The Effect of Vocabulary on Introductory Microbiology Instruction

by

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ABSTRACT

This study examines the effect of the translation of traditional scientific vocabulary into plain English, a process referred to as Anglicization, on student learning in the context of introductory microbiology instruction. Data from Anglicized and Classical-vocabulary lab sections were collected. Data included exam scores as well as pre and post-course surveys on reasoning skills, impressions of biology, science and the course, and microbiology knowledge. Students subjected to Anglicized instruction performed significantly better on exams that assessed their abilities to apply and analyze knowledge from the course, and gained similar amounts of knowledge during the course when compared to peers instructed with standard vocabulary. Their performance in upper-level courses was also better than that of their traditionally educated peers. Hypotheses related to the effect are presented and evaluated; implications for instruction are discussed.

ACKNOWLEDGMENTS

This work was made possible through the assistance of many individuals at two institutions. Dr. Anton Lawson, of Arizona State University, was a peerless advisor throughout the process. His insights throughout this study, in accordance with his teaching philosophy, provided me with many questions and few answers. The guided search for understanding that resulted has allowed me to mature as a scientist. His guidance has demonstrated to me quite personally the extraordinary effects that are possible through inquiry-based teaching and learning. The intellectual freedom I was not only permitted, but encouraged to develop as his student is and will remain the most powerful aspect of my graduate education.

Without the assistance of the Biology Department at Illinois Wesleyan University data could not have been generated that would allow for the straightforward evaluation of the major hypotheses, nor would the ability of the treatment to influence student learning across institutions have been tested. The guidance of the members of the department earlier in my academic career, including but not exclusive to such faculty as Dr. William Jaeckle, Dr. Jon Dey, and Dr. Given Harper, has profoundly influenced my ethical, professional, and scientific development.

TABLE OF CONTENTS

LIST OF TABLES

Table Page

LIST OF FIGURES

Chapter 1

INTRODUCTION

Much attention is being given to the growing difficulty of the United States of America in meeting its need for educated citizens. Though considerable time and energy have been spent addressing these issues in a K-12 context, the US may also suffer systemic difficulties related to quality in higher education (Moreno, 1999; Weiss et al, 2003; Organization for Economic and Co-operative Development, 2007). As of 2001, the United States produced 41% of the world's PhDs in the science, technology, engineering and mathematics (STEM) fields, but approximately one third of the students awarded US doctorates in the sciences and engineering are not US citizens (National Research Council, 2007). An insufficient number of citizens who complete Bachelor's degrees in the STEM fields are prepared for graduate study, meaning that universities must take foreign-born graduate students by necessity rather than in the interest of generating diversity within their programs (Ethington & Smart, 1986). Exacerbating this situation, the employment of foreign-born and educated graduate students as teaching assistants has been shown to adversely affect undergraduate education (Borjas, 2000). This can create a cycle wherein US citizens in undergraduate programs remain unprepared for graduate study, resulting in a greater need for foreign graduate students, and so on.

This study seeks to examine and quantitatively assess a method by which instructors in American universities might make their courses more effective and accessible to undergraduate students in order to better prepare them for future professional and educational opportunities. By more effective, it is meant that students should learn and retain more information about the subject, as well as be more able to utilize and analyze this information. By accessible, it is meant that students from diverse ethnic, linguistic, and cultural backgrounds should be able to experience success in the course.

The method under examination utilizes both studied and experimental pedagogical techniques to examine the effect of inquiry-based learning and vocabulary modification on student outcomes in an introductory microbiology laboratory course. The primary goal of the study was to examine the effect of translating science-specific vocabulary terms into plain-English, a process that will henceforth be referred to as Anglicization, on student learning within an introductory microbiology context. In experimental sections of this course microbiology-specific vocabulary derived from the Classical languages was Anglicized whenever possible. The resulting terms were then used for instruction. For examples, please see Table 1 below. A complete list of vocabulary words that underwent Anglicization can be found in Appendix A.

Table 1 *Classical Terms and Anglicized Equivalents*

Classical Science Vocabulary Term	Anglicized Equivalent Vocabulary Term
Halophile	Salt-loving
Media	Bacteria Food
Lipid	Fat
Thermophile	Warmth-loving
Anaerobe	Oxygen-intolerant

As all human experimentation must be guided by ethical principles including beneficence, it was considered both desirous and necessary that those students enrolled in the study benefit personally in some way by their inclusion in the experiment. Accordingly, a new inquiry-based curriculum was developed for the introductory microbiology lab, to be implemented for both experimental and control groups. The previously used curriculum had focused on memorization and rote exercises, whereas the new curriculum focused on student-directed investigation and experimental design.

Inquiry-based learning is a pedagogical method wherein students learn both content and skills through guided, investigative experiences. These experiences are organized around problems or questions that are authentic and relevant to both the specific discipline under study and the students engaged in the course (Hmelo-Silver, 2007). Inquiry-based learning has its origins in the process of scientific inquiry, is most often used in teaching for various disciplines within the sciences, and helps students learn through the construction of evidence-based arguments (Kuhn & Black, 2000; Krajcik & Blumenfeld, 2006). An important aspect of the pedagogical technique relates to this knowledge construction. In inquiry-based courses instructors design a series of stepwise challenges that build on each other through careful curriculum design and coaching, thus creating intellectual scaffolding. By moving up this conceptual scaffold students involved in inquiry-based learning are able to construct knowledge within a personalized context as they gain knowledge and skills (Hmelo-Silver 2006; Mayer 2004; Palincsar 1998). To allow for knowledge construction, students are not provided with all the information relevant to a lesson ahead of time, as might be anticipated in a traditional lecture-format class. Instead, information is provided to students by the instructor as requested or required (Eldelson, 2001).

These characteristics of inquiry-based learning mean that successful utilization of the method requires sensitivity and deep subject proficiency on the part of the instructor. Additionally, learning how to teach in an inquiry-based fashion can be challenging for some individuals. The benefits of inquiry-based learning for students, however, make a clear case for investing time and energy in the method. Inquiry-based learning has been shown to increase students' reasoning skills, improve their understanding of the nature of science, and enhance their abilities related to knowledge retention and application.

Effective measures have been developed to assess students' reasoning skills (Lawson, 1978). Reasoning skills have been shown to be more predictive of success in college-level science courses than prior subject-specific knowledge (Johnson & Lawson, 1998). College students, when tested pre and post-course, make significant reasoning gains after inquiry-based science instruction, but not after traditional instruction (Gotwals & Songer, 2006; Johnson & Lawson, 1998; Lawson & Wollman, 1976). If reasoning skills are more predictive of future success in the sciences, and, as one might imagine, have a broader application to students' future lives regardless of career path, inquiry-based instruction is a preferable method for developing students' habits of mind.

Related to these habits of mind, inquiry-based instruction has been shown to enhance students' understanding of the nature of science. Science is fundamentally a process of inquiry rather than a body of facts. Under traditional science instruction students often develop predictable misconceptions that slant their understanding towards the latter rather than the former. The procedural authenticity of inquiry-based learning can correct this misconception (Schwartz & Lederman, 2003). This superior understanding of the nature of science can also lead students to develop clearer understandings of scientific concepts that are sometimes made into moral issues in the popular culture (Lawson & Worsnop, 1992). For example, in the US only 40% of adults accept evolution as a reasonable explanation for the development of life on earth (Miller et al, 2006). This percentage is significantly lower than all other first world countries, with the exception of Turkey, and typifies the American science literacy problem. Inquiry-based pedagogy facilitates advances in student learning and understanding in ways that are targeted to correct current American weaknesses in science literacy.

Despite evidence for inquiry's role in the development of reasoning skills, understanding of the nature of science and science literacy, there are many educators who fear inquiry-based learning's process-oriented approach will weaken students' grasp of science content. There is experimental evidence to soothe these concerns. Students who participate in inquiry-based learning are better able to apply information they learn in class to new contexts (Dochy & Segars, 2003). Studies done in high school, undergraduate institutions, and medical schools have shown that students subjected to inquiry-based methods retain more information after their education than their traditionally educated peers (Mergendoller & Maxwell, 2006; Hmelo 1998; Normal & Schmidt, 2000). Inquiry-based methods also increase the abilities of students to engage in future self-directed learning experiences (Hmelo & Lin, 2000). Of additional interest, inquiry-based methods of teaching and learning have been seen to reduce achievement gaps in minority students' test scores, as well as increase these students' levels of subject-specific motivation and engagement (Lynch et al, 2005).

Due to the numerous points above, there is a growing push to incorporate inquiry into all levels of the American educational experience (Hickey & Kindfeld, 1999; Hickey and Wolfe, 2000; Lynch et al, 2005). The National Research Council states that

> "Students at all grade levels and in every domain of science should have the opportunity to use scientific inquiry and develop the ability to think and act in ways associated with inquiry, including asking questions, planning and conducting investigations, using appropriate tools and techniques to gather data, thinking critically and logically about relationships between evidence and explanations, constructing and analyzing alternative explanations, and communicating scientific arguments."

(NRC, 1996). The council established recommended K-12 guidelines for inquiry in education in 2000, which have been incorporated into many states' educational standards (NRC, 2000).

At the university level, it is recognized that inquiry-based methods of teaching and learning can serve to bring together the two main goals of many institutions: research and teaching (Healy, 2005; DiCarlo, 2006). The degree of implementation of inquiry-based methods at the university level is varied at this time. However, these methods have been successfully implemented in many medical schools, indicating that undergraduate institutions may now be more likely to incorporate these teaching techniques in order to generate competitive graduates (Hmelo 1998, Normal & Schmidt, 2000).

There is less experimental evidence to support the ability of vocabulary modification to enhance learning gains, but many reasons to expect it might prove effective. For many students a significant stumbling block towards acquiring biology concepts can be the acquisition of the specialized vocabulary of the discipline. Research indicates that students retain information far better when exposed to concepts before they are taught vocabulary words (Lawson, 2003, pp 225-250). An Anglicized introductory course would allow students to be presented information in this format. There is additional experimental evidence at the K-12 level that indicates that students tend simply not to learn or retain scientific vocabulary under traditional methods of instruction (Yaeger, 2009). If this is the case, there is a significant need for experimental approaches related to vocabulary and knowledge acquisition.

There are related background data in the field of mnemonics that suggest the Anglicization approach to microbiology's vocabulary problems may prove effective. In mnemonics, unfamiliar terms are learned in the following manner. A familiar keyword that sounds like the term under study is identified. The keyword is then placed in a pictorial context related to the term under study (Mastropieri & Scruggs, 1951, pp 3-8).

Mnemonic instruction has been shown to greatly increase student retention of information compared to students who studied new terms using self-determined methods (Carney et al, 1998). This method of instruction has also been shown to improve the ability of students to apply the basic knowledge they have learned through mnemonic instruction in order to answer higher-order questions, again relative to students who studied by whatever method they chose (Carney & Levin, 2003). Additionally, mnemonic instruction results in an improved ability to transfer knowledge to new contexts (Dretzke, 1996; Carney, 2000).

Vocabulary Anglicization differs in many obvious ways from mnemonic instruction. However, it can be argued that they rely on the same underlying principle. Both methods seek to relate unfamiliar new words to familiar known words. In vocabulary Anglicization, pictures are not utilized. However, vocabulary terms are completely reduced from unfamiliar to familiar words, potentially eliminating the need for an intermediary step in concept acquisition.

In terms of direct evidence for Anglicization, two studies are worth noting. In Brown and Ryoo's (2000) study the effect of utilizing plain-English vocabulary, as opposed to scientific terminology, was examined in the education of Hispanic-American students who were English Language Learners. The students showed significant learning gains under the experimental treatment as compared to their traditionally educated counterparts. An additional, qualitative treatment in the field of computer science, where faculty attempted a "jargonfree" classroom setting for their first-year students, was also interpreted to have generated relative learning gains (Neeman, 2008).

In criticism of these studies, there are many valid reasons why one might oppose the adoption of a linguistically and culturally two-tiered university system. Additionally and of crucial importance, neither above study addresses the root causes of the observed linguistic-manipulation effect.

In the current study the prediction that vocabulary Anglicization increases student learning will be quantitatively examined in a linguistically diverse population of students. Three hypotheses related to the root cause of the effect will be tested. These hypotheses are non-exclusive; i.e., it is possible that a combination of the hypotheses may explain any change in students' scores.

