	126	3.0476190	1.4020393	1.0000000	6.0000000
q3	126	2.7936508	1.3164647	1.0000000	6.0000000
q4	126	2.8333333	1.3431307	1.0000000	6.0000000
q5	120	3.0000000	1.3093073	1.0000000	7.0000000

Appendix F

Student Written Responses from Questionnaire

The following information indicates the frequency of student written responses.

TA 1

Question 2

Confusing	Not Enough Time Spent	Easy	Notes on Board Helpful
13	14	7	1

Question 3

Practice Problems	Proportional to Teaching	Feels Good	Learned through Mistakes	Learned through Practice	Helpful but not effective	Hands-On Helped	Did not prepare
2	5	6	6	3	3	7	2

Question 4

Didn't help retention	Wine Helped	Pictures and Diagrams Helped	Quiz Score Low	Easy	Memorizing not Understand-ing
7	3	2	1	5	2

Question 5

Could Have Been Better	Did Well	Reasonably Helpful
17	6	4

TA 2

Question 2

Confusing	Not Enough Time Spent	Easy	Lots of practice
8	6	8	5

Question 3

Confus-ing	Learned Concept	Homework Helped	Good Exposure	Instructor Helpful
3	12	1	4	2

Question 4

Didn't Learn	Repetition Helped	Low Quiz Score	Needed More Examples	Retained and Learned
3	6	1	2	5

Question 5

Not Helpful	Repetition	Not Enough Time Spent	Hands on Preferred	Fine
2	2	3	2	7

Question 6

Math Hard	Hard	Good Exercise
2	1	2

TA 3

More Time/Practice	Fine	Not Clear/Confusing	
1	16	20	

Question 3

Practice Helped	Low Quiz Score	Effective/Understood	Not Effective
6	1	15	11

Question 4

Repetition	Didn't Retain	Retained
6	13	10

Question 5

Fine	Could be Improved
17	17

TA 4

Question 2

More time/practice	Fine/Understood	Not Clear/Confusing
1	20	16

Question 3

Practice Helped/Hands On	Effective Understood	Not Effective
6	16	7

Question 4

Repetition	Didn't Retain	Retained
11	9	11

Question 5

Fine	Could be Improved
22	11

TA 5

Question 2

More Time/Practice	Fine/Understood	Not Clear/Confusing
2	13	11

Question 3

Practice Helped /Hands On	Effective/Understood	Not Effective	Somewhat Effective
9	6	4	5

Question 4

Repetition	Didn't Retain	Retained
13	6	3

Question 5

Fine	Could Be Improved
12	11

TA 6

Question 2

Book was used	Confusing	Fine	Reinforcement	More time
2	7	4	1	1

Question 3

Confusing	Practice Helped	Clear
3	4	5

Question 4

Confused	Not Retaining Information	Helped Retain
2	1	9

Question 5

Hands On Helpful	Somewhat Effective	Enough time was spent	Fine
1	3	2	4

TA 7

Question 2

Fine/Understood	Not Clear/Confusing
18	8

Question 3

Pracrice Helped/Hands On	Effective/Understood	Somewhat Effective	Not Effective
10	9	3	6

Question 4

Repetition	Didn't Retain	Retained
9	8	12

Question 5

Fine	Could Be Improved
15	10

TA 8

Question 2

Teaching Asst. did a good job	Not Clear/Confusing	More Time/Practice	Fair
25	7	2	2

Question 3

Practice Problems Helped	Understood	Fine	Not Effective	Hands-On/Repetition
2	7	4	8	6

Question 4

Retained Information	Practice	Hard to Retain
9	6	10

Question 5

Fine	Unclear	Could Be Improved
19	1	11

The following are the various unique comments students wrote.

Teaching Assistant 1
Question 2
<u>Not Enough Time Spent</u>
-more practice problems
-more time
-other exercises to do

<u>Easy</u>
-students forced to find own methods to solve problems

Question 3
Manual was confusing

Question 6
Too many exercises

Teaching Assistant 2
Question 3
Homework helped

Teaching Assistant 3
Question 2
<u>Fine</u>
-schemes helped
-at first confusing
- learned calculations
- takes time to grasp
-diagrams helped concept
- group helped
- wine helped
<u>Not Clear/Confusing</u>
-would like to have formal explanation
-not taught
-teaching assistant did not explain it well, we had to teach ourselves, not presented well
-not explained well
- didn't understand CFU/ml
-putting a worksheet in front of someone and telling them to do it is not a good teaching method
- worksheet with no lecture
-book and handout showed two different ways of learning
-no lesson
-details needed to be explained better

Question 3

Not Effective

-used book
-needed outside help
-understood concept but not calculations
-vague

Question 4

Didn't Retain

-hands-on confusing
-need teaching assistants help
-memorized
-teaching assistant assumed we knew

Question 5

Fine

-hands on and repetition helped
-confused at first
-working as a group helped
-repetition
-very hands-on, a great way to learn
-given extra work
-well organized

Could be Improved

-teaching assistants need to be more involved in teaching it
-a whole lab needs to be developed to teach step by step
-presentation needs to be more thorough
-needs to be presented better initially, had to figure it out on our own
-more memorization
-forget easily
-more details and reviewing
-more time in class
-little classroom guidance
-questions before exercise confusing
-should be explained better
-more time

Question 6

-took class because I wanted to know how to pass a serial dilution quiz
-not explained well at first but got it eventually

Teaching Assistant 5

Question 2

More Time/Practice

-more explanation

-more problems

Fine/Understood

-lots of practice

-confused at first but worked through it

-diagram and teaching assistant helped

-diagrams

-teaching assistant helped

Not Clear/Confusing

-taught harder than it needed to be

-needs more examples and problems

-better instructions by the teaching assistant

-needed to reread

-hurriedly presented

-self taught

-needs explanation

Question 3

Practice Helped/Hands On

-practical application

Effective/Understood

-should have reviewed scientific notation

-simple exercise, a good starting point

-taught more than normal

Not Effective

-needed more practice

Somewhat Effective

-exercise lacked the math and reason

-unsure at first

Question 4

Repetition

-learned through practice more so than exercise itself

-hands-on

Question 5
Fine
-keep it simple
-hard at first

Could be Improved
-exercise too short enough to practice
-lacked explanation
-no instruction caused more confusion
-problems not explained clearly
-more practice
-math needed review
-too much focus on dilutions than past years
-trouble with math

Teaching Assistant 6
Question 3
Clear
- understood on own
- little guidance from teaching assistant

Question 5
Somewhat
-needed a lecture

Question 6
Fine
-homework graded before concept was taught
-little demonstration by instructor

Teaching Assistant 7
Question 2
Fine/Understood
-peer helped
-explanations and handouts helped
-lectures and diagrams
-diagrams

Not Clear/Confusing
-math confusing
-never taught and had to teach ourselves
-needs better explanation
-math problems
- not confident

Question 3
Practice Helped/Hands On
-visual

Effective/Understood
-diagram on paper harder than it had to be

Somewhat Effective
-not confident
-worksheet different from book

Not Effective
-explanation quick and vague

Question 4
Didn't Retain
-not enough practice

Retained
-was able to teach others
-memorized

Question 5
Fine
-repetitive
-understood it better than rest of class

Could Be Improved
- understood but not mastered
-more time
-could have been presented clearer
-more examples
-exercise didn't help
-needed to be more clear
-math
-more review

Question 6
-explain in more depth in the beginning

Teaching Assistant 8

Question 2

<u>Teaching Assistant did a Good Job</u>

-practice
-could remember
-lots of visual aids
-detailed handouts
-examples and diagrams
-pictures helped
-drawings and visuals

<u>Fair</u>

-already knew material

Question 3

<u>Fine</u>

-hands on
-good teaching

<u>Not Effective</u>

-lack of use, forgot it
-more practice
-presented in various fashions
-needed more hands on
-last exercise indicated, did not understand

Question 4

<u>Retained Information</u>

-visuals
-diagrams
-teaching effective

<u>Hard to Retain</u>

-more practice
-more practice
-calculations forgotten
-not confident

Question 5

<u>Fine</u>

-repetition helped
-annoyingly helpful
-good organization

Could be Improved

-more individual work
-more homework
-too much time involved
-information didn't stick
-more emphasis
-need more hands-on
-confusing for simple exercise
-could have been more pertinent

Appendix G

Transcripts of Student Interviews

B-1 Experimental

Researcher: How did you feel about the serial dilution exercise overall:

Student B-1: Do you mean the problems you gave us, the three separate sets?

Researcher: No think about your whole serial dilutions experience from the beginning to the end.

Student B-1: I felt the first time the problems were introduced some of it seemed like it was relative common sense just multiplication of powers and then some of it of course was terminology I had not referenced before. Stuff I didn't know. After we got through the exercises I mean most of it really felt like more or less simple tasks. Once you knew how to do it basically it was relatively easy. And then when we finally got to the review exercise, the third testing round, I guess most of it basically stuck with me because I felt basically the exercise was considerably easy and I just went through it again.

Researcher: If you had to change the exercise, how would you change it?

Student B-1: I really don't know because personally when I went through the exercise I got everything pretty easily. I don't know if there is anything I would do to change the exercise.

Researcher: What parts of the exercise do you feel were most beneficial?

Student B-1: The group exercise where we worked on the actual problem solving idea where we had to develop a dilution like this using two separate methods. I thought that really kind of put it in perspective what we were really trying to do with the exercises.

Researcher: Any other comments you want to make about serial dilutions?

Student B-1: Personally the little testing system that you gave us I think kind of lost its point. I know I personally noticed it was kind of the same questions over and over again so you kind of stick the answers there and you are retaking the material.

Researcher: How did you feel about the initial exercise?

Student B-2: Well I would have to say that when I first glanced over it seemed like it was a lot especially for a class period where we were doing something else a well but once we got into it since we had a group, I think the problem solving concepts kind of kicked in when you have multiple people it is usually a little easier to work through things like that. It was definitely nice that it was in a group setting and I thought that the exercises were really informative because when you came to the second part of it, it really seemed like it was just a lot easier.

Researcher: Do you feel that had you not had that first part, the Exercise 20 you would have struggled with it?

Student B-1: Well I don't know about struggling, but it definitely would have required a little more thought because when you go through the previous exercise you basically learn the techniques and terminology what you need to go into Exercise 20.

Researcher: Did you have a lot of frustration in the beginning?

Student B-1: I would say there was a bit of frustration trying to figure out exactly what the questions were trying to ask or what we were suppose to be doing. I know they gave us the little reading section in the book and I really don't think that is what I would call informative to say. It really took a lot to try and understand what the book was trying to say.