The first hypothesis is begged by the results of Brown and Ryoo's study (2000). The beneficial effect of an Anglicized vocabulary may be solely related to the English proficiency of the student population. In 1997 approximately 12.7 percent of students entering American universities had limited English proficiency; this number is growing (Rosenthal, 1993).

One of the hurdles students must overcome when initiating the study of microbiology is the large amount of vocabulary they must acquire (ISP Nation, 2001, pp 17-19). Microbiology is a branch of science that originated in the 19th century, when the Classical languages were considered an essential part of a formal education (Roth & Lawless, 2002). However, at this time it has become unusual to come across students in the sciences who have any background in Latin or Greek. Many microbiology terms are quite easily decipherable if one is familiar with the Classical languages, but to one who is not these terms can be mystifying as to both their pronunciation and content. Students who are native English speakers may be able to recognize some common root words, which presumably makes understanding term content easier. Students who are not native English speakers, or native speakers of any Western languages, will not have this presumed advantage (Lee & Fradd, 1996).

If the effect of vocabulary on student learning is purely related to English proficiency, one can predict that students who have native fluency in English would not benefit from the treatment. At the same time, it can be predicted that in diverse populations with students from a variety of language backgrounds the treatment would increase average scores. The student populations to be examined in this study will allow straightforward testing of this English-proficiency hypothesis.

An alternate hypothesis relates not purely to linguistic issues, but to related dynamics of culture and power. Language can be and often has been a tool used not just to communicate, but also to divide (Bartolome, 1998). Language is a tool with very real power to enforce distinctions of class (Diaz-Rico & Weed, 2002). Historically, microbiology terminology arose within an educated class familiar with the Classical languages. The decoding of this vocabulary is still made easier though a deep understanding of Western languages. Such an understanding is more likely to exist in highly educated persons, and access to education is correlated with class (Rist, 2000; Ball et al, 1996). If we desire to offer students an education that embraces diversity we must offer our students a level playing field in the classroom, without a vocabulary that is inherently classist (Finkel & Arney, 1995, pp 85-118).

There is a rich body of literature related to the effects of classroom language on minority students that implies linguistic interventions may be necessary in order to deliver an equitable education to these students (Hodson, 1999; Duran, Dugan & Weffler, 1998). Not only linguistic, but cultural issues related to perceptions of science and science learning affect the success of Asian-American, African-American, and Hispanic-American students (Lee, 1997; Rakow & Bermudez, 1993; Marbach-Ad, 2008). Common issues across traditionally underrepresented groups in the United States relate to perceptions of science as a system of rule-following that serves to create a body of knowledge that is monolithic and exclusive in nature (Wells, 2008). Students tend not to think of science as something that can be done by themselves or persons in their communities (Tobin & McRobbie, 1996).

There is some experimental evidence that the use of plain-English can reduce perceptions of science as an inherently exclusive field (Brown & Spang, 2008; Reveles & Brown, 2008). This evidence supports the cultural-dynamic hypothesis, and suggests that the reason students taught with an Anglicized vocabulary will outperform students taught with a Classical vocabulary is that the Anglicized vocabulary may mitigate repression and feelings of exclusion in the classroom, leading to a more inclusive learning environment.

The cultural-dynamic hypothesis predicts that relatively homogeneous, predominantly white populations would experience mild or no effects from the treatment relative to diverse populations, and that post-course survey measures related to classroom culture would reveal differences between those groups exposed to Anglicized and Classical vocabularies. This prediction does carry the significant assumption held by previous researchers that some racial or cultural populations of students do not find science alienating or exclusive. A recent study indicates that these negative perceptions may be shared by many students across demographic lines, but that they can be changed through positive exposure to science (Gogolin & Swartz, 2006).

A third hypothesis relates to the neurobiology of human beings. Learning and memory formation have a biological basis. When people learn or form memories, linkages develop between neurons in the brain (Carter, 1998, pp 19-21; Kandel, 2006, pp 90-102). These linkages do not occur instantly. Neurons must be repeatedly fired for memories to form; time and repetition are necessary for concepts to root firmly in the long-term memory (Maquire & Frith, 1999). The physical size of neural networks that result from these processes is correlated to the ability of a person to utilize a complex skill set (Schlauge & Jancke, 1995).

One might reasonably expect that students will have pre-existing, well-developed neural networks encoding plain-English words, complete with prior experiences and associations. Conversely, students may not have any prior experiences with words that are part of the specialized vocabulary of microbiology. In some cases the prior associations could be misleading, as with the word “media”. Student may have heard television described as a form of visual media and may think that “media” means a type of art form. In microbiology, “media” refers to bacterial growth media, the types of specialized nutrient sources on which microorganisms can easily be grown in isolation.

If a group of introductory students given an Anglicized treatment were introduced to bacterial “food”, they would be likely to make a number of immediate and correct associations about the substance on hand. If they were given a Classical treatment and introduced to bacterial “media”, it is likely that confusion and misconceptions would result if further instruction was not given. Numerous misconceptions and significant confusion related to microbiology vocabulary have frequently been noted by the author in her traditional microbiology laboratory classes, despite consistent efforts to present traditional vocabulary words in clear, interactive contexts.

If the applied neurobiology hypothesis is accurate students should be able to use their larger and more established neural networks to deal with microbiology concepts under the Anglicized treatment, while students under the Classical treatment will need to build new neural networks to deal with the unfamiliar vocabulary. If one were to give students from each group PET or fMRI scans of the head it would be predicted that more frontal lobe activity would be see in the Anglicized group, as this is where neural networks related to declarative knowledge, including words and concepts, are located (Sousa, 2006, p35-45; Kandel, 2006, p111-113).

However, it is not possible to test that prediction at this time, as the researcher does not have access to medical imaging devices. Additionally, it is uncertain that students would derive any benefit from the testing while potentially incurring the negative effects of radiation exposure. This raises possible ethical issues. Accordingly, for the purposes of this study, information to evaluate the neurobiological hypothesis was gathered based on indirect observations. This necessitated examination of the patterns of behavior and thought exhibited by students. Patterns of behavior and thought correlate with neural activity.

Because the presence of larger neural networks is correlated with the ability to utilize complex skill sets, it is predicted that students exposed to an Anglicized treatment would be able to tap into the large neural networks they have developed for dealing with plain-English words, and thus would be able to work with microbiology concepts in more complex ways. To be clear, it could be predicted that students would be able to engage with concepts at higher Bloom's levels, i.e. would be more successful with application and analysis of concepts.

Performance at different Bloom's levels is readily observed in student populations, and can be identified through careful assessment design. Through a different type of assessment design, a second prediction related to the applied neurobiology hypothesis was tested. This relates to the way the brain processes and stores different types of knowledge.

Since the 1950s, we have had clear evidence that human beings have different physical mechanisms allowing for the encoding and retrieval of declarative and procedural knowledge (Scoville & Milner, 1957; Kandel, 2006, p. 129-131). Declarative knowledge consists of words, ideas, events and concepts, while procedural knowledge is knowledge about how to perform actions (Kandel, 2006, p 129).

Scoville and Milner's (1957) paper provides classic and illustrative evidence of the physical separation of declarative and procedural knowledge. Their work describes a patient known as E.H., who had part of his brain removed in an attempt to treat his epilepsy. Unfortunately, the surgery relieved him of both seizures and the ability to form new declarative memories. E.H. could not learn any new words, and every time he met his psychiatrist he was pleased to make the acquaintance of a new person. However, E.H. could learn new skills. His psychiatrist would, for example, have him engage in "mirror-drawing". Every time she visited him she would ask him to trace a star while looking at his drawing in a mirror. This causes one to see a reversed image of both ones hand and ones picture, and is initially a challenging task for most individuals.

The first time they did this exercise E.H. produced a very wobbly star, but his mirror-drawing skills improved every week. He never remembered that the psychiatrist had visited him last week, nor that she had asked him to draw a star before. Regardless, some intact part of his brain was gaining procedural knowledge related to this specific task (Hills, 1995, p110).

Students learn two types of knowledge in the microbiology lab. They work to understand and communicate about the microbial world, and they acquire and develop technical laboratory skills. Under the applied neurobiology hypothesis, the neural networks related to new words are not stored in the same part of the brain as those related to learning new physical skills. Thus, it would be predicted that the Anglicization treatment would improve performance related to concept analysis and application, but not improve performance related to technical skills.

The English-proficiency and cultural-dynamic hypotheses would not be supported if differential gains are made in declarative and procedural knowledge under the Anglicization treatment. If students are unable to understand the instructor, as in the English-proficiency hypothesis, they should learn tasks as well as concepts more easily in plain-English. If students feel excluded from or incapable in class, as in the cultural-dynamic hypothesis, the inclusive nature of the Anglicization treatment should enhance their experiences and improve their scores in all areas.

The three hypotheses under examination will henceforth be known as the English-proficiency hypothesis, the cultural-dynamic hypothesis, and the applied neurobiology hypothesis. The experimental design that will be used to evaluate these hypotheses follows.

Chapter 2

METHODS

Subjects

127 subjects were involved in this study. Trials of the study were run at two universities: one a large, diverse public institution in the Southwest, the other a small, relatively homogeneous private institution in the Midwest. The student populations involved in the study varied according to the university.

93 subjects were enrolled from the large university. At the large university, course sections involved in the study were populated mostly by students majoring in biology, though some non-majors were included. Students involved in the study at the large university came from a wide variety of backgrounds and represented diverse ages, ethnicities, and cultures. Approximately fifteen percent of students did not speak English as their first or native language. Slightly more than half of students were female. Approximately forty percent of students were non-white. Exact figures are not available as the IRB did not permit tracking of student demographics due to privacy concerns.

44 subjects were enrolled from the small university. At the small university a relatively homogenous population of students was involved in the study. All students were nursing majors between the ages of eighteen and twenty, and all spoke English as their first or native language. All but one of the students in the course were female, and approximately five percent of students were non-white. Exact figures are not available as the IRB did not permit tracking of student demographics due to privacy concerns.

The Course

The introductory microbiology lab utilized for this study is known as MIC206 at the large university and BIO114 at the small university. Class content and duration was identical for both lab courses. The lab met two times a week for ninety minute sessions over the course of a sixteen week semester. Students entering the lab are not expected to have prior training in microbiology, though it is expected they will have taken previous courses in biology and chemistry. While in the lab, students are expected to learn introductory information related to the care, feeding, and habits of microorganisms, and to develop procedural knowledge related to lab techniques.

Design

Both trials at the large university involved four classes, two of which were assigned the control treatment and two the experimental. The trial at the small university involved three classes, two of which were assigned the control treatment and one the experimental. Data were also collected for two traditionally instructed introductory microbiology laboratory classes at the large university. These traditionally instructed groups utilized the same traditional science vocabulary found in Classical vocabulary inquiry-based sections. No groups instructed with the traditional curriculum were subjected to the Anglicized vocabulary due to the experimental nature of the Anglicization treatment. As it was desired that those students participating in the study should be likely to derive at least some benefit from the treatment, and inquiry-based learning has been found to benefit students, the Anglicization treatment was always combined with the inquiry-based treatment.

Control groups were instructed using the inquiry-based curriculum and a traditional, Classical microbiology vocabulary. Experimental groups were instructed using the inquiry-based curriculum and an Anglicized vocabulary. Whenever possible in instruction scientific vocabulary was replaced with plain-English equivalents. For example, halophilic organisms were referred to as “salt-loving” organisms, bacterial growth medium was referred to as “bacteria food”, organisms with aerobic metabolisms were referred to as “oxygen-requiring”, and so on. For complete vocabulary lists, please see Appendix A.

Efforts were made to eliminate variables other than vocabulary between the two sections. One instructor taught all Anglicized and Classical laboratory sections. Guidelines and activities as written in the curriculum were followed as closely as possible given time and materials available. The curriculum is available in Appendix B. The instructor made conscious and critical attempts to treat both experimental and control sections impartially. Students’ instructor evaluations were utilized as a quantitative metric to assess instructor performance in Anglicized vs. Classical sections. Other variables controlled included the day and time of the course and the mean incoming knowledge and reasoning skills of the students.

The traditionally instructed sections were taught by a different teaching assistant than the inquiry-based sections, which were all taught by the author. To ensure quality of instruction for the traditional sections, the sections selected were taught by an experienced teaching assistant. The instructors for the traditional sections and the inquiry sections had both been officially recognized for excellence in teaching by Arizona State University prior to the study. They had both taught the introductory microbiology lab on previous occasions. In terms of additional similarities that might induce variables in student response, both instructors are similarly-aged women of comparable height, appearance, and temperament.

For those readers interested in an overview of hypotheses and resulting predictions related to the experimental design before examining the results of the study, please see Appendix E.

<u>Instruments</u>

Student performance was evaluated using a number of assessments. They will be described in the sections below.

<u>In-Class Exams</u>

Students in Anglicized and Classical sections were given three exams over the course of the semester. Identical exams were given to experimental and control sections. The exams focused on analysis and application of microbiology knowledge and the scientific method, and are available in Appendix C. Scores on three exams were collected from students subjected to Anglicized (n=44) and Classical (n=64) vocabularies during instruction. The exams assessed students' abilities to perform at application and analysis Bloom's levels using knowledge gained in the course. Example exam questions include the following:

-*Why do you think bacteria bother having different metabolic properties? Wouldn't it make more sense to be able to digest everything? Argue why or why not.*

-*When you collect bacteria in the field using nutrient agar and incubate the plates overnight, the bacterial colonies you see the next day may not be representative of bacterial populations in the field. Why is this? Give three potential reasons and explain them clearly.*

-*Everyone has heard about antibiotic resistant bacteria. We know that they can make people sick and are very difficult to kill. However, we know that there are many bacteria in the environment that do not make people sick. Do you think any of these bacteria are antibiotic resistant? Tell me why or why not, and if you do think they are, explain where their antibiotic resistance may have come from.*

These essay questions were all to be answered within a half-page. They were graded based on logical consistency and evidence of accurate understanding of knowledge gained in the course. Students who gave incorrect but logically supported answers based on ignorance of topics that were not covered in the course were able to obtain credit. The exams in their entirety may be found in Appendix C.

Content validity was established by a panel of content experts. As well as the face validity determined by the experts above, the assessments can be seen to possess predictive validity. The results, as will follow, fall in line with theory presented in the introduction, in that those students subjected to Anglicized instruction do perform better at higher Bloom's levels than those receiving Classical instruction. The reliability of the three exams is demonstrated by the similarity in average scores generated, per treatment, by students across trials and institutions.

The maximum score for each exam was 100. Exam scores were entered into a PASW18 database. Anglicized vs. Classical sections' scores were examined with independent-sample t-tests for significance.

<u>Practical Exam</u>

Students in Anglicized (n=44) and Classical (n=65) laboratory sections took one lab practical over the course of the semester. The lab practical assessed technical skills, including Gram staining, isolation streaking, media inoculation, and identification of tests.

Content and face validity were established by a panel of content experts. The reliability of the exam is demonstrated by the similarity in average scores generated, per treatment, by students across trials and institutions.

The maximum score for the lab practical was 100. Scores were entered into a PASW18 database. Anglicized vs. Classical sections' scores were examined with independent-sample t-tests for significance.

<u>Surveys</u>

Students in Anglicized, Classical, and Traditional sections were also given three matched pre and post-course surveys. The surveys examined reasoning skills, microbiology knowledge, and student impressions. Pre and post-course surveys regarding microbiology knowledge and basic reasoning skills were collected on students in Anglicized (n=43), Classical, (n=55) and Traditional (n=19) lab sections. Full copies of knowledge, impressions and reasoning surveys may be found in Appendix D. After data collection, Anglicized and Classical lab sections' scores were compared utilizing unpaired t-tests in PASW18. Classical and Traditional lab sections' scores were compared utilizing unpaired t-tests in PASW18.

Microbiology Knowledge Survey

The knowledge survey has a maximum score of 16. Representative knowledge questions include the following:

-*Gram staining gives you information about an organism's*
a) metabolism/oxygen requirements
b) cell wall/membrane
c) motility
d) ability to cause disease

-*A bacterium consists of*
a) one cell containing ribosomes and a nucleus
b) two cells containing ribosomes and genetic material
c) one cell containing mitochondria and endosomes
d) one cell containing ribosomes

One correct answer could be selected for each knowledge question.

Content validity for this assessment was established by a panel of content experts. Reliability of the instrument was determined through calculation of Cronbach's alpha, with the resulting value of 0.821 indicating sound internal consistency.

Reasoning Skills Survey

The reasoning survey has a maximum score of 8. Representative reasoning questions include the following:

-*You have two cylinders filled to the same level with water. The cylinders are identical in size and shape.*

You have two marbles. They are identical in size and shape. One is made of glass and one is made of steel. The steel marble is much heavier than the glass marble.

When you put the glass marble in the first cylinder, it sinks to the bottom. The water level rises by three units.

If the steel marble is put into the second cylinder, the water will rise

a) to the same level as cylinder 1
b) to a higher level than in cylinder 1
c) to a lower level than in cylinder 1

Please show or explain how you arrived at your answer

If a student exhibited formal reasoning skill, they were given two points for a question. Intermediate reasoning earned one point, whereas answers demonstrating concrete reasoning or below were not awarded points.

Validity of the reasoning survey has been established by previous work (Johnson & Lawson, 1998; Lawson, 1978). The reasoning survey as administered was shortened considerably from Lawson's original design, consisting of only four questions. The validity of a reduced survey was established by Johnson and Lawson (1998). Those questions selected for the purposes of this study assessed reasoning ability in a variety of contexts, such as proportional reasoning and variable isolation. The reliability of the assessment has been determined through calculation of Cronbach's alpha, with the resulting value of 0.839 indicating sound internal consistency.

Pre-Course Impressions Survey

Raw scores for the pre-course impressions survey were generated by adding points for all measures. Measures included statements such as "I enjoy biology", "I remember most of what I learn after tests", and so on. Each measure was assessed on a 1-5 scale with a score of 1 representing "strongly disagree" and a score of 5 representing “strongly agree”. A raw score of 50 was possible on the pre-course impressions survey. Data collected via this assessment were further analyzed to examine differences between culturally significant measures.

Content validity for this assessment was established by a panel of content experts. Reliability of the instrument was determined through calculation of Cronbach’s alpha, with the resulting value of 0.772, indicating sound internal consistency.

Post-Course Impressions Survey

Raw scores for the post-course impressions survey were generated by adding points for all measures. Measures included statements such as “I enjoy biology”, “I remember most of what I learn after tests”, and so on. Each measure was assessed on a 1-5 scale with a score of 1 representing “strongly disagree” and a score of 5 representing “strongly agree”. A raw score of 60 was possible on the post-course impressions survey, which was two questions longer. Due to the difference in total point value between the pre and post-course assessments, data will be presented as percentages of the maximum score to allow for comparison between assessments. Data collected via this assessment were further analyzed to examine differences between culturally significant measures.

Content validity for this assessment was established by a panel of content experts. Reliability of the instrument was determined through calculation of Cronbach’s alpha, with the resulting value of 0.732, indicating sound internal consistency.

Chapter 3

RESULTS

Anglicized Vocabulary Enhances Exam Performance

Scores on three exams were collected from students subjected to Anglicized (total n=44) and Classical (total n=64) vocabularies during instruction. The exams assessed students' abilities to perform at application and analysis Bloom's levels using knowledge gained in the course.

The maximum score for each exam was 100. Scores were analyzed using PASW18. As seen in Figure 2, in all trials mean scores of Anglicized sections exceeded those of Classical sections. When independent-sample t-tests were performed on pooled data, the differences were significant ($p < 0.05$).

Independent-sample t-tests on pooled data for Exam 1 resulted in $t=2.290$, $df=110$, $p=0.024$, and Cohen's $d=0.451$. Independent-sample t-tests on pooled data for Exam 2 resulted in $t=2.353$, $df=108$, $p=0.020$, and Cohen's $d=0.464$. Independent-sample t-tests on pooled data for Exam 3 resulted in $t=1.928$, $df=106$, $p=0.040$, and Cohen's $d=0.392$. Error bars represent standard deviation.

Fig. 1 *Pooled subjects' scores on the three in-class exams.*

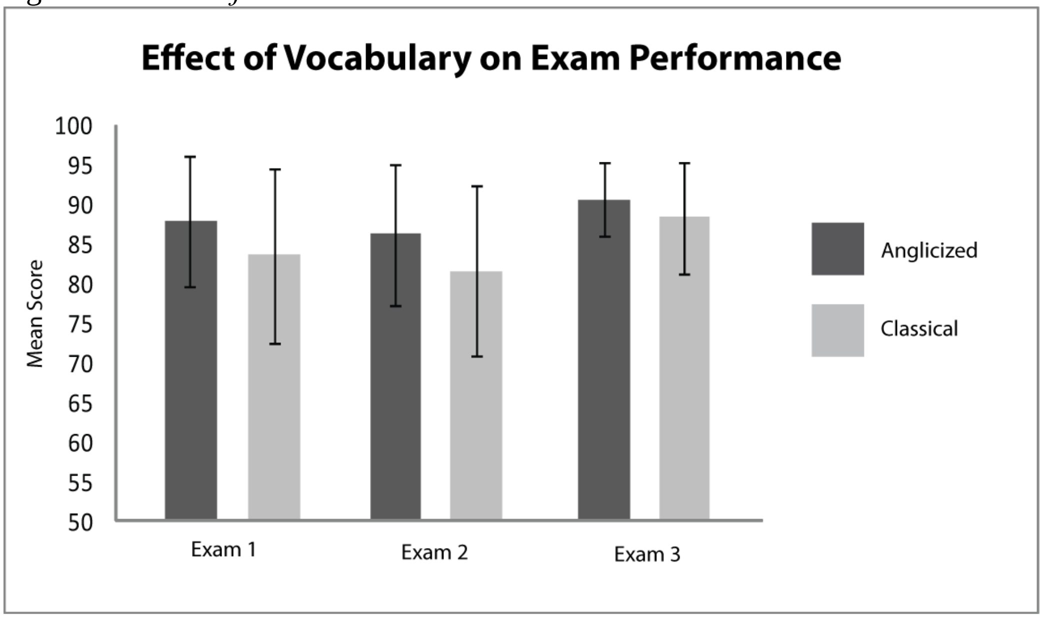
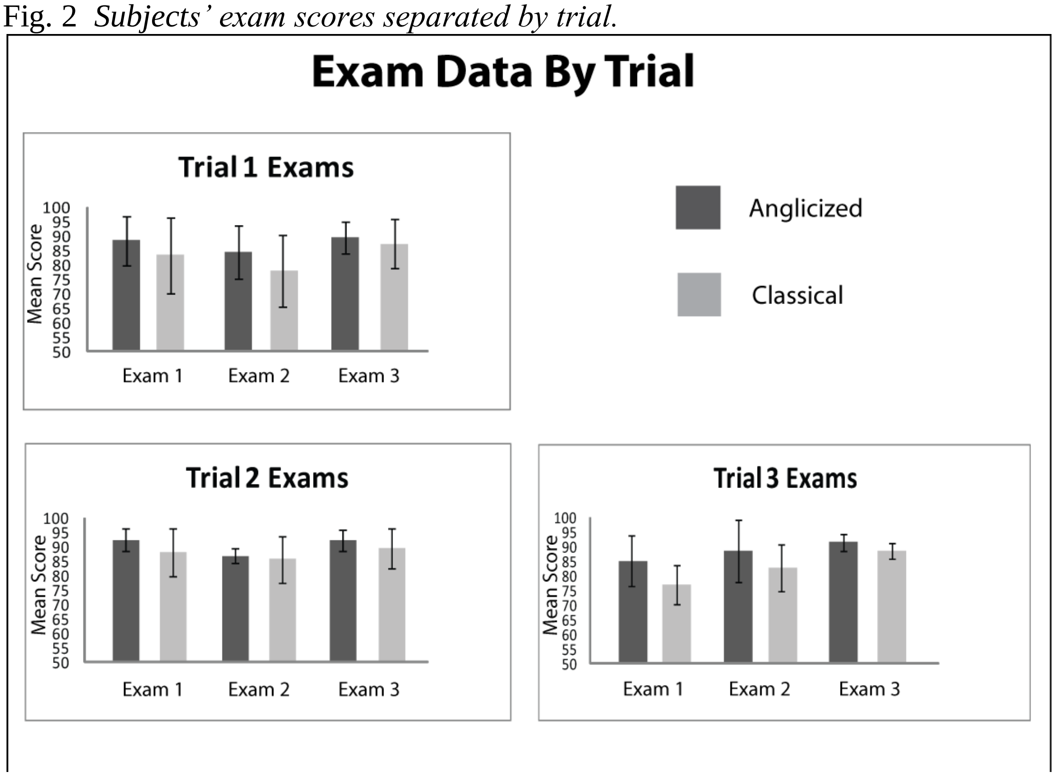


Fig. 2 *Subjects' exam scores separated by trial.*



Pre-Course Assessments Show Similar Microbiology Knowledge and Reasoning Skills

Pre and post-course surveys regarding microbiology knowledge and reasoning skills were collected on students in Anglicized (n=43), Classical, (n=55) and Traditional (n=19) lab sections.