Student B-2 Experimental
Researcher: What are your thoughts on the serial dilution exercise from the beginning to the end?
Student B-2: I understood it once we actually did it, like measured it out with the plates but the calculations and stuff I still feel like I don't know it very well. Like I could do it set it out and do the plates but calculated it…that's confusing. Overall I pretty much understand it.
Researcher: What were the things you liked about the exercise and what were the things you didn't like about the exercise?
Student B-2: I liked the water. That was a good one because you could see it and the wine I liked because it really applied to real life. Like sometimes we do stuff that like only microbiologists care about and do, so the wine was good and doing it every week I feel like made you understand it better, made it more engrained in your mind.
Researcher: What were things you didn't like?
Student B-2: I guess with being so precise with the stuff. I can't really think of anything I didn't like. I didn't love it but I didn't like it.
Researcher: Quiz wise how did you do?
Student B-2: I didn't do as well as I thought I would on the quiz. I just for some reason I don't know if I didn't seek as much help as I should have or what I just didn't understand it. I understand the concept but when it comes to the vocabulary and figuring it out I just get confused. Like I don't know if it is asked in different ways or I understand it and when it gets down on paper I don't do that well. I don't really know why.

Student B-3 Experimental
Researcher: Tell me how you felt about the serial dilutions exercise from the beginning when it started with the colored water that exercise all the way to the end when it finished with the wine making exercise.
Student B-3: Oh it wasn't too bad. I mean we definitely learned it a little better what dilutions were about cause it kind of gave you hands-on kind of thing. Instead of writing it down on paper and saying oh this is ten to the fifth, ten to the sixth kind of thing we at least see. The fact that we used colored water we could actually see the dilutions too, even the pink from going to four to three. There's definitely a slight difference and once you focus you can definitely see something.
Researcher: Then you progressed to the next exercise in serial dilutions. There was Exercise 20. How did you feel about that?
Student B-3: Going from the pink stuff to the wine stuff you are asking? So yeah it was fine. We did the exact same thing kind of thing. I learned it from the pink stuff. It definitely helped in a sense, since I know how to do this I can now see it and I can apply it to the wine. The fact that we did it twice definitely helped us learn it a little better.
Researcher: Tell me some positive things about the exercise and then tell me some negative things about the exercise.
Student B-3: Well the positive was that you were able to work with groups so you were at least able to gather information at once instead of getting it from one source and as the saying goes more heads are better than one. It was a good positive. I guess a negative was I guess the fact that well a negative could be that it was so long. I guess it had to be a long process. You are making wine but I mean I guess. I can't think of anything too

negative about the project. I mean first of all you are in a microbiology lab so bacteria is I mean yeast is made in wine so I mean it's the application of how wine is made so obviously it's a long process. I mean that's the one thing that's kind of an invalid excuse cause it is taking so much time. Of course it is going to suck it is for a class. I guess that's the only real negative.
Researcher: Quiz wise how did you do on your dilution quiz?
Student B-3: Well quiz wise I actually like to tell you the truth the way I study is there was like what I do is see what the pattern is learn so the application of the stuff and I can see like a pattern in my head. Quiz wise I guess I got a B. I forget to set up the thing correctly. I guess I got the concept right but the numbers were kind of wrong. The way I learned I look at the pattern of the math. I looked at the differences.
Researcher: Any other comments you want to make about serial dilutions?
Student B-3: Well I mean it was alright I guess. I mean there was no, serial dilutions is definitely something you learned in class and taking the lab definitely helps learn what serial dilutions is. I mean the way it is taught I have no complaints. It is kind of applied and it definitely helps you.

Student B-4 Experimental
Researcher: What is your overall feeling about the serial dilution exercise from the very beginning to the end?
Student B-4: I felt like it wasn't, they really didn't teach it at all. You just had to read it and go through it and learning it. I thought that was a lot more difficult than if they had just taught it to us. I still think I am fuzzy of stuff just because it wasn't taught. I don't think I know it as well as if I would have.
Researcher: How did you feel about the initial part of the exercise?
Student B-4: Which part is that?
Researcher: The initial exercise with the colored water and the plates.
Student B-4: Ok I really didn't know what we were doing for it. I had a lot of the group members teach me. I felt like I was probably the weakest link in the group.
Researcher: Why?
Student B-4: I think I just need people to tell me what is going on and teach me to it.
Researcher: Did that exercise have any impact on your understanding later on?
Student B-4: It definitely helps. I guess the process of hands-on helps.
Researcher: What is the thing you liked the least about the whole exercise?
Student B-4: I guess just the fact that there is never a lecture on it or anything.
Researcher: What was the best part about the exercise?
Student B-4: The fact that it was very hands-on.
Researcher: How did you do on the quiz?
Student B-4: I guess I got a B on it.

Student A-1 Control
Researcher: Tell me your overall feeling about the serial dilution exercise.
Student A-1: At first a little bit confusing but once you got the hang of it I thought it was a really good exercise. I really learned how to do dilutions and I barely even needed to study for the final exam because I feel like the exercise was designed really well just for learning it.

Researcher: Were there any things that you would improve?
Student A-1: I don't know. I guess it is like I was saying before, at first it is a little confusing so maybe..
Researcher: What about it at first?
Student A-1: Well maybe because it was just a new concept. Just the dilutions into the things it took a while to grasp it. It is not a hard concept at all. It is just maybe a brief introduction about it. I don't remember if there was one.
Researcher: What parts of it would you keep?
Student A-1: Well the receptiveness of it. It just helped cement it in my mind.
Researcher: How well did you do on the dilution quiz?
Student A-1: I got an A.
Researcher: Any other comments?
Student A-1: No

Student A-2 Control
Researcher: What is your overall feeling about the serial dilutions exercise?
Student A-2: I thought it was pretty good. I was confused at first but it wasn't that difficult to get once you looked at it.
Researcher: What was confusing at first?
Student A-2: I think the written description. The picture was great but the written description could have been better. For me it takes me a couple different ways to kind of supplement something so I think seeing it in the picture and then having word description but the words just didn't really correspond to what you were doing as well.
Researcher: How well did you do on the quiz?
Student A-2: I think I got like a low A.
Researcher: Anything that you would change about the exercise?
Student A-2: Like I said just the description part. The hands-on practice was really good.
Researcher: Anything that you would keep?
Student A-2: Definitely the picture, the picture helps. With a little more explanation I think it would have made a little more sense just mainly drawing it out and seeing what exactly, how much exactly you are putting into the plates. I think that was a good thing.

Appendix H

Transcript of Teaching Assistant Interviews

Teaching Assistant 1

Researcher: When were you first exposed to the concept of serial dilutions?
TA 1: Um four and a half years ago.
Researcher: How does this experience compare to your own person experience with serial dilutions?
TA 1: Wait was this my teaching experience or my experience versus learning it?
Researcher: Your experience teaching it…right.
TA 1: This one I was a little better than when I learned it. I guess it is like a three. A little better than when I had to learn it.
Researcher: Can you tell me about your personal experience when you learned serial dilutions?
TA 1: When I learned it, it was just..it is always harder to learn something than when you teach it so I think that with my TA I think we had like a language barrier issue. So that made it a little more difficult, just slightly more difficult. This experience teaching it was slightly better than when I had to learn it myself.
Researcher: How many semesters have you taught before or was think your first experience?
TA 1: I have taught this lab once before this semester.
Researcher: How would you rate your current teaching experience and why?
TA 1: I would rate it as a two. It was pretty positive. I taught seniors before this and it was harder to make the transition back to teaching younger students who weren't always as interested as seniors are but it was still fun.
Researcher: What is the attitude you take towards teaching?
TA 1: I really love teaching. When I first had to teach I didn't think that I would really like it at all but I really love it.
Researcher: How do you think the class as a whole responded to the lesson on serial dilutions?
TA 1: Initially they hate learning it and they are very overwhelmed by it but I think we give them enough practice that it is just something they learn how to do. I don't think that they really like doing serial dilutions but I think they can do it and they will do it. I guess they are neutral about it.
Researcher: As the graduate teaching assistant how well do you think the students understood serial dilutions after the exercise?
TA 1: I think they did understand it. I think overall some of them understood it really well and some of them just learned it enough to get by so I think it is in between.
Researcher: When the class as a whole was working on serial dilutions did the class as a whole rely more on their peers, equally on their peers and their instructor, or just their instructor?
TA 1: I think it is a five and a half. I think they did rely on their peers but everyone was kind of in the same boat to being a little bit clueless about it so I guess since I knew more about it slightly more but not totally.
Researcher: Did you see any cases where students were able to teach other students?
TA 1: Oh yes, especially when it got to when they were doing their wine dilutions every week and they had to work together in groups of four. Someone in the groups would always be confused but someone in the group would always know how to do it.

Researcher: How would you rate the training you received for the exercise on serial dilutions?
TA 1: My training provided by Laura and you, or my own when I first learned it?
Researcher: Laura
TA 1: I don't think that we got any training to teach it. I think it's just kind of all the stuff we teach we should know how to do. If we have questions of course Laura is there to answer them but when I first had taught this, I had forgotten most of it. I went back and did the exercise and that was enough of a refresher for me. Neutral
Researcher: Are there any things you would change about the serial dilutions exercise?
TA 1: I would change..this semester I did not like how it coincided with the wine exercise. During the wine exercise they are physically doing serial dilutions and they get so use to that so they think oh the quiz is on serial dilutions oh I have been doing that for four weeks I know how to do that. But, actually writing it down is a lot different. I think that, I am not positive, that their scores would be better if they had to write it down just here as far as book work before they actually went to the bench and did it. I think that by doing it at the bench first they automatically assumed that they knew how to do it when they did not know necessarily what was going to be on the quiz.
Researcher: Didn't they write up their own dilution schemes when they were doing the wine making?
TA 1: They never have to physically draw out a scheme. They just know if I take this and dilute it into here that is a minus one. If I put 100 microliters on the plate that plate is a minus two. They can all do that without having to write that down but when it shows you the whole scheme and asks for what is the dilution factor or when it gives you the various schemes written out like one to hundred or one to the minus two.
Researcher: Maybe if they had gone into wine making and showed the teaching assistant a scheme before even starting the wine?
TA 1: Yes something where it asked for the student to fill out the scheme and had a place to put what is the dilution factor and write it out in a different way. But they didn't have to do that. It is just a chart asking for what is the pH and what is the hydrometer reading.
Researcher: Are there any other things you noticed with the serial dilutions exercise?
TA 1: I guess that was just one of the things I really didn't like/ I felt that the scores were a lot lower because they knew or they thought they knew what they were doing. They can physically do it. If I said plate me out a ten to the minus two and three they can do that but I think that if you would have had a while to spend on the book work and waited. I liked doing the wine at the end. I feel like it is a good refresher. There were a few weeks in the middle of the semester that were solid serial dilutions and I am not sure if..they need a little more refreshing. It is such an important concept not in just microbiology but really in all research.