After data collection, Anglicized and Classical lab sections' scores were compared utilizing unpaired t-tests in PASW18. Classical and Traditional lab sections' scores were compared utilizing unpaired t-tests in PASW18.

Differences on exam scores as seen in Figures 1 and 2 cannot be attributed to differences in microbiology knowledge or reasoning skills. Pre-course microbiology knowledge (see Fig 3) and reasoning skill (see Fig 4) scores were similar between Anglicized and Classical sections, and across traditionally instructed groups. One should again note that the microbiology knowledge survey differed from material on exams in that survey items related to awareness of simple facts, whereas exam materials related to problem solving and analysis using information gained in the course.

Independent-sample t-tests on pooled data for the microbiology knowledge survey resulted in $t=0.114$, $df=92$, and $p=0.909$. Independent-sample t-tests on pooled data for the reasoning skills survey resulted in $t= 1.538$, $df=90.866$, and $p=0.128$. Error bars represent standard deviation.

Fig. 3 *Pooled subjects' pre (left side of paired columns) and post (right side of paired columns) course scores on knowledge survey.*

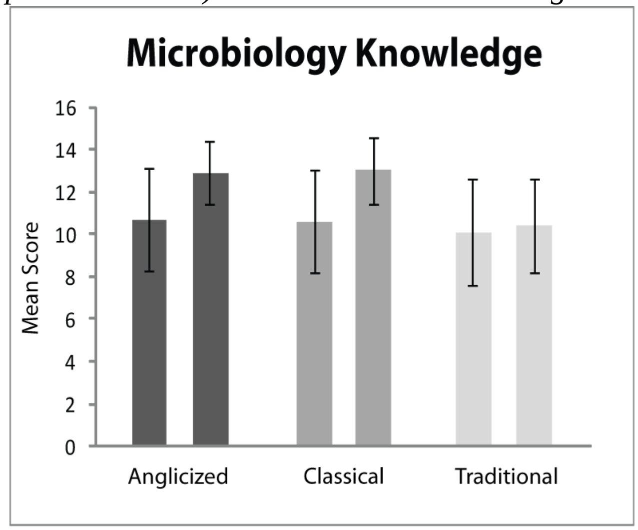
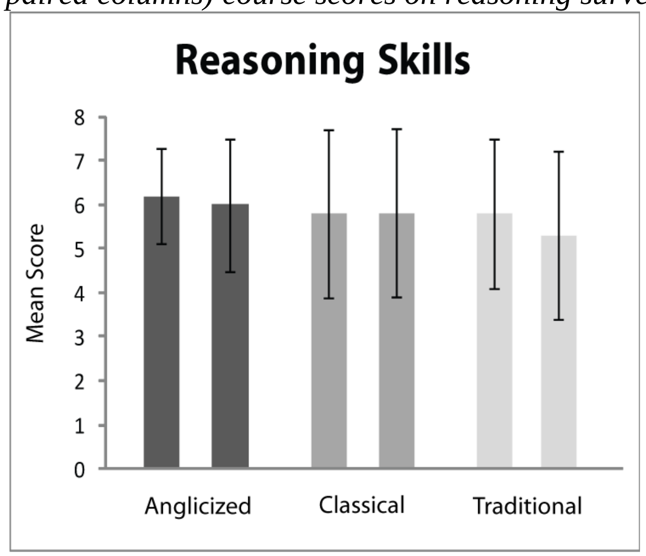


Fig. 4 *Pooled subjects' pre (left side of paired columns) and post (right side of paired columns) course scores on reasoning survey.*



<u>Pre-Course Impressions Show Raw Differences</u>

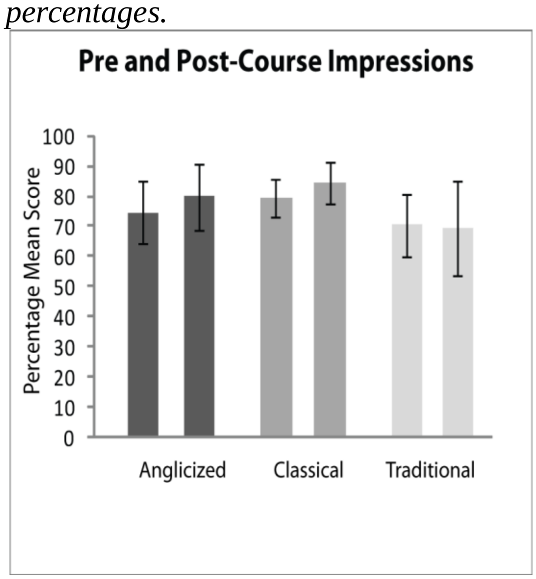
Pre and post-course surveys regarding students' impressions and perceptions of the sciences were collected on students in Anglicized (n=43), Classical, (n=55) and Traditional (n=19) lab sections. A raw score of 50 was possible on the pre-course survey. A raw score of 60 was possible on the post-course survey. Accordingly, in Figure 5, the data are presented as percentages to allow comparison between pre and post-course surveys.

Anglicized and Classical lab sections' scores were compared utilizing unpaired t-tests in PASW18. Classical and Traditional lab sections' scores were compared utilizing unpaired t-tests in PASW18.

Slight but significant differences were present between Anglicized and Classical sections on raw scores from pre-course impression surveys.

Independent-sample t-tests on pooled data for the pre-course impressions resulted in t=2.867, df=99, p=0.005, and Cohen's *d*=0.556. Error bars represent standard deviation.

Fig. 5 *Pooled subjects' pre (left side of paired columns) and post (right side of paired columns) course scores on impressions survey. Scores are presented as percentages.*



Further Examination Clarifies Sample Differences

When examined measure by measure in PASW18, the following significant differences ($p < 0.05$ as determined by independent-samples t-tests) were seen between the Anglicized and Classical lab sections.

No other measures showed significant differences. In all cases, averages of Anglicized and Classical scores differed by less than one point on a five point scale. Differences between the campuses examined do not account for the statistically significant measures.

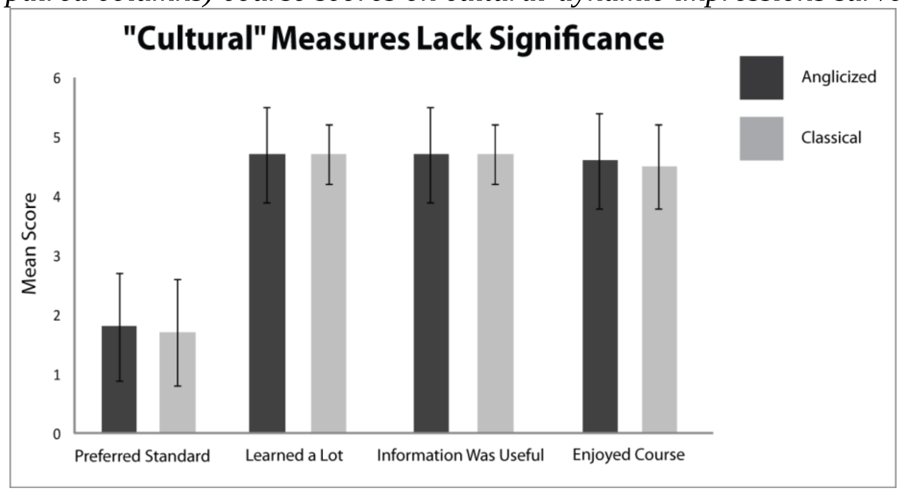
Table 2 *Comparison of significant pre and post-course impressions survey measures.*

Query	Significant Pre-Course	Significant Post-Course
"I find biology interesting/enjoyable."	Yes	Yes
"I plan to take another biology course."	Yes	Yes
"I plan to work in the biological sciences."	Yes	Yes
"I plan to take another science course."	No	Yes
"I remember most of what I learn after tests."	Yes	Yes
"Science applies to my daily life."	No	Yes

No Quantitative Evidence For Classroom-Culture Differences

Further examination of the post-course impression survey, as seen in Figure 6, allows comparison of classroom culture between Anglicized (n=43) and Classical (n=55) sections. Questions include "I would have preferred a standard (non-inquiry) course", "I learned a lot from this course," "This course gave me knowledge I can use", and "I enjoyed this course". No significant differences were found on any of these measures when analyzed in PASW18 using independent-samples t-tests. Error bars represent standard deviation.

Fig. 6 *Pooled subjects' pre (left side of paired columns) and post (right side of paired columns) course scores on cultural-dynamic impressions survey measures.*

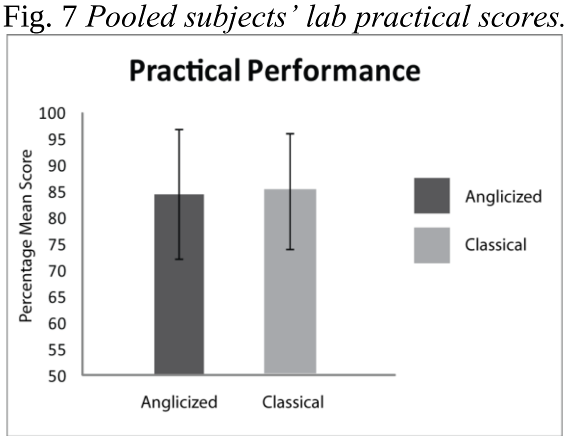


Anglicization Does Not Result in Differential Procedural Knowledge Gains

Average scores on the lab practical were collected from Anglicized (n=44) and Classical (n=64) laboratory sections. Scores have been converted to percentages.

Scores were entered into PASW18 and analyzed with independent-samples t-tests. No significant differences were observed. Error bars represent standard deviation.

Fig. 7 *Pooled subjects' lab practical scores.*

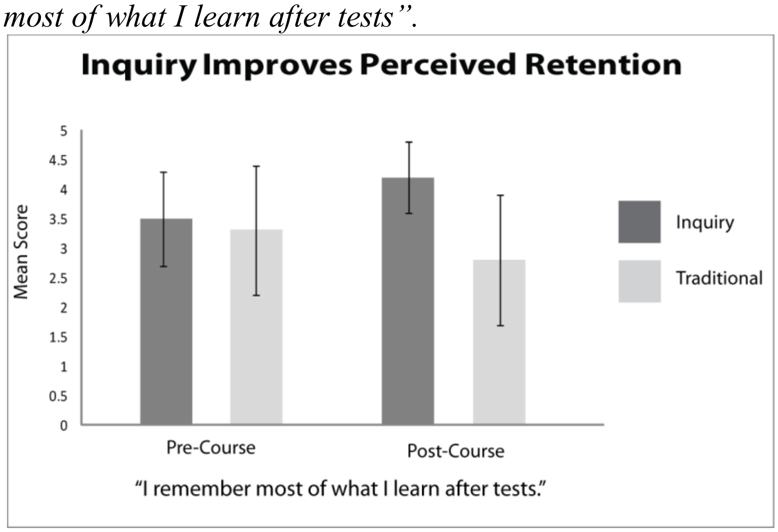


Further Information From Impressions: Inquiry Treatment Increases Perceived Retention

Various measures were significantly different between Classical (n=55) and Traditional (n=19) sections of the course when examined in PASW18 via independent-samples t-tests. All but one of these significantly different measures was significant in both pre and post-course testing. The groups start out answering similarly and slightly positively the query "I remember most of what I learn after tests". These scores diverge significantly over the course of the semester, as can be seen in Figure 8.

Independent-sample t-tests on pooled data for the pre-course query "I remember most of what I learn after tests" resulted in $t=0.842$, $df=57$, and $p=0.403$. Independent-sample t-tests on pooled data for the post-course query "I remember most of what I learn after tests" resulted in $t=5.993$, $df=57$, $p=0.001$, and Cohen's $d=1.65$. Error bars represent standard deviation.

Fig. 8 *Pooled subjects' scores on impressions survey measures "I remember most of what I learn after tests".*

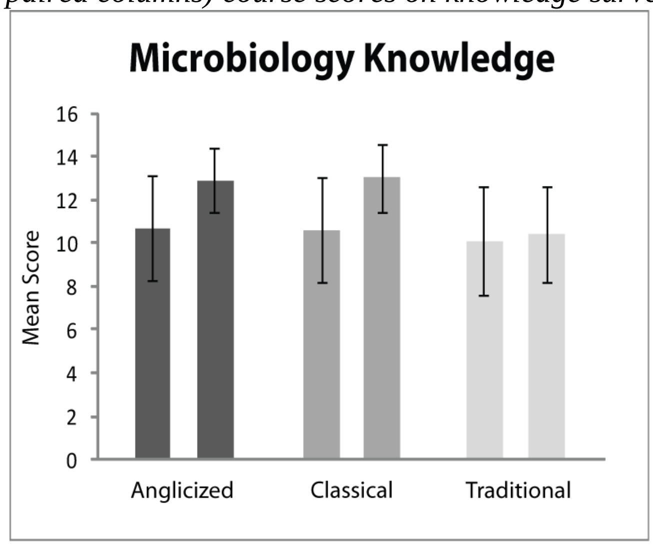


Inquiry Treatment Improves Actual Retention

By returning to Figure 3, it can be seen that students' self-perception of their learning was accurate. Anglicized and Classical sections significantly increased their knowledge scores over the course of the semester, while students in the Traditional sections make no significant gains in knowledge.

Independent-sample t-tests on pooled data for pre-course microbiology knowledge resulted in t=0.868, df=68, and p=0.379. Independent-sample t-tests on pooled data for post-course microbiology knowledge resulted in t=5.006, df=66, p=0.001, and Cohen's *d*=1.36.

Fig. 3 *Pooled subjects' pre (left side of paired columns) and post (right side of paired columns) course scores on knowledge survey.*



Chapter 4

DISCUSSION

The results of this study confirm the prediction that an Anglicized vocabulary treatment would improve students' test scores compared to the use of a traditional, Classical vocabulary. Additional data from pre and post-course surveys indicate that students from both types of lab sections had similar increases in microbiology-related knowledge, meaning that students in Anglicized sections experienced gains related to knowledge application rather than knowledge acquisition.

The three proposed hypotheses for this effect follow:

1. The English-proficiency hypothesis. The use of plain-English vocabulary increases course accessibility for English Language Learners due to the relative familiarity and accessibility of the vocabulary.

2. The cultural-dynamic hypothesis. The use of plain-English vocabulary promotes a more equitable classroom culture, reducing pressures related to perceived exclusivity and inaccessibility of science.

3. The applied neurobiology hypothesis. The use of plain-English vocabulary enhances the utilization of existing neural networks, increasing the physical neurological processing power students can devote to the discipline.

To understand the full meaning of the results it is important to recall what was assessed by the three exams. The exams were designed to assess student's abilities to apply and analyze knowledge. Questions were written at Bloom's levels that built on a knowledge base. Simple matching, fill in the blank, and true/false questions were entirely absent from the exams. All exams were in essay form and required problem solving and experimental design.

In pooled data, Anglicized lab sections had higher averages and smaller standard deviations on all three exams vs. Classical lab sections. Cohen's *d* values for the three exams ranged from 0.39-0.46. This means that the Anglicized treatment caused a shift of almost half a standard deviation on exam scores. In terms of classroom experience, this meant that the exam averages tended to be 5 to 7 points higher, or about half a grade. This is of course interesting, as statistically significant effects do not always translate into changes of meaningful magnitude in the classroom.

Another point of interest lies in the smaller standard deviation seen in Anglicized lab sections vs. Classical lab sections. In terms of real-world experience and actual analysis of numbers, this indicates the reduced rate of failure of students in the Anglicized course.

This study was conducted in part because of frustrations related to the differential failure rates of minority students in the traditional course. Though the collection of demographic information was not authorized by IRB for this study, it can be anecdotally said that failure rates for minority students were significantly reduced in Anglicized course sections. No student has failed an Anglicized course section, whereas about 5% of students fail the Classical section. In the Anglicized course sections the lower-scoring cluster (with grades of C-E) of the course is demographically proportionate to the population of the class, whereas the lower-scoring cluster in the Classical course sections is disproportionally weighted towards minority students.

From this it should not be assumed that the Anglicized treatment is only effective on students from minority groups. A trial of this study was run on a student population that was approximately 95% white. Those students subjected to the Anglicized vocabulary also showed higher averages and lower standard deviations as compared to the Classical controls, with similar effect sizes.

This evidence does not support the English-proficiency hypothesis. If this hypothesis were a reasonable explanation, we would expect the treatment to have a smaller or nonexistent effect in a population consisting entirely of individuals who were native English speakers, such as the students enrolled in the trial at the small private school. This was not the observed. The treatment had an effect of similar magnitude in such a population.

The differential exam performance noted above could have resulted from differences in the student population. Students in the Anglicized sections might have had more microbiology knowledge coming into the course, or perhaps superior reasoning skills. Examination of pre-course measures related to knowledge and reasoning show this is not the case.

When examining Figure 3 one might comment on the contrast between the Anglicized group's higher exam scores and the fact that they appear to gain the same amount of knowledge as the Classical group over the course of the study. Again, one should remember that the exams assess the application and analysis of knowledge, whereas the knowledge survey measures raw knowledge. Similar scores on knowledge surveys and divergent scores on exams are reconcilable. Two individuals may know the same quantity of information, but one individual may be better able to apply the information they know to various situations.

Information from the knowledge survey clarifies the effect of the Anglicization treatment. The treatment is enabling students to better function at higher Bloom's levels. This result supports the applied neurobiology hypothesis.

An additional point of interest in Figure 4 relates to the slight drop in reasoning scores one sees in all sections in the post vs pre-course surveys. The drop is not statistically significant, but may be explained by the conditions under which the surveys were administered. Pre-course surveys were administered near the beginning of class on first day, whereas post-course surveys were administered after the final exam on the last day of class. Students often reported exhaustion after the final exam and were otherwise stressed due to finals week. A number expressed verbally that they "couldn't think anymore" after the final exam. Administering surveys before the final exam may have yielded different results. The decision to administer surveys after the exam was made due to limited contact time with students and the desire that class time be prioritized in favor of students' academic interests above the research interests of the investigator.

While we do not see significant differences between the Anglicized and Classical sections relative to the reasoning and knowledge pre-course surveys, significant differences are seen in raw scores on the impressions surveys. The difference in mean is small, consisting of two points of raw score on both pre and post-course surveys, with the Classical group outscoring the Anglicized group. However, the Cohen's *d* value is 1.65, indicating that an average individual in the Classical group tends to score higher than an averaged individual in the Anglicized group by more than a standard deviation and a half.

Raw data were converted to percentages to allow more meaningful comparison between pre and post-course total impression values. Post-course surveys had an additional two questions, so simple raw-score increases would not necessarily indicate actual increased impressions scores. As can be seen through score-percentage comparison in Figure 5, students' raw positive impressions of the course increase in inquiry-based sections, but do not increase in the traditional course.

Raw impression scores do not show the complex differences that might exist between the groups. By examining the impressions surveys measure by measure the sources of the difference between Anglicized and Classical sections were identified. These differences can be seen in Table 2. The majority of the differences remained the same between the pre and post-course surveys. No survey measures other than those reported in Table 2 showed significant differences between the Anglicized and Classical sections.

The simplest explanation for this information is that more students in the Classical sections happened to be biology majors. Efforts were made to control the student population in all course sections, but many non-biology majors did enroll in the course, potentially with a slightly skewed distribution across sections. Due to IRB requirements related to student privacy, all information that might identify individuals was stripped from the dataset after collection. Because of this it is not possible to examine the data and definitively state whether or not there was an uneven distribution of biology majors, nor is it possible to remove majors from the dataset with any degree of confidence, thus eliminating the potential variable.

The biology major population-level hypothesis could also account for one of the truly divergent measures on the impressions survey between the courses: “Science applies to my daily life”. Both groups experienced gains on this measure from pre to post-course survey. The average score of the Classical group was .4 points higher, on a five point scale, on the post-course survey. Biology majors, having a greater interest in the subject, might be more responsive to the inquiry treatment that was common to both the Anglicized and Classical sections. Biology majors might be more conducive towards thinking of experimentation in biology as a part of their daily lives.

The data presented in Figure 6 is important for the evaluation of the cultural-dynamic hypothesis. If the Anglicized vs. Classical treatment did positively affect power dynamics in the classroom, we would predict that measureable differences would emerge in the classroom cultures of the sections. If effects of cultural repression were mitigated in the Anglicized laboratory sections it could be predicted, for example, that students would find the course more enjoyable.

None of the data collected reveal a divergence in classroom culture between the two sections. The results do not support the cultural-dynamic hypothesis. As an additional consideration, if the second hypothesis were the best explanation for the increase in test scores under the Anglicized treatment, one might expect relatively fewer differences in classroom culture measures in the second trial of the experiment, which was conducted at an institution with a predominantly white student body. When analyzed separately, classroom culture measures in Anglicized and Classical sections at the small university are not significantly different from the classroom culture measures of those sections at the large university.

There is no quantitative evidence for the creation of divergent classroom cultures due to vocabulary through these assessments. However, there were some qualitative differences between the Anglicized and Classical sections that are worth exploring.

An independent observer visited Anglicized and Classical lab sections during instruction, and made the following observations on classroom culture.

> "Observations were made on Anglicized and Classical lab sections during the final month of class. At this time, students were working on final projects and student groups had become cohesive units.
>
> There were no immediate differences between the observed Anglicized and Classical lab sections. All groups observed, regardless of vocabulary treatment, were working co-operatively, appeared to mostly know what they were doing, and had developed interesting final projects. However, after 10-15 minutes of observation, subtle differences in the attitudes of the students emerged.

> Though students in both lab sections were focused and on-task throughout the observational period, students in the Anglicized lab sections seemed more “happily nerdy”. They talked more freely about science and seemed more genuinely enthusiastic about their projects. They communicated freely with the instructor. They were more casual when they requested supplies or information from the instructor.
>
> Students in the Classical lab sections had slightly different attitudes while they worked. They appeared to be somewhat more focused on “being cool” than their counterparts. They were focused and worked efficiently in teams, just as students in Anglicized sections, but their work was more plodding in their approach to their experiments. Classical lab section students gave more of an impression that their work was something they had to do than something they wanted to do. There was less creative thinking in their experimentation, and generally less enthusiasm. Classical lab section students appeared to be preserving a “cool” student identity that was separate from the “nerdy” instructor identity. More students seemed anxious to finish their work so they could leave class early.
>
> Through observation, it was verified that more experimental than descriptive final projects were being produced by the Anglicized group, with the opposite occurring in Classical group.” (Stout, personal correspondence, 12/2010)

As referenced in the above description, another difference between the sections that was not measured by the assessments related to the types of final projects students designed. Students in each class worked in teams of four throughout the semester. The course culminated in a month-long project of the students' design. In Classical sections the majority of groups would engage in final projects that transferred skills they had learned earlier in the semester into a new context. For example, they would gather, isolate, and identify species of organisms in novel environments, such as the skin of Komodo dragons, or they would count the number of organisms that could be found in different environments, such as various bathroom doors around campus. In Anglicized sections the majority of groups engaged in final projects that utilized skills they had learned over the course of the semester to conduct experiments. Their diverse studies looked at the efficacy of different laundry detergents at reducing bacterial loads on fabric, examined the effect of temperature on the production of hard and soft cheeses, tested the effects of different types of music on bacterial growth rates, and so on.