Teaching Assistant 2

Researcher: When were you first exposed to the concept of serial dilutions?
TA 2: I guess it was when I took this class. I guess it was about 98 about six, seven years ago.
Researcher: How does this experience compare to your own personal experience with serial dilutions?
TA 2: That is such an abstract question. I guess neutral.
Researcher: Why neutral?
TA 2: I guess I can't say one way or the other.
Researcher: Well what types of things did you do back then?
TA 2: I went to undergrad here so I remember doing kind the same type things that I am teaching now. The only difference is I am kind of on the giving end this time around as oppose to receiving the information. We used the same lab manual.
Researcher: As a student was the exercise clear to you back then?
TA 2: Looking back on it I don't know if I understood all the math behind it but I understood the concept of why you took serial dilutions of something. So at least the concept was right.
Researcher: How many semesters have you taught before?
TA 2: This is my eighth semester.
Researcher: How would you rate your current teaching experience?

Teaching Assistant 2's Second Interview
The tape did not record the entirety of the first interview. Therefore, teaching assistant 2 had to be interviewed again.

Researcher: When were you first exposed to the concept of serial dilutions?
TA 2: It was in I think the fall of 1998 when I took Microbiology lab here. So roughly seven years ago.
Researcher: How does this experience compare to your own personal experience with serial dilutions?
TA 2: I would say four because when I took the class as a student it was pretty much the same material. So it's not a whole lot that's changed as far as the exercises.
Researcher: Did you do the same set up as your TA when you were taking the class?
TA 2: Yeah from what I can remember, I taught basically the same. Just kind of going through some examples on the board, yeah doing I guess the problems in the book. Yeah pretty much the same type of thing.
Researcher: How many semesters have you taught before or was this your first experience?
TA 2: Five or more semesters.
Researcher: It was a total of how many semesters?
TA 2: This is my eighth semester.
Researcher: How would you rate your current teaching experience?
TA 2: Ah I would say four. You know I have had some really good classes and I have has some problem students too so it kind of evens out. Unfortunately the problem

students kind of ruin it for the other students that are dedicated and also kind of for myself as well.
Researcher: What is the attitude that you take towards teaching?
TA 2: I try to go into it with a positive attitude. I enjoy teaching. There's certain things about it I don't like.
Researcher: What are those things?
TA 2: I don't like grading and I don't like dealing with those problem students. It just seems like once a semester or one or two students a semester for what ever reason I have had trouble with. It kind of leaves a sour taste in your mouth. You got to remember there is still a lot of other students you need to teach. You can't let the one or two bad students affect what you are doing.
Researcher: How do you think the class as a whole responded to the lesson on serial dilutions?
TA 2: Ah four, I think a lot of students pick it up fairly quickly and those are usually the students that sit down and spend a little time working on the problems and trying to understand the concept of dilutions. You know the other side, you have a lot of students that don't take the time to do the homework or try to figure out through the reading just the concept or the math behind it.
Researcher: As the graduate teaching assistant, how well do you think the students understood serial dilutions after the exercise?
TA 2: I would say four again. I mean it's kind of the same answer before. The students that spend really not a whole lot of time studying and doing the work pick it up pretty quickly and then there's students that just don't. But I think as the semester goes along they do more dilutions in the lab from various exercises. I think the get a better grasp of it just from doing it over and over again.
Researcher: When the class as a whole was working on the serial dilutions exercise did they rely more on their peers or on the instructor?
TA 2: Again four, right around the middle. I think they tried to rely on their lab partners initially and they don't you know really have good understanding and they come to me. It kind of depends on the group and how well they prepare you know before coming in the lab. You know it seems, it seems like a lot of at a table at least one person sort of knows what's going on so you know they kind of figure it out amongst themselves but still they call me over a lot and ask me kind of more to double check and make sure that they are doing it right more than anything else.
Researcher: How would you rate the training you received for the exercise on serial dilutions?
TA 2: I would say a three or four. There's not a whole lot of training behind it so it's kind of hard to rate so I guess kind of neutral. Yeah we go through the exercise in the lab meeting besides it's kind of the basics that we discuss in the lab meeting.
Researcher: Do you think there needs to be more training?
TA 2: I don't know. I think I have always had a pretty firm grasp on serial dilutions so it has not been something I had a hard time teaching but some TA that are coming out teaching maybe I don't know, they need a little bit more training. It is kind of hard to pick and chose what all you are going to train people on because there are so many exercises we do. It just can get real time consuming and get real involved on training on everything.

Researcher: If you had to change the exercise, what would you change?
TA 2: The initial exercise that we did?
Researcher: Exercise 20
TA 2: I like they way it is set up the way it is now. I think it gives them a little time to think about the concept and do some problems before they actually do the exercise themselves. At least they get a little exposure to what they should be thinking about and what they need to be doing. I like that aspect of it. One of the things I think is good with the wine exercise is the wine is colored so you can kind of see the color change over the different dilutions. I think visually that might help them.
Researcher: How do you think moving the wine exercise up made an impact?
TA 2: I think it was good in the sense that they are being exposed to a lot of serial dilutions and a short period of time so they are really getting hit with the material pretty hardcore. Instead just spreading it out and picking it up they sort of forget what they doing. I think it kind of helped them. It worked out better.

Teaching Assistant 3

Researcher: When were you first exposed to the concept of serial dilutions?
TA 3: In college
Researcher: So that would be how many years ago?
TA 3: four
Researcher: When you were first exposed to serial dilutions did you, or how did you respond to it?
TA 3: At that point I understood it.
Researcher: Your experience that you just had teaching the concept of serial dilutions, how did it compare to your own personal experience that you had in learning the concept?
TA 3: I actually started getting confused when we had the extra exercise because it was in fourths instead of tenths. I actually was confused and I had to sit there and think before I could help my students.
Researcher: So if you had to rate it was your personal experience much better being one, neutral, or seven much worse?
TA 3: To when I was originally taught it or how you taught it?
Researcher: How the students were taught it versus how you were taught?
TA 3: Mine was much better.
Researcher: So this experience was much worse?
TA 3: Yes
Researcher: So you would rate it a seven?
TA 3: Yes
Researcher: How many semesters have you taught before?
TA 3: One other (semester)
Researcher: How would you rate your current teaching experience, one very positive, four neutral, or seven very negative?
TA 3: A three
Researcher: Why? Tell me some things why you think it is more positive?
TA 3: When teaching I am learning more. How to think about things before I can teach them, I have to learn more concepts more thoroughly before I can teach. Also it is helping me understand more own personality flaws and how I am perceived by other students and how I should correct my attitude and be more presentable.
Researcher: How would you describe your attitude towards teaching?
TA 3: Sometimes I am bored and frustrated with being in a teaching position. That's just because I teach for the first half hour and they do their own work. Sometimes it is just hard sitting there for an hour and a half and not doing anything.
Researcher: Do you think that your students can sense this from you?
TA 3: I know they did last semester, some of them. I am hoping this semester was better. I am hoping they don't sense it as much. I am trying to be more positive about being there. I am trying to bring more of my own work just to do something so I am not staring at the students and being in their faces. I am kind of being around and they know I am there but not being on top of them. I am doing my own work.
Researcher: Do the students approach you?

TA 3: All the time. I still look around and make sure there are no questions but at the same time I get kids coming up to me. Students come up to me asking questions. They are still coming up to me even though I might be reading they still come up to me without a problem.
Researcher: How do you think the class as a whole responded to the lesson on serial dilutions with one being very positive, four neutral, and seven very negative?
TA 3: I have to say a five or a six with the extra exercise. The students were frustrated with that experiment. They just didn't know what they were doing. Unfortunately we had the problem with the Kool- Aid not reading one fourth so they couldn't figure out how to do that part and they were stuck on that part. We really couldn't answer any questions. They couldn't understand the one to four reading because it wasn't a one to four reading at all. Once that occurred the students had to go have me help them but by that point they had already been working on it for 45 minutes and they still had the rest of the page to go.
Researcher: How long into the activity did you finally have to say look it is one to four dilution?
TA 3: I waited about half and hour so I didn't waste their time too much.
Researcher: Did this happen for both your classes and how did you handle the second class knowing that there was going to be something wrong?
TA 3: Pretty much the same.I did tell them at the beginning their might be some problems in some of the things. I can't answer questions for the first half hour. After a half hour I will be glad to answer questions you have. The students would come up to me and I was like you have to wait a half on hour and then I will help you. I made them work on their own first to figure things out.
Researcher: Did you see any continuity from the extra exercise to exercise 20 to the wine making exercise?
TA 3: Unfortunately I wasn't around for exercise 20. I was not there that day. My family had a family emergency. I had other TA's teach it for me so I wasn't around for that. I know that my students did the homework but I didn't realize that they didn't answer sheets until later. They didn't tell me they were not handed out. I don't think the students learned exercise 20 that well. I think most they taught themselves without any help out all. I know that caused frustrations. It was reflected on some of their serial dilution quizzes. The grades weren't that positive.
Researcher: Who stood in for you? Who was there for the 12 and who was there for the 2?
TA 3: Nassiba and Brad
Researcher: Nassiba for 12 and Brad for the 2?
TA 3: Yes
Researcher: Did you see anything in the wine making where they reflected back to some previous activity or someone was like this was like this or were they just worried about wine?
TA 3: They just seemed geared up to get out of there and get everything done. Wine making was very intense because we had so many exercises going on that everybody just got frustrated that day and a lot of tensions ran high. There is too much unfortunately scheduled in one day so there whole purpose that day is to get out by 1:50 or 3:50.
Researcher: It goes back to there so much in one lab period that it is hard really to connect a concept you think?

TA 3: That day especially. Most days there is enough time where they can ask me questions but that day it was more get that done, get that done, get out of here you must get that done get out of here.
Researcher: I guess a lot of inquiry is removed if they aren't having a lot of time to think?
TA 3: They are not having time to think..some days they have a lot of time to think and I get a lot of questions. Other days they don't have much time to think at all and I get none.
Researcher: As the graduate teaching assistant how well do you think the students understood serial dilutions after the exercise one being very well, four neutral, and seven did not understand?
TA 3: I think some students started to pick up on it and look into it and understood it more. I think some of them just don't understand and don't care. So overall maybe fifty percent to seventy- five percent understood or tried to understand.
Researcher: So that would be neutral?
TA 3: Yes
Researcher: When the class as a whole was working on the serial dilutions exercise did they rely more on their peers, equally on their peers and the instructor, or solely on the instructor?
TA 3: Which exercise?
Researcher: Think of the exercise together?
TA 3: Sometimes they relied on their peers. Like I said I wasn't there for exercise 20 so I can't tell you. I know that some students did not have good countable colonies when I looked around but there are various reasons for that. It could be just that they didn't dilute it out enough. For the original extra exercise they spent more time working with their peers because they were frustrated with each other. Each person was trying to tell the other person how to do it. One or two had read the extra exercises online and they just happened to see it and went through it. A lot of people had never seen it before and didn't know what to do. People who did know what they were doing pretty much took over the group just to move things along.
Researcher: Again kind of a four because depending on the situation?
TA 3: Yes
Reseacher: How would you rate the training you received for the exercise, one being excellent, four neutral, and seven very poor?
TA 3: I guess four.
Researcher: Why?
TA 3: Just tell us what to do and I knew what was going on. I just got handed the sheet and told go do this.
Researcher: We had a workshop right before you all did the exercise.
TA 3: I don't think I really did it. Did I do everything?
Researcher: I don't think anybody did anything. We just showed you what to do.
TA 3: But you just showed me. I didn't quite..I am more of a visual. I have to see what's going on..hands on learner. So some good some bad. I know that the previous semester had been more hands on.
Researcher: Last semester, fall semester, you were a control teaching assistant, versus this semester you were an experimental teaching assistant, what differences did you see

between your fall students and your spring students did you see? Did you see where that extra exercise may have made an impact?

TA 3: Not really because I had a whole different type of student. I taught morning versus afternoon which is a whole different genre. Fall semester is older students, spring semester is younger students. There is such a wide range. I think my averages were about the same among the quizzes between the two classes. Control versus experimental..I know that they got frustrated the experimental with the extra exercise in general. I don't know if that really helped a whole lot because most of it was four fold dilution and everything else was ten fold dilution except for that one section in exercise C. I think if they would have been taught ten fold the entire time it would have been more beneficial than throwing different types of serial dilutions in there. Four fold for me is as a teacher was a difficult concept to grasp and to teach and I had seen this before so I had a lot more problems with it.

Researcher: Any other comments you would like to add? So you didn't seem much of a benefit between the control and the experimental?

TA 3: I found the experimental class to be more high stress to teach in general. Yes they did get a whole day to spend on inquiry based learning and yes they did get to do hands-on work which is beneficial but at the same time for me the problem was that the four fold dilution the Kool-Aid was so off it wasn't even close to a four fold dilution so that alone frustrated them. I know for myself once frustrated I am going to quit or just not going to grasp as much because I am so frustrated with the exercise. I did eventually have to tell them it was a one to four dilution. For my control class I wasn't given the opportunity to do anything. I wasn't given the opportunity to put a problem up on the board. I had a lot more questions last semester than I did this semester. It could be the type of students though.

Teaching Assistant 4

Researcher: When were you first exposed to the concept of serial dilutions?
TA 4: six years ago
Researcher: How does this experience compare to your own personal experience with serial dilutions?
TA 4: I would give it a three.
Researcher: Why and tell me some things about your own personal experience?
TA 4: The first time that I remember doing serial dilutions was in a textbook basically. Out teacher said study it and make sure you understand this kind of stuff and we will be doing it in lab next week kind of deal. Then what happened of course when we finally got down to doing it there were a lot of questions. It is not the easiest concept I suppose in the world. See you just kind of dumb your way through it that first time. I feel this way the students kind of dumb there way through it the first part and instead of having kind of all those questions welling up in their head they can kind of get them answered right away.
Researcher: So slightly better than your own personal experience then?
TA 4: Yeah I think so
Researcher: How many semesters have you taught before or was this your first experience?
TA 4: This would be my second semester of teaching.
Researcher: How would you rate your current teaching experience?
TA 4: As far as my enjoyment of doing it?
Researcher: Yes, your knowledge, your background, what you bring to the classroom.
TA 4: I guess it would be four.
Researcher: Why?
TA 4: I don't think I am doing an amazing job but I don't think I am being terrible either.
Researcher: What type of attitude do you have towards teaching?
TA 4: Oh well actually as far as doing what I have been doing these last couple of semesters it has been pretty fun. It is usually kind of my relax part of the day. I am not getting graded directly and I get to interact with people that are outside of here. Sometimes I usually really enjoy it. I am normally in a pretty good mood.
Researcher: How do you think the class as a whole responded to the lesson on serial dilutions?
TA 4: I am going to say neutral just for the simple fact that I only ever saw them approach the serial dilution exercise in this particular manner so I don't have anything to compare them against. Also they kind of go at it as the way they do they do with every other task that we have had in the lab. Especially as when it is something new, I get a big groan or a sign and then they finally start going through it and whether they end up liking it later doesn't have any indications as to how they start.
Researcher: How does the spring semester compare to the fall semester?
TA 4: As far as their initial reactions and stuff? I would say it is pretty much the same…another activity that they had to do and when they find out there is this worksheet and I am not really going to help them they all start kind of rolling their eyes. That was kind of the same from one class to the next.
Researcher: Did you have an opportunity after they finished the worksheet to go over it as a class or time to have a discussion?

TA 4: Not as a class, we didn't do that.
Researcher: Did you see them discussing things as a group at least?
TA 4: Oh yeah.
Researcher: Was there a lot of upper level thinking going on?
TA 4: There were basically two things that I noticed in the groups. It depended on how people were grouped. There were some groups where they were all pretty much everybody had some amount of input and that they were talking about it and one person would suggest something. Someone else would offer a different view and they would work it out and come to a compromise and usually that was the correct answer I thought. Then there were always groups where there'd be one person seemed to grasp the idea and everybody else just followed. I never saw any groups where they were filling in blanks and not kind of thinking about it.
Researcher: Which style was the majority? Where they all contributing or someone was a leader?
TA 5: This semester there was more one leader in the group. In one class I know I have six lab groups of four and four of the six it seem like there was one person in charge. The other two they were working together in groups.
Researcher: As the graduate teaching assistant, how well do you think the students understood serial dilutions after the exercise?
TA 4: Right after doing the exercise, I would probably give them a two for the class overall. Then as I go around the room and discuss..we didn't really discuss the answers as a whole. What I had them do as they were done when they completed it, is I would come over and have them talk about cause everybody kind of went about it different ways and I tried to address that. Almost everyone seem to grasp that particular activity and how to apply it and if they had it blank again I think everybody would be able to do alright. I don't know if that is just cause they memorized the answers or if they really reasoned it out. It seemed then when we talked about it and I used other demonstrations that almost everybody got a hold of it. How long they retained that knowledge I am not totally certain.
Researcher: When the class as whole was working on the serial dilution exercise, did they rely solely on their peers, equally on peers and GTA, or solely on GTA?
TA 4: I guess it would be two mostly on peers. They were talking to each other.
Researcher: Did you see any incidents where students were actually teaching other students?
TA 4: Yes there were lot of times where that was going on and most of that would be in the groups where there was someone who really grasped it and saying look here, see here, and writing out extra examples. Everyone else was trying to watch.
Researcher: So at least where there was a dominant person it wasn't like they were just copying, they were actually trying to gain some knowledge?
TA 4: They seemed as if they were really trying to facilitate the rest of their groups understanding of the idea.
Researcher: How would you rate the training you received for the exercise on serial dilutions?
TA 4: So the training I got was two semesters ago?

Researcher: Well actually you received training as a group when we sat down prior to that Friday, right after the regular TA meeting when I went over, Laura and Sharon were there.
TA 4: I remember. I would give it a four. We went over and talked about it. I would say what I got to do the first semester was more beneficial for me because we actually went through the motions.
Researcher: Are there any additional comments that you want to add about the serial dilution exercise? Anything that you think would improve it? Anything that the students had trouble with that caused them to stumble?
TA 4: Things that for the student, I think that really bothered them was when they actually ran out the serial dilutions. The last tube is not going to have the same volume of liquid as all of the ones previous. I don't know how many times I had and it would just be luck I was walking by that group at the time when they were doing this. They are holding this odd man out tube. They think they have done it right the whole way and the instructions say there should be four milliliters in ever tube but then you have one to five. They are like where does this extra milliliter come from and for some reason they don't get it. In the demonstration tubes they are all the same volume, so that is just one thing that came up.

Teaching Assistant 5

Researcher: When were you first exposed to the concept of serial dilutions?
TA 5: The first time ever?
Researcher: Yes
TA 5: In my microbiology undergrad lab which was one year ago.
Researcher: Did you have a hard time with the concept?
TA 5: We didn't elaborate on it much, so I understood the basics but I didn't.. I have to do a lot of problems so I didn't have problems with it because we didn't do much with it. I think I don't think I would be able to do the same things that we were doing. Although when you explained it to us last semester, that was the first time that I went as in depth and it took me awhile to grasp the idea but I think I caught on pretty quickly.
Researcher: Have you in your own research had to use serial dilutions a lot?
TA 5: No
Researcher: How does the experience that you gave to your students compare to your own personal experience with serial dilutions?
TA 5: It goes into much more detail. It explains the purpose of it much better. I don't think I really understood why I was doing it. We just did one quick experiment and I didn't really understand why. So I think this helped us a lot and we applied it a lot. We did so many applications. Like the bacteriophage exercise and the wine exercise. I know there's more. I really think that what they did really helped explain it a lot better and see ways to actually apply it.
Researcher: How many semesters have you taught before or was this your first experience?
TA 5: This was my second semester.
Researcher: How would you rate your current teaching experience? Between one being very positive and seven being very negative.
TA 5: I guess two. I really like it but I know I think I could probably do better but I just am so busy with other things and I know I don't put probably as much effort into it as I should. Overall it is pretty good.
Researcher: So what type of attitude would you say you bring to the classroom?
TA 5: I try to start out and kind of being a hard a** so they wouldn't take advantage of me but now I try to be pretty light hearted. I make dumb jokes. I try to talk one on one with the students but stuff sometimes even outside of the classroom. I try not to talk about anything that should not be talked about outside of class. I try just to be easy going and funny and easily approachable. I tell them if you have any questions, anything let me help you and come talk to me.
Researcher: How do you think the class as a whole responded to the lesson on serial dilutions, one being very positive, four being neutral and seven being very negative?
TA 5: The first exercise or as a whole.
Researcher: Think about I guess..or we can go ahead and break each component down. The first exercise, then exercise 20, and then I guess going on to wine making, so the initial exercise.
TA 5: I don't..they don't seem to like the initial exercise. They didn't like that I didn't really explain it. They didn't really see how it applied at first. I think as we started doing

more exercises that showed how you can actually use it they felt..they definitely were more confident with it and I think they really understood the purpose of it.
Researcher: Then exercise 20, how did they feel about it?
TA 5: That was..I think they felt more confident that they could do it since they had done other exercises. But I don't think they thought they could do it..but oh wait I am thinking about the problems but the actual exercise. I they were sort of neutral. Like by then they kind of sort of had the concepts. I don't know. They weren't like oppose to it but they weren't excited about it.
Researcher: Did anyone reflect back to their experience with the initial exercise?
TA 5: I don't think so.
Researcher: You didn't see any continuity between the two exercises where the students seem like their learning was building or did they take it as separate exercises?
TA 5: I think when students looked back they looked back to exercise 20 because that explained. I think it just had more explanation and it had some of the schemes they were suppose to follow. I think a lot of people also got confused between doing a 4 fold dilution and switching to a 10 fold dilution. So I think they usually looked back to exercise 20.
Researcher: So now looking at it as a whole experience how do you think the class responded to the lesson on serial dilutions with one being very positive, four neutral, and seven very negative?
TA 5: Wow that is a really hard question. I would probably say four neutral. I really guess I didn't get really much of a feeling out of one way or the other.
Researcher: As the graduate teaching assistant, how well do you think the students understood serial dilutions after the exercise, one understood it well, four neutral, and seven did not understand?
TA 5: After the whole..the whole series?
Researcher: yes
TA 5: I think pretty well so two. They did pretty well on the quizzes I think. There were just a couple who didn't quite understand. They sometimes didn't really get like why you transferred like 0.1 ml on to the plate. Overall I think they really understood it. They understood it, I just didn't get much of an attitude that they really liked it or disliked it. I think they understood it pretty well.
Researcher: When the class as a whole was working on the serial dilutions exercise, did they rely more on their peers or on the instructor with one being solely on peers, four equally on peers and instructor and seven being solely on their instructor?
TA 5: I would say two and a half.
Researcher: So between two and three.
TA 5: I guess I would say three. They just tend to..I tell them to ask me questions and they just usually ask each other. Especially with the dilutions they were really relying on each other.
Researcher: So were other students able to actually teach other students?
TA 5: Yes actually I had one example I can think of off the top of my head. One girl that sits by me was really confused and she just sat down with me and had me explain it and she got it. She got excited and she explained it to her lab partners. I was there while she explained it. I think she did a pretty good job. I think they came to me only when they couldn't the answers from other people.