Generally, in an Anglicized section with 8 groups, 5-6 groups would perform experimental and 2-3 would perform descriptive studies. In a Classical section with 8 groups, 2-3 groups would perform experimental and 5-6 would perform descriptive studies.

This observation is particularly interesting in light of the results from the impressions surveys, which indicate that students in the Classical sections were more likely to be biology majors. One might expect that biology majors would be more inclined by training and temperament to engage in experimental projects. From this, it is possible to conclude that the experimental treatment has more effect on what type of studies students perform than the prior training of the population.

Under the English-proficiency and cultural-dynamic hypotheses one would predict that Anglicization would cause gains in both procedural and declarative knowledge, while under the applied neurobiology hypothesis one would predict that only declarative knowledge gains should result. As seen in Figure 7, evidence supports the applied neurobiology hypothesis.

Student results on the lab practical were striking from the classroom perspective. For the typical student, no correlation could be made between individual students' scores on written exams and their performance on the lab practical. Most students had taken lab practicals in other courses, but these exams generally revolved around identifying objects. This course's lab practical, which assessed physical skills and involved one-on-one observation, was considered unusual by many students. The experience caused extreme anxiety in a subset of the population, despite the fact that it accounted for only ten percent of the total grade and, as can be seen, resulted in fairly high average scores.

As many of the students that participate in introductory biology courses will work in laboratory or healthcare settings that require practical, technical skills, it is advisable that more physical practicals be administered to students in the early years of their training. This form of stress inoculation may prove helpful later in students' educational careers.

Before returning to the central question of this study and further consider the evidence regarding the three possible explanations for the Anglicized sections' improved exam scores, it is worth examining a differential effect that was noted when Classical and Traditional lab sections were compared using unpaired samples t-tests. These sections were compared because they had a vocabulary in common, with traditional vs inquiry-based instruction as a variable. Direct comparison of Anglicized and Traditional sections seemed unreasonable due to an excessive number of variables between sections.

As can be seen in Figures 3 and 4, pre-course knowledge and reasoning scores are similar for the Classical and Traditional sections. In Figure 5, they show significant, sizeable differences in raw scores on the impressions surveys both before and after the class. When the impressions surveys were compared measure by measure, it was found that, in general, measures that were significantly different on the pre-course survey remained different in the post-course survey.

Only one measure did not follow this pattern. In response to the statement "I remember most of what I learn after tests", pre-course measures were similar between the Classical and Traditional groups. The groups' responses diverged dramatically in the post-course survey. Students in the traditionally-instructed laboratory experienced a decrease in this measure, changing from slightly positive to slightly negative over the course of the semester. Students in the Classical sections increased their average response by a point, meaning they felt more strongly that they remembered information after testing. Quantitatively, this shift can be noted through the Cohen's *d* value of 1.65, meaning that the student population of the inquiry based sections was shifted over a standard deviation and a half in the direction of positive response to the query. A standard deviation is equivalent to approximately one point in this case.

People do not always have accurate insight into their strengths and weaknesses. To see if students actually remembered information after testing, let us return to an examination of Figure 3. Classical and Traditional lab sections have significantly different scores on the post-course knowledge survey. While the Classical group's knowledge increased by more than twenty percent, the traditionally-instructed students experienced no significant gains in knowledge. The Cohen's *d* value of 1.36 in this instance indicates that the group instructed with inquiry had a post-course knowledge distribution that was shifted more than one standard deviation to the right. The average student in the Classical group can be calculated to possess about 15% more post-course knowledge than the average student in those groups given traditional instruction.

This finding relates to previous research that compares inquiry-based to traditional methods of instruction. Many studies have found that inquiry-based treatments increase knowledge retention (Normal & Schmidt, 2000; Hmelo-Silver, 2007).

As an additional point, one of the concerns committee members expressed during the design of this study involved the possibility that students in the Anglicized lab sections would not gain sufficient knowledge to perform well in upper-level courses. Figure 3 seems to suggest this concern can be laid to rest, as their knowledge gains are comparable to their Classical counterparts.

This significant inquiry-related effect now noted, let us return to the examination and evaluation of our three hypotheses.

Under the English-proficiency hypothesis it was predicted that the treatment would have a smaller or nonexistent effect in a population consisting entirely of individuals who were native English speakers. This did not occur. The treatment had an effect of similar magnitude in such a population. The results do not support the English-proficiency hypothesis.

If we were to find support for the second hypothesis, we would expect to find measurable differences in classroom culture between Anglicized and Classical sections in post-course testing. No measurable differences were found. We might also expect some quantitative differences related to the treatment to emerge between the diverse student population at the large university and relatively homogenous student population at the small university. No quantitative differences that could be attributed to classroom culture were found. Students at the small university had similar pre and post-course scores in knowledge and reasoning, with some differences in the impressions surveys. These differences, as those seen between the Anglicized and Classical sections, can be explained due to differences in the populations' career trajectories. The students at the small university were all nursing majors, and had lower scores on measures related to working in the biological sciences, interest in biology, and so on. No differences in the classroom culture measures were seen.

Some qualitative support for the second hypothesis was found. Subtle differences in classroom culture were described by an outside observer and experienced by the researcher. It is possible assessment tools were not sensitive enough to pick up these subtle differences, especially as students subjected to both Anglicized and Classical treatments were generally enthusiastic about the inquiry-based curriculum and had positive experiences in the course. However, it is just as likely that these qualitative differences could be explained by the third hypothesis as the second.

Anecdotally, the lower-clustering students in Anglicized sections tended to proportionally represent the demographic makeup of the class, whereas the lower-clustering students in the Classical sections were disproportionally weighted towards minority students. Quantitative data related to this measure was not collected due to IRB limitations and student privacy concerns. Future work in a larger classroom setting should be done to examine the demographic-related effects of the Anglicization treatment, so that it can be determined if some groups experience disproportionate benefit. Current data suggest that the treatment is beneficial across demographic lines and is not harmful to students, meaning that IRB approval for this proposed study should be relatively easy to obtain.

The most supported of the three hypotheses relates to the application of findings from neurobiology research. Though, as stated in the introduction, evidence collected in this study can only be related to neurobiology indirectly, there are many aspects of the study that can be used to make a compelling argument for the validity of Anglicization as founded in modern neurobiology.

If students physically had more of their neurons and thus brains involved in the Anglicized course it could be predicted that they would be more capable of application and analysis on exams, as has been seen. They might also design more complex final projects and perhaps be more visibly engaged in the course, as was observed.

One might safely assume that students would have larger neural networks associated with words with which they were familiar than with new words. The physical size of neural networks has been experimentally correlated to the ability of a person to utilize a complex skill set that involves many kinds of knowledge, such as playing an instrument (Schlauge & Jancke, 1995; Ebert & Pantev, 1963). This gives us a simple argument that may explain the increased performance seen in Anglicized section students. There is, however, another point to consider. A student in a Classical lab section might need to construct new neural networks if they were to incorporate new words and concepts into their long-term memory.

Research suggests that this multiplicity of neural networks might have a detrimental effect on problem solving. For example, it has been seen that when a person learns to play a computer game, a task which involves problem solving, a large amount of neural activity occurs. As the player becomes more skilled, neural activity actually decreases (Neubauer & Grabner, 2004). Skills related to problem solving and complex tasks are thought to be related to this phenomenon of neural efficiency. Increases in neural efficiency are correlated to increases in skill. In a person with good neural efficiency for a particular task, fewer neural networks are utilized and less neural activity is observed (Neubauer & Grabner, 2004; Neubauer & Grabner 2005).

Under Anglicization treatment students would utilize neural networks that might be expected to lend themselves to neural efficiency. The networks would include words and concepts they use every day. Students did not need to think much before choosing appropriate words to use in the Anglicized class when they wanted to discuss their ideas, whereas they often took a few moments to consider vocabulary in the Classical sections. This observation is likely an indirect indication of greater neural efficiency occurring in those students subjected to the Anglicized treatment.

Neural efficiency and neural network size are both linked to the ability to skillfully execute complex behaviors involving problem solving. They provide a theoretical, biological framework that can explain the results seen in Anglicized classrooms, where students consistently engage in more complex experimentation and are more able to apply and analyze microbiology knowledge.

Anglicization has now been shown to enhance students' in-class performance related to higher-order thinking skills. Related to this study, limited data have been collected on the grades of Anglicized and Classical group students in their upper level courses. The dataset is too small to be of high quality, with n values of 5 and 8 for Anglicized and Classical sections, respectively. Accordingly, this data should not be considered as statistically significant evident for positive longitudinal effects as a result of the Anglicization treatment.

Regardless of issues with sample size, the data are pertinent to this discussion and will be presented below. Grades are shown on ASU's 4 point scale. As predicted by breakdown of impressions data, slightly more follow-up data were available for Classical sections. These sections do appear to have contained more biology majors.

Table 3 *Anglicized students achieve higher grades in future courses*

Course	Anglicized Average Grade	Classical Average Grade
MIC 314: HIV: Biology & Society	4.00 (range, 4.00-4.00)	2.89 (range, 2.00-4.00)
MIC 360: Bacterial Physiology	3.56 (range, 3.00-4.00)	3.07 (range, 2.00-4.00)

The data suggest that the Anglicized treatment improves retention. In retention, the information under consideration moves from the immediate memory to the working memory, and then is incorporated into long-term memory. Not everything that we process in our working memory goes into long-term storage. For example, when a person goes shopping they often make a mental list of groceries to buy. Most people can then be trusted to buy all the groceries, but if one were to ask a person what they had purchased a week afterwards they would probably not be able to recall many specifics. Their mental list was a part of their working memory, but its contents did not make it into long-term storage. Most educators will agree that students do not always retain information from their previous courses.

Two known factors that contribute to information entering long-term storage are meaning and sensibility (Maquire & Frith, 1999). By meaning, it is meant that people are more likely to retain information that has personal relevance to their goals or interests. By sensibility, it is meant that people are more likely to retain information that they are able to reconcile with their experience or prior knowledge.

We have seen in the results of this study that both sections exposed to the inquiry-based treatment retained more knowledge than the traditionally instructed sections. The above neurobiological findings likely relate directly to this phenomenon, providing a theoretical basis for this and other experimental findings that support inquiry's ability to boost retention. In inquiry-based teaching and learning students process information in an individualized context, where they derive ownership of their ideas. By increasing the relative depth of their learning, the meaning this information has to them should increase (Crake & Tulving, 1975). Of meaning and sensibility, meaning is thought to be the more important factor in whether or not information is selected by the brain for retention. (Sousa, 2006, p47-49)

Anglicized vocabulary is likely to increase the sensibility of microbiology knowledge to students. We would expect this to lead to greater knowledge retention in students from Anglicized sections as compared to Classical sections. This is seen in the limited data available.

We can theorize that Anglicization provides the observed benefits of increased abilities at higher Bloom's levels and increased knowledge retention because of its utilization of extant neural networks and the resulting increase of neurological efficiency, as well as the way in which the method increases the sensibility of material. However, there are some aspects of microbiology education that Anglicization cannot improve. The types of knowledge gains seen in this study relate to declarative knowledge. Gaining declarative knowledge involves gaining knowledge of concepts, such as developing an understanding of bacterial physiology. This is separate from procedural knowledge. Procedural knowledge relates to our knowledge of how to perform different activities, such as a Gram stain. Neurobiology has developed a body of evidence that suggests declarative and procedural knowledge are stored differently in the brain (Squire, 2004; Kesner 2002, p 27). Such evidence includes the phenomenon that individuals with dementia may forget the word “bicycle”, but recall how to ride one (Rose, 1993, p 119-120).

Further evidence for separate mechanisms related to declarative and procedural knowledge was obtained during this study. While students consistently experienced increased exam scores in the Anglicized sections, there was no significant difference in their performance on the lab practical. The lab practical examined the ability of students to successfully perform technical skills taught during the course, such as Gram staining, isolation streaking, microscopy, and test inoculation. There was no correlation between the exam grades of individuals and their scores on the practical. Students who scored in the upper quartile on exams would not infrequently score in the lower quartile on the practical, and vice-versa.

While there is clear evidence that Anglicization increases retention and processing of declarative knowledge, it does not appear to have an effect on the efficacy of procedural knowledge acquisition. We should not predict that it would, as the brain processes information related to language through different anatomical structures than information related to physical skills. Information related to language is stored in the frontal lobes and processed by the pre-frontal context with the help of the basal ganglia. Information related to physical skills is processed by the motor cortex, with regulation and potential storage of higher level skills occurring in the cerebellum (Sousa, 2006, p 35-45; Schumann 2004, p 43-44, p 79).