Researcher: How would you rate the training you received for the exercise, one being excellent, four neutral, and seven very poor?
TA 5: I guess I would say two. Just because I actually got to do the exercise and we weren't rushed and I got to sit down and work out the problems. Yeah it was pretty good.
Researcher: Did you find a difference in the students from first semester to the spring semester since you were in both the experimental group both semesters?
TA 5: They seemed a little more belligerent first semester. Second semester they seemed to know something was going on ahead of time. So I think they might have heard from other people because some students seemed to expect that quiz even the first quiz. Which first semester made everyone blow up. First semester really reacted more but I think they probably heard.
Researcher: Even working through the actually exercise, were the groups comparable?
TA 5: Yeah, I think they actually did a little better second semester. Which is probably because I understood it better and the first exercise I couldn't really help them out too much. I think they started wine before the exercise this semester so I had to explain it a little so I think that had something to do it with it. They already at least had some understanding of what they were doing. First semester now that I am thinking about it they had a much harder time with it. I do remember it took them forever and they just didn't get it so yes definitely second semester was better.
Researcher: This is going back to the continuity, them connecting the concepts from start to end. They didn't think about each exercise each time they came to class as separate.
TA 5: I think they had a better..well second semester had a better continuity but the did seem to be able to connect it. They got a little confused with the bacteriophage exercise because this time is was the virus they were diluting instead of the bacteria and I just thought they did not understand at first why. I was actually out of town the day that they looked at those results. I think overall both semesters has a pretty good understanding. I think second semester I tried to point out more often remember this is like exercise 20 or with the wine exercise you have to do this. I think I did a better job second semester because I kept trying to enforce it. Overall I think.

Teaching Assistant 6

Researcher: When were you first exposed to the concept of serial dilutions?
TA 6: Six years ago when I was a freshman.
Researcher: How does this experience compare to your own personal experience with serial dilutions?
TA 6: Three, it was pretty similar to what I did.
Researcher: How was it done differently?
TA 6: I can't think of any differences right now, pretty similar.
Researcher: What format where you taught, were you given an exercise like exercise 20. Can you talk about your own experience?
TA 6: No I didn't talk with my students my own experience.
Researcher: How many semesters have you taught before?
TA 6: First time.
Researcher: How would you rate your current teaching experience?
TA 6: I would pick one.
Researcher: Why do you feel you have had a very positive experience?
TA 6: First it will help me in my English. Secondly it help me with how American undergraduates learn the lab. What I learned in China the undergraduate lab is quite different from here.
Researcher: Can you tell me how a lab in China is?
TA 6: We have a lot of people 3 people or 4 people working in a group. They are not individual. There is not enough room for individual student. The instrument we used is a little bit different.
Researcher: Different how?
TA 6: Better here.
Researcher: What size are your classes?
TA 6: In one class I only have eight students and another one I have thirteen students.
Researcher: So your students do a lot of individual work?
TA 6: Yeah most of the time they do it individually, sometimes they work as a group with two people.
Researcher: How do your students respond to you? Do they come to you a lot for help?
TA 6: Do you mean for the dilution exercise or for the whole class. Yeah they come to me the whole time and ask for help.
Researcher: Do you feel you help them well?
TA 6: yeah pretty good
Researcher: How do you think the class as a whole responded to the lesson on serial dilutions?
TA 6: Do you mean the exercise or the quiz?
Researcher: Exercise 20 and the wine making exercise.
TA 6: I think like two.
Researcher: Why?
TA 6: I think they like the exercise. (They) never done this before.
Researcher: Do you think the smaller class size helped you?
TA 6: yes so I don't need to talk that loud

Researcher: As the graduate teaching assistant how well do you think the students understood serial dilutions after the exercise?
TA 6: I pick two.
Researcher: Why?
TA 6: Because most people understand but some of them..I don't know why but probably because they didn't listen to me at the time. Sometimes when I give them the quiz some students completely mess up so I know they didn't understand that. So I had to teach them again and again and finally they understand that.
Researcher: When the class as a whole was working on the serial dilution exercise did they rely solely on their peers, equally on their peers and the GTA, or solely on the GTA?
TA 6: I pick four.
Researcher: Did you see any cases where there were students teaching other students?
TA 6: yes a lot of cases..probably some students know serial dilutions before I taught them.
Researcher: How would you rate the training you received for the exercise on serial dilutions?
TA 6: A two.
Researcher: Why?
TA 6: During the exercise..tell me how to do the dilutions and substituted a page downloaded from the website and also I looked at the notebook manual. They are pretty good.
Researcher: How would you describe your attitude towards teaching this past semester?
TA 6: Very positive.
Researcher: Do you enjoy it?
TA 6: Yes. I think the exercise right now is pretty good.
Researcher: What do you think was the key aspect that helped them understand it?
TA 6: The time I talked with them. I pointed to the board. I write a flow chart. That make them understand it better without them we could not do that job very well.
Researcher: Did the wine exercise have an impact?
TA 6: Yes but we did the wine exercise after we taught serial dilution so an extra step so they can understand better.

Teaching Assistant 7

Researcher: When were you first exposed to the concept of serial dilutions?
TA 7: Three years ago
Researcher: How does this experience compare to your own personal experience with serial dilutions?
TA 7: One
Researcher: Why?
TA 7: Being a teacher, you have to understand it so you can teach it to your students so I think I took a lot more time understanding it. Then I could tell them what to do.
Researcher: What types of things did you do as a student when you were taught serial dilutions?
TA 7: As a student, I think I followed what the instructor told us. He gave us, I actually had Brad, he gave us the sheets so I practiced on my own. I read the book. I am pretty good at math so it was not very difficult for me.
Researcher: How many semesters have you taught before or was this your first teaching
TA 7: Ah this is my second semester.
Researcher: How would you rate your current teaching experience?
TA 7: Two
Researcher: Why?
TA 7: I enjoy being around the kids. The students I really get along with them. I interact with them. I think they understand me ok so it works out. We just have good dynamic in class.
Researcher: What type of attitude do you have towards teaching?
TA 7: Positive, I feel that it's a good experience for me and for them. That's why I try to make it a really positive environment in the classroom.
Researcher: How do you think the class as a whole responded to the lesson on serial dilutions?
TA 7: In the beginning they were confused. They were intimidated but actually my students were just talking about it, could we have our final be just serial dilutions. They feel very, very confident about it now and they feel that they know what they are doing.
Researcher: How would you rate it on the scale?
TA 7: Three
Researcher: As the teaching assistant, how well do think the students understood serial dilutions after the exercise?
TA 7: Two, I think they understood it pretty good.
Researcher: What type of signs or indicators did you see?
TA 7: I felt that they felt very confident by the time the third quiz came around. They felt very confident and none of them gave me empty pages. Most of them tried.
Researcher: You had the opportunity to teach the control class in fall of 04, and then teach the experimental class of spring of 05. Can you talk about any differences that there were between the two groups of students.
TA 7: There was a huge difference. This group definitely learned it a lot better and they had more experience with it. They understood it especially with the first experiment when they didn't know what they were doing. The last one the wine or the milk they really

knew what they were doing. They understood it completely. I definitely see a more positive result this semester than I did last semester.
Researcher: What impact did my inquiry- based set up have?
TA7: It was a lot better. Addressing it as a unit made a lot of sense cause then they knew that they could build on it everytime. Starting off easy and then going to something hard, having the wine concept. I think I liked the progression. I liked the unit idea. I think it worked.
Researcher: When the class as a whole was working on the serial dilutions exercise, did the students rely more on their peers or on the instructor?
TA 7: I think I'll give it a five.
Researcher: Why?
TA 7: Because I would see them explain it to each other in class but then most of the time it was just easier to come to me and I could explain it to them. They would call me over. They would be working mostly in groups working on it and they would call me over. I think they interacted a little bit with each other but they depended on me for the final advice.
Researcher: How would you rate the training you received for the exercise on serial dilutions?
TA 7: I think it was neutral. I was exposed to it before so I think they training did not help me as much.
Researcher: If you have to go through and change the exercise, what would you do?
TA 7: I don't think I would change anything. I think the practice problems that they had I would take more time out working it out with them, giving them a set, making it more like a homework, taking it up, correcting it, putting it on the board. Which I didn't do a lot of that this semester because I wanted them to learn it on their own. I answered their questions but I didn't officially go through a lot of problems. I think I would do that more often, treat it like a math course in which I would go over the problems. They have actual notes on how to do it rather than just reading a hand-out. Other than that I don't think I would change anything.

Teaching Assistant 8

Researcher: When were you first exposed to the concept of serial dilutions?
TA 8: Six or more years ago..oh I would say seven or more years ago.
Researcher: How did this experience teaching serial dilutions compare to your own personal experience learning serial dilutions?
TA 8: Four
Researcher: Can you describe you own personal experience?
TA 8: Problem exercises similar what we had done in the lab as well as actual lab dilutions that were components of the lab itself.
Researcher: How many semesters have you taught before or was this first teaching experience?
TA 8: I have taught General Microbiology one semester before this and Pathogenic Bacteriology
Researcher: How would you rate your current teaching experience?
TA 8: Two
Researcher: Why?
TA 8: Experience. I feel like I have evolved as an instructor. My experience having taught this class once before has indicated certain problem areas so I have stressed this more this time around.
Researcher: What is your attitude you take towards teaching?
TA 8: I feel that I have an obligation to the students to offer my assistance
Researcher: How would you rate the training you received for the exercise on serial dilutions?
TA 8: Um a two. They were always available for questions. They encouraged us to use certain examples. We were given basically a set of problems to go over which made it easier for us to understand what they felt was important and since they are the professional educators that carried a lot of weight. Furthermore if we did have issues when trying to relay certain information or skills to the students they were always available to give us their input and make suggestions. One time I know that Laura made a suggestion to me that I was able to use. The first year I taught it and this year as well. I think it helped the students understand why we made a dilution the way we did.
Researcher: If you had to change the exercise, what would you change?
TA 8: I think that I would try to draw more correlation between what we do in lab. I felt as though the students sometimes turned off what we had just learned on the quiz and didn’t understand how to apply it to the lab. Maybe questions involving the wine exercise. Something that would make them understand and maybe have a bacteriophage question cause a lot of them didn’t understand that CFU or PFU were the same concepts. That would be the only thing that students would just have to evolve to an understanding on their on and no matter what you do that evolution. There is that certain amount of independent evolution.
Researcher: Did you think moving wine making up for both the experimental and control classes make an impact?
TA 8: I did. I thought it was better for them to do it and I think for a lot of them it did help. When I made a suggestion, I meant to actual have a problem within the example

problem in the initial handout be a problem they would have to do for the wine handout. Yes I do. I thought that helped them a great deal.
Researcher: Is there anything else that you observed that may have been overlooked in this interview that stood out in the serial dilution exercise?
TA 8: Not that I can think of.

Appendix I

Consent Forms

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Informed Consent for Students

Title of Project: Implementing Inquiry Based Learning in a General Microbiology Laboratory

Investigator(s): Candace Walker, Dr. Ann M. Stevens (advisor) and Dr. Arthur Buikema (advisor)

I. Purpose of this Research/ Project

The purpose of this study is to explore different teaching methods in a General Microbiology laboratory. This study will involve approximately 400 students and an undetermined number of teaching assistants.

II. Procedures

If you choose to participate in this study you will be a member of a focus group for a research project. The researcher will be videotaping and observing you as you participate in a science laboratory. Your responses and comments will be used as data. After participating in the laboratory you will be interviewed and asked questions concerning how effective you thought the exercise was conducted.

III. Risks

This research does not involve any physical or emotional risks beyond the normal risks involved in a science laboratory.

IV. Benefits

This study may impact the curriculum design of the General Microbiology laboratory at Virginia Tech. The possible benefits of this study include the ability to implement a more effective teaching strategy in the General Microbiology laboratories at Virginia Tech. This study does not promise or guarantee that these benefits have been made to encourage you to participate.

V. Extent of Anonymity and Confidentiality

Students' identity will be kept confidential. The two focus groups will be identified by numbers. Individual students with in a focus group will be identified by letters. The students interviews will be tape recorded and students will be videotape while completing the science exercise. The videotape will only be viewed by the researcher. These tapes will be kept in the researcher's procession and when the research is completed after the spring 2005 semester the tapes will be destroyed.

VI. Compensation

There will be no compensation given for participating in this study.

VII. Freedom to Withdraw

You are free to withdraw from this study at any time without penalty. You are also free to not answer any questions or respond to experimental situations that you choose without penalty.

VIII. Subject's Responsibilities

I voluntarily agree to participate in this study. I have the following responsibilities:

1. Willing to be videotaped and observed while participating in a science laboratory.
2. Participate in post-exercise interview.

X. Subject's Permission

I have read and understand the Informed Consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent:

____ Date______________
Subject signature

Should I have any pertinent questions about this research or its conduct, and research subjects' rights, and whom to contact in the event of a research- related injury to the subject, I may contact:

Candace Walker — 804-721-4674/ candacew@vt.edu
Investigator — Telephone/e-mail

Dr. Ann M. Stevens — 540-231-9378/ ams@vt.edu
Faculty Advisor — Telephone/e-mail

Dr. Arthur L. Buikema Jr.
Faculty Advisor
540-231-5180/ buik@vt.edu
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Dr. George Glasson
Committee Member
540-231-8346/ glassong@vt.edu
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Dr. Mary Barksdale
Departmental Reviewer
540-231-3166/ mbarksda@vt.edu
Telephone/e-mail

David M. Moore
Chair, Virginia Tech Institutional Review Board for the Protection Of Human Subjects
540-231-4991/ moored@vt.edu
Telephone/e-mail

Office of Research Compliance- CVM Phase II (0442)
Research Division

This Informed Consent is valid from Aug. 1, 2004 to Jun. 30, 2005

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Informed Consent for Teaching Assistants

Title of Project: Implementing Inquiry Based Learning in a General Microbiology Laboratory

Investigator(s): Candace Walker, Dr. Ann M .Stevens (advisor) and Dr. Arthur Buikema (advisor)

III. Purpose of this Research/ Project

The purpose of this study is to explore different teaching methods in a General Microbiology laboratory. This study will involve approximately 400 students and an undetermined number of teaching assistants.

IV. Procedures

If you choose to participate in this study you will be a member of one the two groups of teaching assistants. There will be those teaching the control classes and those teaching the experimental classes. Teaching assistants teaching the control classes will receive no additional background besides what is normally given to prepare the teaching assistant for the usual semester. Teaching assistants teaching the experimental class will be expected to participate in training that goes beyond what is usually required of teaching assistant to gain an understanding of inquiry based learning. Teaching assistant will also be expected to conduct the Serial Dilution laboratory using inquiry based learning.

Teaching assistants in this study will be responsible for conducting the laboratory of interest, Serial Dilutions. The teaching assistants from both the control and experimental groups prior to teaching the laboratory will be interviewed. The interview will be tape recorded. The interview will include questions about his or her previous teaching experience. The teaching assistant will also undergo a tape recorded interview after conducting the Serial Dilutions laboratory. Interview questions will include how effective he or she felt their teaching skills were.

III. Risks

This research does not involve any physical or emotional risks beyond the normal risks involved in a science laboratory.

IV. Benefits

The benefits of this study may impact the curriculum design of the General Microbiology laboratory at Virginia Tech. The possible benefits of this study include the ability to implement a more effective teaching strategy in the General Microbiology laboratories at Virginia Tech. This study does not promise or guarantee that these benefits have been made to encourage you to participate.

V. Extent of Anonymity and Confidentiality

Teaching assistants' identity will be kept confidential. Teacher assistants will be identified by letters assigned to them by the researcher. The teaching assistants' interviews will be tape recorded and tapes will be labeled by the letters they are assigned. These tapes will be kept in the researcher's procession and when the research is completed after the spring 2005 semester the tapes will be destroyed.

VI. Compensation

There will be no compensation given for participating in this study.

VII. Freedom to Withdraw

You are free to withdraw from this study at any time without penalty. You are also free to not answer any questions or respond to experimental situations that you choose without penalty.

VIII. Subject's Responsibilities

I voluntarily agree to participate in this study. I have the following responsibilities:

1. Participate in pre-exercise interview
2. Participate in workshop for inquiry-based learning (experimental group)
3. Teach the laboratory of interest
4. Participate in post- exercise interview

X. Subject's Permission

I have read and understand the Informed Consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent:

____ Date______________
Subject signature

Should I have any pertinent questions about this research or its conduct, and research subjects' rights, and whom to contact in the event of a research- related injury to the subject, I may contact:

Candace Walker — 804-721-4674/ candacew@vt.edu
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Dr. Mary Barksdale — 540-231-3166/ mbarksda@vt.edu
Departmental Reviewer — Telephone/e-mail

David M. Moore — 540-231-4991/ moored@vt.edu
Chair, Virginia Tech Institutional Review Board for the Protection Of Human Subjects — Telephone/e-mail

Office of Research Compliance- CVM Phase II (0442)
Research Division

This Informed Consent is valid from Aug. 1, 2004 to Jun. 30, 2005

Appendix J

Wine Making Exercise

THE MICROBIOLOGY OF WINE

General Microbiology Laboratory
Biology 2614

(Revised July 1, 2004)

Fermented foods and beverages are probably as old or older than civilization itself. Historical evidence shows that beer- and wine-making were well established by at least 2000 B. C. Fermentation may also be thought of as a means of food preservation. The formation of acids and alcohols, plus the reduced (anaerobic) environment retards the growth of spoilage bacteria. If the reduced environment becomes oxidized, spoilage will often ensue. An example is the conversion of wine into vinegar (acetic acid) by members of the genus *Acetobacter* when the wine is aerated.

Wine is essentially fermented fruit juice in which the major end products of this fermentation are ethanol and carbon dioxide induced by the yeast *Saccharomyces cerevisiae*. It is desirable to have the best strain of this culture for the wine because varying results are obtained with different strains. A winery will guard their yeast strains to protect their market. Other species are sometimes used for special wines. The winery will add this yeast to the starter material. Otherwise "wild" yeast naturally present on the grapes will take over the fermentation and produce a poor wine.

We usually associate wine with fermented grape juice although other juices (such as berry, dandelion, and rhubarb) commonly are used for wine production. The production process for wine is not nearly as involved as that for beer. In beer, the barley grain must first be converted to "malt" (the sprouted seeds), and then the starch in the malt must be converted to fermentable sugars. In wine, no such conversions are necessary because the fruit already contains fermentable sugars. In modern wineries, quality control related to fermentation, aging and blending is carefully regulated. Moreover, pure yeast cultures are prepared for use in modern winemaking operations.

The two basic wine types are red and white. Red grapes are used for red wines, and the skins are left on the grapes during the initial stage of fermentation. White or red grapes can be used for white wines, but, if red grapes are used, the skins are separated from the must and discarded early during the processing.

In this exercise, we will make wine from grape juice, but we will not use all of the steps (written below) used in making fine table wines.

Major Steps Used in Making Fine Table Wines

a. Stemming and Crushing: Ripe grapes are stemmed and crushed, and the resulting mixture is called the "must". Must is transferred to a fermentation tank. **Time = 1 day**

b. Fermentation: Sulfur dioxide is added to destroy unwanted wild yeasts. Wine yeast is added and alcoholic fermentation begins. **Time = 7 – 10 days**

c. Pressing: The fermentation must (wine) is passed through a press where the skin and seeds are removed. **Time = 1 day**

d. Racking: The new wine is transferred to a settling tank to facilitate initial clarification by separating sediment (the "lees") from wine. **Time = 30 – 60 days**

e. Aging and Fining: The wine is aged - this oxidizes undesirable tannins and develops bouquet. Then the aged wine is periodically racked and "fining" material added, if necessary, to promote clarification. **Time = 6 months – 5 years**

f. Filtration, Bottling and Pasteurizing: The wine is filtered, bottled and sometimes pasteurized in the bottle. **Time = 1 day**

Materials:

Cultures: - *Saccharomyces cerevisiae* (the "Montrachet" strain) grown on SAB slants.