Different techniques will need to be developed to increase efficacy of procedural knowledge processing. Current evidence and experience suggest physical repetition is the key component to learning any procedural skill. Considering the increased interest in online lab courses, it will be interesting to see if methods other than physical practice can be developed to ensure graduates of online colleges gain practical, technical skills.

The results of this study related to Anglicization apply to students being introduced to a new discipline in biology. Individuals who have achieved mastery in a scientific discipline are not hampered by the specialized vocabulary of their discipline. They may find that this vocabulary gives them clear and simple tools with which to communicate with others in their field, and they will use the specialized vocabulary with ease when describing their ideas. The neural networks in which they encode their specialized terms have achieved neural efficiency. There is no doubt that an education with a Classical vocabulary has led to success for many individuals, or that with time and practice many students can achieve neural efficiency through traditional means. However, it seems possible that more students might be able to reach mastery of a scientific field if taught with an Anglicized vocabulary. With loss-rates of undergraduate students in biology remaining as high as fifty percent, novel but tested methods such as

Anglicization may be interesting to departments that seek to increase retention (Seymore, 2001). Anglicization's concept-first approach may enhance the ability of students to bind the specialized vocabulary they will eventually learn into existing, already-efficient neural networks.

Chapter 5

CONCLUSION

From the data collected it can be concluded that the use of an Anglicized vocabulary provides both short term and long term benefits to students. This teaching technique enhances the ability of students to utilize higher order thinking skills as classified by Bloom and, though current evidence is limited, appears to improve their grades in future courses. The treatment also appears to reduce demographically differential failure rates.

Future studies utilizing Anglicization should be conducted in a general biology context. The potential for long term student gain in such a context is compelling. Future studies should also be designed in order to more closely examine potential differential effects of the treatment along ethnic or cultural lines.

This study also serves to confirm previous research that inquiry-based treatments improve student knowledge retention. A future study involving the isolation of the effects of Anglicization and inquiry treatments in order to examine their proportional contributions to knowledge retention should be conducted. Now that it has been demonstrated that Anglicization does not cause academic harm to students, it can be ethically combined with a traditional curriculum with the expectation that students should receive some degree of direct benefit from the study. In such a study, it is predicted that inquiry treatments would have a greater retention-related benefit. However, it is also acknowledged that successful inquiry-based teaching can be very difficult for some educators and requires curriculum development. If Anglicization alone results in some retention-related benefits, it might prove an easier and more cost-effective change for departments to implement in their introductory courses.

Though many positive findings were made through this study, the lack of evidence for the ability of Anglicization to harm students should be considered most important. Legitimate concerns related to potential short or long term harm of students were raised prior to the beginning of this study. No evidence has been produced that Anglicization causes any harm to students through quantitative or qualitative analysis.

Because of this complete lack of harm, it is recommended in conclusion that Anglicization be utilized in introductory microbiology contexts, and it is reasonable to consider that it would be safe to utilize in other disciplines of biology. The technique is not as easy to use as one might think, as undergraduate instructors tend to have been successful in assimilating traditional science vocabulary. There is a strong tendency to naturally utilize those words that are most personally descriptive and effective. However, attempting the technique has no financial cost, is low-risk, and can potentially give significant short and long term benefits to our students.

Anglicization is recommended for use both in courses for biology majors and non-majors. From the data it appears that majors students do not have difficulty acquiring the relevant vocabulary when they are exposed to it in their upper-level courses. Non-majors students may not take further science courses. However, when considering the needs of an educated non-scientist, greater lasting utility may be obtained by learning how to use science and scientific thinking than by remembering particular vocabulary words. A goal of science instruction should be to deliver an understanding of science as a method of thinking and acting rather than as a monolithic body of knowledge. If a student will be exposed to biology only once in their undergraduate career, that educational opportunity can best be used to develop skills related to application, analysis, and problem solving.

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APPENDIX A

COMPLETE ALTERED VOCABULARY LISTS

The information presented in this section is distributed throughout Appendix B, but is presented clearly and entirely here. Some words were kept the same between sections, such as the names of unique bacterial structures like flagella, as it was assumed no common equivalents could be found in students' previous experience. Names of reagents were kept the same between sections to avoid safety concerns. Names of components of the scientific method, such as prediction, hypothesis, and protocol, were also kept the same between sections as it was assumed students would have prior knowledge of these terms, though their content and application was reviewed in both sections.

Vocabulary words and their Anglicized equivalents are presented below. As can be seen, relatively few words were changed in the Anglicized treatment. The profound effects of the treatment were unexpected, and certainly demonstrated the potential power of minor modifications. Both Anglicized and Classical groups were presented with identical, accurate definitions for the relevant terms below.

Classical Vocabulary	Anglicized Vocabulary
Inoculate	Put

Let's inoculate this plate with bacteria./ Let's put these bacteria on the plate.

Media	Food

Let's pour some fresh media for the bacteria./ Let's make some fresh food for our bacteria.

Psychrophile	Cold-loving

The organisms that live in Antarctica are psychrophiles./The organisms that live in Antarctica are cold-loving.

Psychrotroph	Can grow in the cold

The organisms that show up in your fridge on your food are psychtrophs./ The organisms that show up in your fridge on your food can grow in the cold.

Mesophile	Warm-loving

Bacteria we find on our bodies are often mesophiles./ Bacteria we find on our bodies are often warm-loving.

Thermophile	Heat-loving

Bacteria that live in the middle of compost piles are often thermophiles./ Bacterial that live in the middle of compost piles are often heat-loving.

Extreme thermophile	Really heat-loving

Bacteria that live in hot springs are extreme thermophiles!/ Bacteria that live in hot springs are really heat-loving!

Anaerobe Oxygen-intolerant
Strict anaerobes won't grow on this media./ Strict oxygen-intolerant organisms won't grow on this food.

Aerobe Oxygen-loving
Aerobes need oxygen to grow./ Oxygen-loving organisms need oxygen to grow.

Facultative Oyxgen-tolerant
Facultative organisms can live with or without oxygen./ Oxygen-tolerant organisms can live with or without oxygen.

Halophile Salt-loving
Halophiles need to live in specialized habitats, like the Dead Sea./ Salt-loving organisms need to live in specialized habitats, like the Dead Sea.

Halotolerant Salt-tolerant
Halotolerant organisms can survive in places like pickle jars./ Salt-tolerant organisms can survive in places like pickle jars.

Alkalophile Basic pH loving
Alkalophiles will cause a reaction in this media./ Organisms that love a basic pH will cause a reaction in this food.

Alkalotolerant Basic pH tolerant
Alkalotolerant organisms can handle environments where the pH rises./ Organisms that can tolerate a basic pH can handle environments where the pH rises.

Acidophile Acid-loving
Acidophiles include organisms like <u>H. pylori</u>, which can live in the stomach./ Acid-loving organisms include organisms like <u>H. pylori</u>, which can live in the stomach.

Acidotolerant Acid-tolerant
Acidotolerant organisms can handle environments where the pH sometimes drops./ Organisms that are acid-tolerant can handle environments where the pH sometimes drops.

Neutrophile Neutral pH loving
Neutrophiles like to live in everyday environments./ Organisms that love neutral pHs like to live in everyday environments.

Barophile Pressure-loving

At the bottom of the sea, you can find specialized barophilic organisms./ At the bottom of the sea, you can find specialized pressure-loving organisms.

Barotolerant	Pressure-tolerant

Barotolerant organisms might have unusual cell-membrane structures./ Pressure-tolerant organisms might have unusual cell-membrane structures.

Metabolism	Digestion

We're going to use this media to see if our bacteria metabolize lactose./ We're going to use this food to see if our bacteria can digest lactose.

Lipid	Fat

This media is cloudy because it is full of lipids. If it clears, the organisms can metabolize lipids./ This food is cloudy because it is full of fats. If it clears, the organisms can digest the fat.

Carbohydrate	Sugar or starch as appropriate

This series of tests will examine carbohydrate metabolism./ This series of tests will examine what type of sugars our bacteria can digest.

Colony Forming Unit	One growing bacteria

Dilution series allow us to determine the concentration of colony forming units in a solution./ Dilution series allow us to determine the concentration of individual, growing bacteria in a solution.

APPENDIX B

INQUIRY-BASED INTRODUCTORY MICROBIOLOGY LAB CURRICULUM

Course Goals: Introductory Microbiology: A Problem-Based Curriculum

A sample Curriculum for 16 Week Course, meeting 2X week, arranged in four 4-week units. Students will work in fixed teams of 4.

Declarative knowledge students should gain during this course:

-eukaryotic vs prokaryotic life

-the mechanics of unicellular life

-eating: metabolism (how do you eat without a mouth? use of various compounds by bacteria. contents of various media. use of metabolic tests.)

-growing: physiology (what does a bacterium's body look like? capsules, flagella, cell wall structure, etc. use of various stains.)

-location: understanding of microbial life based in microbial ecology

Procedural knowledge students should gain during this course:

-lab safety

-sterile technique

-dilution techniques

-quadrant streaking

-isolation techniques

-how to read a protocol

Application and analysis skills students should gain during this course:

-how to identify unknown organisms via use of isolation, physiological and metabolic study

-how to classify organisms

-how to utilize scientific thinking to ask and answer questions using skills and knowledge gained in the course

-*Grading breakdown: 50% written examinations, 40% lab reports, 10% effort and improvement.*

Introductory Microbiology: Student Syllabus

-It is essential that you come to class every day! Your team will be depending on you, and it will not be possible to make up work.

-If you are unable to attend class you must give me a valid doctor's note.

-Grades in this course are based 10% on participation, 50% on the three written tests, and 40% on lab reports

Course Outline

Chunk 1: Where to live, what to eat, how to look

Day One Theme: Using Hand Tools
Day Two Theme: Using Brain Tools
Day Three Theme: Trap Your Microbes
Day Four Theme: The World is Gross! Isolating your Favorite Microbe
Day Five Theme: Making Trees
Day Six Theme: What do Microbes Eat?
Day Seven Theme: A Physiological Mystery
Day Eight: Assessment One
Day Nine Theme: What else Can they Come up With?
Days Ten-Thirteen Theme: Discovering Structures
Day Fourteen Theme: What do we Know now?
Day Fifteen: Technique Olympiad
Day Sixteen: Midterm Assessment

Chunk 2: Guided major projects

Days 1-4, First Mini-Freedom: Helpful Bacteria
Days 5-8, Second Mini-Freedom: Harmful Bacteria. Helpful Bacteria lab report due Day 5!

Chunk 3: Armed for Exploration

Day 1: Harmful Bacteria lab report due!
Days 1-7, Into the Wild: An Exercise in Exploration
Day 8: Final assessment. Into the Wild lab report due.

<u>Chunk 1: Where to live, what to eat, how to look</u>

Day One Theme: Using Hand Tools

Day 1:

Learning Goals: Exploring tools for microbiology. Developing technical skill. Learning about lab safety.

Vocabulary Words: Loop, needle, striker, agar, media

Supplies Needed: Students will need access to individual loops and inoculating needles. They will need group access to strikers and supplies needed to make nutrient agar.

General Class Structure: Hand out syllabus, then allow students to examine their tools. Have them handle them, and come up with ideas for what they could be used for.

This constitutes the Exploration Phase of Technical and Safety Skills Learning Cycle.

Bring up the notion that there are several branches of skills we need for success in the sciences. We need to know background knowledge, we need to know how to think scientifically, and we need technical skill. Tell students that we will use this course to develop all three of these skills.

Address student ideas as to how the tools could be used. Praise creative, logical explanations. Then, give a tutorial as to how to use a striker, and how to sterilize the instruments. Have students tell you why sterilizing the instruments is important. Show students where alcohol and safety stations are. Talk with students about why cleanliness and sterility are important. Talk about aseptic technique.

This constitutes the Term Introduction Phase of Technical and Safety Skills Learning Cycle.

In the last twenty minutes of class, have students follow recipes by group to make media. Autoclave this and put it in a hot waterbath to stay liquid for the next class period. If that will be a while, pour the plates yourself to make stock and prepare fresh uncooled media before the next class for the students to use.