Media – Grape juice, frozen concentrate, diluted according to package directions

Procedure:

Week 1: Preparing Juice Culture

1. Using a funnel, add table sugar (sucrose) to juice. You will be given 60g sugar pre-measured and stored in a plastic (Ziplock-type) bag. Screw cap on tightly and swirl bottle gently until the sugar dissolves.
2. Fill a clean 300 ml cylinder with a sample of this grape juice and sugar mixture. Use a hydrometer to measure and then record the potential alcohol content of the mixture. (Your TA will demonstrate how to use a hydrometer.) Return this 300 ml sample back into the bottle, using the funnel.
3. Rinse the hydrometer with warm water, pat it dry with a Kimwipe and place it back in its holder.
4. Use a sterile 5-ml pipette to transfer 3 to 4 ml of juice mixture onto each of three SAB slants of wine yeast. Carefully vortex each slant to mix the yeast with the juice. Pour this yeast suspension into the remaining juice mixture. Do not allow the agar slant to go into the bottle. Mix by swirling the jug.

5. With another sterile 5-ml pipette, remove 4 ml of **inoculated-juice mixture**, and place this volume into a clean test tube. Measure the pH of this inoculated-juice mixture. (Your TA will demonstrate how to use this type of pH meter.) Record the pH of the inoculated-juice mixture, and then discard this juice sample as you would any microbial culture.
6. Thoroughly rinse the pH electrode and discard the rinse water. Store the electrode in the storage buffer provided.
7. Determine steps necessary to prepare a 10^{-2} and a 10^{-3} dilution of the juice culture. Use ten-fold dilutions, sterile supplies, and sterile techniques throughout. After you have removed your initial sample, place the rubber stopper, which has the "water-trap" tubing attached, into the neck of the juice culture bottle. Label this bottle with your name or initials and section time, so that you will know which one belongs to your group. Incubate at room temperature, at the wine station on the side bench.
8. Prepare one SAB plate from each dilution by pipetting 0.1 ml of the diluted juice culture onto the plate using good aseptic technique. Be sure to label your plates with the dilution, your name and section time. Discard the pipettes, tubes and diluted juice as you would any microbial culture.
9. Incubate all plates at 30°C until next lab period.
10. Count colonies and record your results as CFU/ml after incubation.

Week 2: Sampling

1. Mix the **fermenting juice** by holding the bottle upright and gently swirling.
2. Fill a clean 300 ml cylinder with a sample of fermenting juice. Use a hydrometer to measure and then record the potential alcohol content of this juice. Return this 300 ml sample to the bottle that contains the fermenting juice.
3. Rinse the hydrometer with warm water, pat it dry with a Kimwipe and place it back in its holder.
4. Use a sterile 5-ml pipette to remove about 4 ml of fermenting juice, and place this volume into a clean test tube. Measure the pH of this juice mixture. Record the pH of the inoculated-juice mixture, and then discard this juice sample as you would any other microbial culture.
5. Thoroughly rinse the pH electrode and discard the rinse water. Store the electrode in the storage buffer provided.
6. Determine the steps necessary to prepare a 10^{-4}, 10^{-5} and 10^{-6} dilution of the fermenting juice. Use ten-fold dilutions, sterile supplies, and sterile techniques throughout. Prepare one SAB plate from each dilution by pipetting 0.1 ml from each dilution tube, and spread this volume on the plate's surface using good aseptic technique.
7. Discard the pipettes, tubes and diluted juice as you would any microbial culture.
8. Incubate all plates at 30°C until the next laboratory period, and then count and record the number of CFU on each plate.
9. Replace the stopper and water trap. Continue to incubate fermenting juice at room temperature.

Weeks 3 AND 4: Sampling

1. Mix the **fermenting juice** by holding the bottle upright and gently swirling.

2. Fill a clean 300 ml cylinder with a sample of fermenting juice. Use a hydrometer to measure and then record the potential alcohol content of this juice. Return this 300 ml sample to the bottle that contains the fermenting **juice**.

3. Rinse the hydrometer with warm water, pat it dry with a Kimwipe and place it back in its holder.

4. Use a sterile 5-ml pipette to remove about 4 ml of fermenting juice, and place this volume into a clean test tube. Measure the pH of this juice mixture. Record the pH of the inoculated-juice mixture, and then discard this juice sample as you would any other microbial culture.

5. Thoroughly rinse the pH electrode and discard the rinse water. Store the electrode in the storage buffer provided.

6. Determine the steps necessary to prepare a 10^{-4}, 10^{-5} and 10^{-6} dilution of the fermenting juice. Use ten-fold dilutions, sterile supplies, and sterile techniques throughout. Prepare one SAB plate from each dilution by pipetting 0.1 ml from each dilution tube, and spread this volume on the plate's surface using good aseptic technique.

7. Discard the pipettes, tubes and diluted juice as you would any microbial culture.

8. Incubate all plates at 30°C until the next laboratory period, and then count and record the number of CFU on each plate.

9. Add about 1 teaspoon of sugar to the fermenting juice, and gently mix by swirling. You will be given the sugar pre-measured and stored in a plastic (Ziplock-type) bag.

10. Replace stopper and water trap. Continue to incubate the fermenting juice at room temperature.

Week 5: Sampling and Handling

1. "Rack" the "must" (separate the **new wine** from the settled yeast cells) in the following way:

   a) Remove the stopper and water-trap-tubing from the bottle, and use a sterile 5-ml pipette to remove about 4 ml of the new wine. Place that 4-ml volume into a clean test tube.

   b) Without disturbing the sediment, carefully pour (decant) 300 ml of the new wine into the hydrometer cylinder.

   c) Place a piece of cheesecloth over the top of the 1 L beaker. (Beaker and cheesecloth will be provided.) Carefully pour the remainder of the wine into the beaker.

   d) Use warm water to thoroughly rinse the bottle, so that all of the yeast cells are removed. Discard the rinse water (and yeast cells) into the sink. These cells are now dead, so do not need to be discarded as you would other microbiological cultures. Set the bottle aside to cool. Make sure that all yeast cells are washed down into the drain.

   e) Pour the new wine from the beaker back into the rinsed bottle. Use a funnel to prevent spilling during this transfer. Pour gently to avoid mixing a lot of oxygen into this new wine.

   Note: If new wine is not "racked" (separated from the yeast cells), these cells may impart bitter flavors to the wine during storage.

2. Place the hydrometer in the new wine previously poured into the 300 ml cylinder. Measure and then record the potential alcohol content of this new wine. Return this 300 ml sample to the bottle that now contains the "racked" wine.
3. Rinse the hydrometer with warm water, pat it dry with a Kimwipe and place it back in its holder.
4. Place the pH electrode into the 4-ml sample of new wine, and measure the pH of this new wine. Record the pH and then discard this juice sample just as you would any other microbial culture.
5. Thoroughly rinse the pH electrode and discard the rinse water. Store the electrode in the storage buffer provided.
6. Your TA will store the bottled new wine in the cold room (about 4°C) until your final laboratory period.

Results:

Sample Interval	pH	Hydrometer Reading	CFU per plate	CFU / mL in fermenting juice
Week 1			10^{-2}	
			10^{-3}	
Week 2			10^{-4}	
			10^{-5}	
			10^{-6}	
Week 3			10^{-4}	
			10^{-5}	
			10^{-6}	
Week 4			10^{-4}	
			10^{-5}	
			10^{-6}	
Week 5			not done	not applicable

Conclusions:

Appendix K

Preparation Sheets for the Serial Dilutions Exercise

Preparation Sheets

1. Serial Dilution Addendum

Preparation for *E. coli* observation plates needed for Part B:
Make 3 sets of plates per classroom.
Cultures:
E. coli

Materials needed:
5/ T-soy agar plates
1.0 ml sterile pipettes
5/ 9.0 ml distilled water dilution blanks (sterile, screw cap tubes)
100 ml distilled sterile water bottle
Pasteur pipette
Spreader wheel, glass rod, and 95% ethanol

Begin with an *E. coli* culture grown overnight to 10^5.
Take three drops of the culture using a sterile Pasteur pipette and place into the 100 ml of distilled sterile water.
Gently mix.
Label the 5 dilution blanks A-E.
Using the 1.0 ml sterile pipette, transfer 1.0 ml of the diluted *E. coli* culture to dilution blank A.
Gently mix.
Transfer 1.0 ml from tube A to tube B.
Gently mix. Between each transfer use a new pipette.
Transfer 1.0 ml from tube B to tube C.
Gently mix.
Transfer 1.0 ml from tube C to tube D.
Gently mix.
Transfer 1.0 ml from tube D to tube E.
Gently mix.
Immediately after the serial dilution has been completed, the spread plates should be made.
Label the underside of the T-soy agar plates I-IV.
Transfer 0.1 ml from tube B to plate I. Remove the glass rod from the ethanol and pass the rod through the flame. Using the glass rod and the spreader wheel, spread the culture evenly over the T-soy agar. Replace the cover of the dish and return the rod to the alcohol. Allow the spread plate to sit right side up for 5 minutes.
Continue the same procedure plating 0.1 ml from tube C to plate II, tube D to plate III, and tube E to plate IV making sure to follow the steps described above.
Invert the plates and incubate them at 30 degrees Celsius for 24 hours.
The following day remove the plates from the incubator. Label plate I TNTC, and then count and label the colonies for plates II-IV. The colony counts should follow a ten fold dilution scheme.

Materials per Lab:

	1 L bottle for master stock, 1pack of Cherry Kool-Aid per 50 ml of water
1/ 4 students	6 Colored water demonstration sets, 1:4 serial dilution
4/ 4 students	Small screw cap tubes
1/ 4 students	50 ml orange cap corning bottles (bottles for stock concentration)
1/ 4 students	50 ml orange cap corning bottles (bottles for water)
	Pipettes
	Spectrophotometer

2. Wine Making

Week 1

Culture Media:

1/ 4 students	2-3 SAB slants *Saccharomyces cerevisiae* ("Montrachet" strain)

Materials per Lab:

3 cans/ class	Grape juice, frozen concentrated (to be diluted per pkg dir.) Set up station on the bench beside the 55 degree C. incubator, the station will stay till the end of the semester
1/ 4 students	500ml plastic jug w/plug
1/ 4 students	Sugar- measured before class
1/ class	Weigh boat
1/ class	Graduated glass cylinder, 250 ml
1/ 4 students	Rainin pipette
1/ 4 students	Box of tips for Rainin pipette
1/ 2 students	Pipette tips discard cup
	Triple Beam Balance
3/ class	250 ml flask filled with 150 ml dH_2O, foil lid
1/ 4 students	Flask rubber stopper with tubing and glass pipette attached
	Bag of pipettes
1/ 4 students	Pipette aid, green and blue
1/ 4 students	Turntable
1/ 4 students	Ethanol dish
2/ 4 students	9 ml sterile H_2O blanks
2/ 4 students	SAB plates
1/ 4 students	Sterile capped tube (pH)
1-2/ room	Hydrometer

Week 2

Materials per Lab:

1/ 4 students	1 sterile capped tube
5/ 4 students	9 ml sterile H_2O blanks
3/ 4 students	SAB plates
1/ 4 students	sugar- measured before class

Week 3

Materials per Lab:

1/ 4 students	1 sterile capped tube
5/ 4 students	9 ml sterile H_2O blanks
3/ 4 students	SAB plates
1/ 4 students	sugar- measured before class

Week 4

Materials per Lab:

1/ 4 students	1 sterile capped tube
5/ 4 students	9 ml sterile H_2O blanks
3/ 4 students	SAB plates
1/ 4 students	sugar- measured before class

Week 5

Materials per Lab:

1/ 4 students	Capped, sterile tube
1/ 4 students	1000 ml beaker
1/ 4 students	Funnels
1/ 4 students	Cheesecloth
1/ 4 students	500 ml plastic jug/ screw cap for storage

Appendix L

Serial Dilution Exercise (Instructor's Copy)

Serial Dilution Exercise (Instructor's Copy)

Dilutions are used to diminish the strength of solutions. Dilutions are an important tool utilized in a microbiology laboratory. In this exercise you will determine the definition of serial dilutions and investigate how dilutions can be used to obtain a viable cell count. For additional background information please refer to Exercise 20 in your text, *Understanding Microbes*, and the handout, Calculating Serial Dilutions.

Students should complete the following pre-exercise before attending class. The day of class briefly check students' worksheets for completion and go over the following terms with the students.

Pre-Class Exercise

Prior to class in one sentence define the following vocabulary:

Viable number- the number of cells capable of division on a solid medium

Colony-forming units (CFU)- cells capable of division

Dilution factor- the ratio of the original volume to the final volume

TNTC- too numerous to count

TLTC- too little to count

Part A.

Instructions: You will be given 4 control test tubes with various colored water samples labeled A, B, C and D and a water blank. Each test tube contains 3 ml of solution. Please observe these test tubes.

1. a. What observations regarding color intensity can you make about the various water samples?

Students are to visually observe the four test tubes. They should observe that the test tubes go from a more concentrated red color in tube A to a less concentrated red color in tube D.

b. Use the spectrophotometer to record the absorbance of the 4 test tubes. Read the spectrophotometer on a wavelength of 650 nm. Remember to use the water blank for accurate spectrophotometer readings. Read the test tubes from dark to light.

Students are to use the spectrophotometer to record their absorbance readings.

Make sure students have set the spectrophotometer to 650 nm.

Students should blank the machine with the water blank first before taking their colored water readings.

Before inserting the colored water tubes into the spectrophotometer, have the students rock the tube gently back and forth to ensure even color distribution and use a Kim Wipe to remove any finger prints from the tube.

Students should read tube A first, B, C, and D last.
Students will record the absorbance for each colored water tube.

c. Based upon the recorded absorbance readings, the dilution pattern is

___________________ fold.
Based upon the student's spectrophotometer readings, students should observe a four fold dilution.

2. If you were placed in a laboratory and asked to dilute a concentrated stock solution, describe two methods that could be used to obtain concentrations equivalent to the 4 control tubes. (Pour plate and spread plate are not the two methods.)
Students will provide two different dilution methods that would recreate the four colored water test tubes. Answers will vary in this section but at least one of those methods should describe serial dilutions.

a.

b.

3. Cost can be a factor when working in a laboratory. The method chosen to perform the dilution should take into account the amount of materials and supplies used. If it does not, and material and supplies are not used efficiently that would be a disadvantage of the method. This is just one example. Below please describe 1 to 2 other advantages and disadvantages for each method described in question 2 that have an impact on the methodology of the technique.
Answers may vary in this section. A number of answers are acceptable. Students may take into account cost, availability of materials, time, and other factors not mentioned. Students may be guided but please allow them to determine their answers.
a.
Advantages-

Disadvantages-

b.
Advantages-

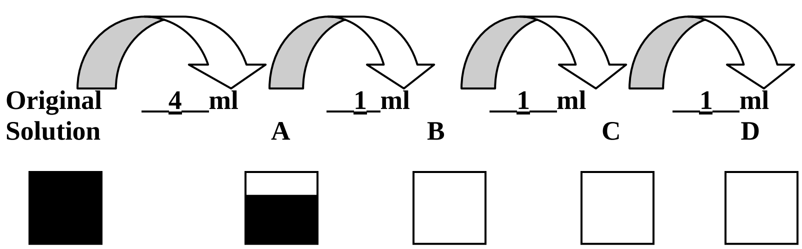
Disadvantages-

4. Of the two dilution methods described in question 2, which method is the best method to use when the initial stock concentration is in small quantity?

5. Complete the dilution scheme below. After drawing the dilution scheme, perform the dilutions that will recreate the four test tubes observed in question 1. Remember to use the water blank for accurate spectrophotometer readings. Space is provided for you to describe the steps you are taking to recreate the four test tubes. Be specific and provide clear details in a way that someone else could re-create this dilution scheme.
The following materials are made available for performing the dilution:

Concentrated stock solution	**Screw Cap Tubes**
Spectrophotometer set at 650nm	**Pipettes**
Water	**Pipette Aids**
Kim Wipes	**Water Blank**

Students will physically recreate the four colored water test tubes.
Before beginning their re-creation, students will need to complete the dilution scheme below. <u>There is no dilution from the original solution to tube A.</u> Students' answers should be as follows.



	B	C	D
Blank Volume	__3__	__3___	__3___
Total Test Tube Volume Before	__4___	__4___	__4___

Transfer

Dilution from stock	**1:4 or 1/4**	**1:16 or 1/16**	**1:64 or 1/64**
Dilution Factor From Stock	**4**	**16**	**64**

After completion of their dilution scheme students will use the written scheme as a guide for their re-creation. In the space below students will write out their procedure.

The concentrated stock solution is the solution in test tube A. Put 4 ml of the concentrated stock into test tube A.
Put 3.0 ml of water into tube B. Transfer 1 ml of solution from tube A to tube B. Mix well.
Put 3.0 ml of water into tube C. Transfer 1 ml of solution from tube B to tube C. Mix well.
Put 3.0 ml of water into tube D. Transfer 1 ml of solution from tube C to tube D. Mix well.

Students will use the spectrophotometer to verify a four fold dilution scheme. Students should record the spectrophotometer readings.

Part B.
You will be given four plates labeled I- IV. On each plate a bacterial culture is growing.
Countable plates are those plates that contain between 30- 300 colonies. For more information refer to your textbook, *Understanding Microbes*, pages 185-186.

1. Count the colonies and write the number of colonies of the countable plates on the line provided.

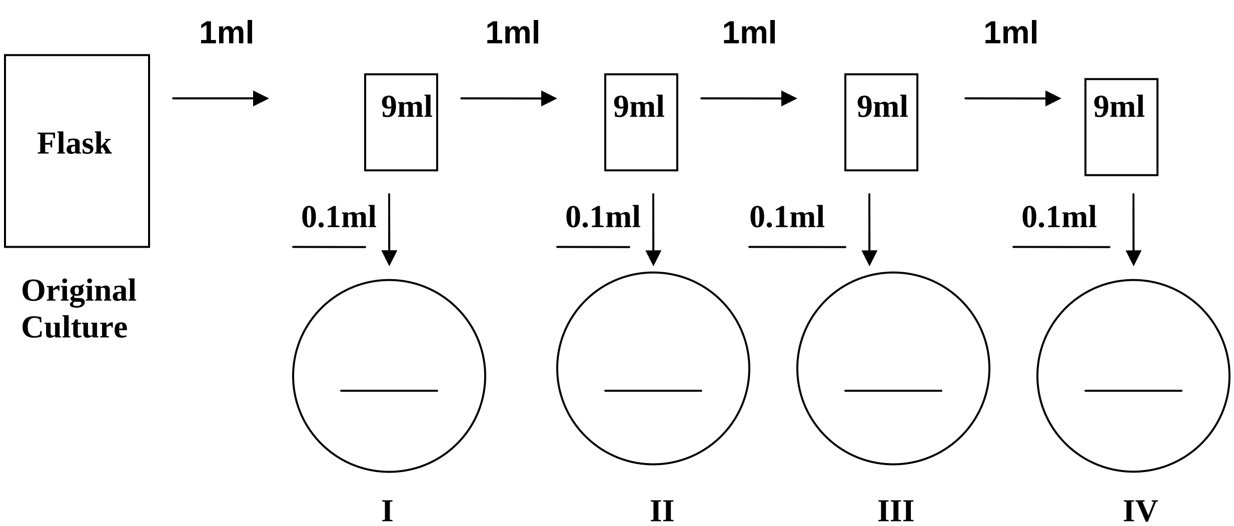


Plate I is too numerous to count. Only plates II and III are in the countable range. Plate IV is countable but there are so few colonies it is considered too little to count. Plate I is statistically insignificant.

2. What observations can be made about the four plates in regards to colony numbers?
Students' answers may vary. Student will observe there is a decrease in colony number from the plates. They may speculate that some type of dilution has occurred.

3. All of the dilution steps, designated by the arrows, use the same dilution factor. The dilution factor is _____________ fold.
Students should observe a 10 fold dilution.

4. Using the dilution factor:

a. Calculate the total dilution factor between the original culture and plate III.
Each arrow represents a 1/10 dilution. There are four dilutions between the original culture and plate III. The dilution between the original culture and plate III is 10^{-4}, therefore the dilution factor is 10^{4}.

b. Calculate the CFU/ml in the original culture.
To calculate the CFU/ml take the number of colonies counted on plate III multiplied by the dilution factor between plate III and the original culture.

$$\frac{CFU}{ml} = \frac{\text{Average number of colonies}}{\text{plate}} \times \text{dilution factor}$$

Part C. Based upon your observations in Parts A and B, determine and write a definition of "serial dilution."

Answers may vary but should include sequentially diluting a solution or culture with the use of dilution blanks.

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Education

Master of Science, Biological Sciences, Virginia Polytechnic Institute and State University, August 2005

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Professional Experience

August 2004- May 2005 **Teaching Assistant**

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August 2002- June 2003 **Life Science Teacher**

J.E.J. Moore Middle School, Prince George County Public Schools

June 2002- August 2003 **Teaching Professional**

National Youth Sports Program, Virginia State University

June 2001- July 2001 **Student Leader**

Summer Transition and Enhancement Program, Virginia State University

March 2001- March 2002 **Private Tutor**

Presentations

June 25, 2005 ABLE Conference, Virginia Tech, “Implementing Inquiry-Based Learning in a Microbiology Laboratory”

June 4-9, 2005 Poster Presentation: ASM 105th General Meeting, Atlanta, GA, “Implementing Inquiry-Based Learning in a Microbiology Laboratory”

November 10, 2005 Microbiology Departmental Seminar, Virginia Tech, “Inquiry-Based Learning in Science”