Notes on Teaching Procedure: While handing out syllabus, ask students to fill out index cards with their name, year, and how they hope to apply the knowledge they will gain in this course. Collect these cards and utilize information gathered to guide connections you will point out between the course and real life situations.

Do what you can to make the classroom environment positive and interactive. Give students sufficient wait time before answering questions. Validate student responses whenever possible. Stress with students the vital importance of maintaining safe lab practices in the microbiology laboratory. Warn students about the dangers of having long, unrestrained hair or acrylic nails. Lab safety is often successfully highlighted by stories of lab accidents the instructor has caused or experienced.

To some, this day may seem unnecessary. However, we must remember that no one is born knowing how to use any particular tools. In upper level microbiology courses bad and dangerous techniques are often seen. Many students can be observed demonstrating techniques that do not adequately sterilize their instruments, and large numbers of students are unable to successfully use a striker. Also, students are not born knowing how to be safe in a lab or what the realistic consequences of unsafe behavior may be. By talking to them like responsible adults and illustrating requirements with examples of things that can go wrong, respect for laboratory safety can be instilled in the group. As the instructor, it is very important to consistently demonstrate and practice good lab safety yourself.

Learning Cycles: Exploration and Term Introduction, Technical & Safety Skills.

Day Two Theme: Using Brain Tools

Day 2:

Learning Goals: Understanding the scientific process. Developing technical skill in the making of media.

Vocabulary Words: Hypothesis, prediction, theory, result, conclusion, media, inoculate

Supplies Needed: Liquid media from the previous period. Petri dishes. Water bath. Thermometer. Science case studies.

General Class Structure: Have student pour their plates. First, do a few yourself at each table to demonstrate proper technique and show how much media should go in one plate.

This constitutes further Term Introduction and Application of Technical and Safety Skills

Point out how the media solidifies. The media was liquid in the water bath. What happens if the solid media is put back in the water bath? Be sure to test both agar and gelatin containing media. Now students have a puzzling observation. Ask students to come up with ideas in their groups to explain the strange behavior of the media.

This Constitutes Exploration of Scientific Thinking

Have a discussion with the whole class about their ideas. Introduce the vocabulary word hypothesis. Apply it to ideas the class has developed. Then ask the class what they think will happen in different situations if their ideas/hypotheses are correct. After collecting some of these ideas, introduce the vocabulary word prediction. Talk with the students about the difference between hypotheses and predictions.

This Constitutes Term Introduction of Scientific Thinking

Allow the students to carry out some of their ideas. Then have them tell the group what happened. Introduce the vocabulary word results. Did the results support their hypothesis or not? Then ask the student why they thought the results occurred. Introduce the vocabulary word conclusion.

Have the class take a step back from their agar exercise and consider the differences between hypotheses and theories. Ask them to name any theories they are familiar with. After developing these ideas, ask the group what kind of a theory could explain the behavior of the media they have been observing.

This Constitutes Concept Application of Scientific Thinking

After this, give each group a case study of an important incident in microbiology. Have students identify the hypotheses, predictions, results, and conclusions. Have students share and discuss their thoughts with the class.

Notes on Teaching Procedure: Be sure to give students enough time to talk during class discussions. It is more important that they talk than that you talk!

Try to ask students thoughtful questions instead of giving them thoughtful answers.

Learning Cycles: Term Introduction and Concept Application, Technical and Safety Skills. Exploration, Term Introduction, and Concept Application, Scientific Thinking.

Day 3 Theme: Trap Your Microbes

Day 3:

Learning Goals: Uncovering the diversity of microbial life.
Vocabulary Words: Protocol.
Supplies Needed: Plates students poured previously.

General Class Structure: Send students out to collect bacteria from the environment from places they find interesting.

This Constitutes Concept Application of Technical and Safety Skills

Before you let them go, have them make hypotheses and predictions about what they will find and where they will find it as groups. Then have the groups share these hypotheses and predictions with the class.

This Constitutes Application of Scientific Thinking

Ask students how they will test these hypotheses and predictions. What kind of plan will they have? Introduce vocabulary word protocol. A protocol gives a scientist a very practical plan. Have students write down protocols for how they will do their collecting. Then set them free. Remind them to come back at the end of the period to incubate their plates for next time!

This Constitutes further Term Introduction for Scientific Thinking. The Data Collection process initiates Exploration for Ecology, Metabolism, and Physiology.

Notes on Teaching Procedure: Do your very best not to influence students' hypotheses, predictions, or protocols. Allow them to explore and own their ideas. At this point, student groups should be starting to cohere. Try to spend time with each group every day to make sure the group is behaving functionally and all members are participating. If necessary, this is a good time to break up and reorganize any really dysfunctional groups. Ideally, balance groups to increase in-group diversity.

Learning Cycle Stages: Application, Technical and Safety Skills. Term Introduction and Application, Scientific Thinking. Collection lab initiates exploration for Learning Cycle 1: Ecology, Learning Cycle 2: Metabolism, and Learning Cycle 3: Physiology

Day Four Theme: The World is Gross! Find your Favorite Microbes

Day Four:

Learning Goals: Understanding how isolated colonies form, the many ecological niches of bacteria, introduction to the metabolic properties of bacteria.

Vocabulary Words: cfu, cryophile, mesophile, thermophile, halophile, metabolism, lipids, carbohydrates, proteins.

Supplies Needed: Loops for quadrant streaking. Needles for inoculation. Nutrient agar plates for quadrant streaking. Nutrient agar slants for pure culture storage. Bunsen burners.

General Class Structure: Examination of resulting organisms. Discussion. Point out puzzling phenomenon. Did different media do different things (color change) or pick up different looking colonies? Why do students think that happened? Discuss the concept of cfus. Introduce isolation techniques.

This process involves initiation of further Exploration and Term Introduction portions of Technical and Safety Skills.

Have each individual student pick a microbial colony they like best. Recommend pigmented, small, round colonies. These usually end up being relatively easy to identify.

In describing the colonies, initiate Term Introduction for Metabolism and Ecology.

Go around and make sure students aren't picking fungi. Have them use this microbe to practice isolation techniques.

Notes on Teaching Procedure:

-Results can be expected to show that a wide variety of bacteria can be found more or less anywhere on more or less everything, but let students state this conclusion. Also encourage students to think of what kinds of organisms they might have missed while sampling. Ask them to come up with environments that might be inhabited by species adapted to various niches. Write down a list of potential niches, and adaptations that might suit each, according to speculations supplied from the class. This should help students begin to grasp the extraordinary diversity of microbial life. If necessary, prompt students to think about oxygen requirements and bacterial life, as this may not come up in discussion. After creating a list of niches, introduce applicable microbiology terms that describe in scientific language the concepts covered.

-When looking at media that changes color, ask students to come up with hypotheses that could explain the changes. If necessary, prompt students to think about metabolism. Have students list potential metabolic properties of bacteria. Afterwards, apply relevant science terms to student created descriptors.

-Ask the class why they think various colonies have different physical appearances. Ask how many bacteria it takes to generate a colony. At this point, begin a clear discussion of the concept of cfus. From the ecological samples they collected, have students pick favorite colonies. Discuss how pure cultures of bacteria might be obtained, considering that only one cfu is needed to start a colony. Hopefully, students will come up with the notions of streaking and diluting, among other hypotheses. Prompt if not. Then, introduce formal technique protocols. At this point, it is a good idea to point out that protocols, and techniques, are generally not so much things that must be done by rote, but arts that every person must develop for themselves. If time allows, have the students work together to figure out how to use a dilution series to determine the number of cfus present in a colony. This is a simple yet highly informative exercise.

-The concept of developing technical art, and taking personal responsibility for improvement of technique to find a synthesis between personal style and optimal results, is essential. All students who will in the future perform jobs that involve technical skills should be able to find value in exploration and examination of this concept.

<u>Learning Cycle Stages</u>: Discussion of Collection Lab initiates Term Introduction for Learning Cycle 1: Ecology, and Learning Cycle 2: Metabolism.

Day Five Theme: Making Trees

Day Five:

Learning Goals: Understanding of the purpose of taxonomy. Doing taxonomy. Understanding of taxonomy, and other branches of science, as processes rather than absolutes.
Vocabulary Words: Clade, phylogeny, taxonomy, taxonomic key, taxonomic tree, primitive, derived.
Supplies Needed: Bergey's Manuals. Large sheets of paper, colorful markers.
General Class Structure: Discussion isolation results. Have students look at each others' isolates. What characteristics do they have? Have each student write on the board five characteristics about their bacterial colony. Have the class work together to try and organize everybody's bacteria according to a rational classification system. Each group can work to make their own system, and then the class can get together and compare these. The opportunity for discussion should allow the development of new ideas and help students decide what qualities are significant enough to merit inclusion at different levels of the system.

This Constitutes Exploration for Classifying Microorganisms

After this discussion, introduce formal vocabulary related to taxonomy. Students are making their systems based on physical properties. What other types of properties could they use?

This Constitutes Term Introduction for Classifying Microorganisms.

Notes on Teaching Procedure: Most students have some experience with classification, even if it is not formal. Humans love classifying things. Demystify this branch of science by showing similarities and applications to everyday life. Before creating a taxonomic tree, it may be helpful for students to create individual concept maps to help summarize and organize the knowledge they have gained so far.

It is important in this lab to stress that there are not really any "right" answers when attempting taxonomy and classification. Some systems are better than others (bring in some historical systems for comparison) but none are an absolute truth. Have students brainstorm valid criteria by which one might judge the strength of one classification system over another.

Learning Cycle Stages: Exploration and term introduction, Classifying Microorganisms.

Day Six Theme: What do the Microbes Eat?

Day Six:

Learning Goals: Understanding specific metabolic tests, and how these might be used to learn about bacteria. Understanding that metabolic tests reflect real things about bacterial metabolism.

Vocabulary Words: acidophile, alkalophile, neutrophile, anaerobe, aerobe, facultative, barophile

Supplies Needed: loops and needles for inoculation. Bunsen burners. Various kinds of media ranging from citrate slants to EMB plates to tryptone broth

General Class Structure: Start a class discussion about how we could improve our tree(s). One way to do this would be to learn more about the microbes. Make students look up tests they find interesting in their lab manual, then have them present some information on their chosen test to the class. Afterwards, show students what tests are available, and give a brief tutorial explaining what each test is, how to inoculate it, what metabolic property it tests, and how it shows that test result.

This Constitutes Application of Metabolism

Before beginning inoculations, ask students why they want to do these tests. What's the point of just gathering random information? They don't really want to do that, do they? They want to gather purposeful information! For scientists, purposeful information tests hypotheses. The students want to improve their classification schemes.

Have them write up hypotheses and predictions about how the tests could improve their classification schemes.

This Constitutes Application of Classifying Microorganisms

Students should work on this in their groups. If one group is having particular trouble, have them go talk to other groups to get ideas rather than supplying them yourself.

Once all groups have devised reasonable hypotheses and predictions for what these metabolic tests can do for their understanding, allow them to take and inoculate the tests they desire.

Notes on Teaching Procedure: Allow students to speculate about what went wrong in plates that do not have successfully isolated colonies.. If you are lucky, some poor student will have picked a "spreader"; a nice way to prove exceptions from rules. Have students think about how they might improve their techniques. Try to stress that technique skills are skills that need to be practiced- if the students aren't great at them now that doesn't mean they can't improve!

Before inoculation, ask students to record how test media look in an un-inoculated state for reference next class period.

Learning Cycle Stages: Beginning Metabolic Tests initiates Application of Learning Cycle 2: Metabolism. Application of Classifying Microorganisms runs through the lesson as a theme.

Day Seven Theme: A Physiological Mystery

Day Seven:

Learning Goals: Understanding how color changes in media imply metabolic differences between strains of bacteria. Understanding the general physiology of bacteria. Performing a Gram's stain.

Vocabulary Words: capsule, flagella, cell wall, cell membrane, cilia

Supplies Needed: Crystal violet, Saffronin, Gram's iodine, Gram's decolorizer. Microscopes.

General Class Structure: View metabolism results. Discuss, stressing how concrete visual differences indicate abstract fundamental metabolic differences. Ask the students to tell you what the information they gained did for them. Did it support their hypotheses or not? Have students use this information to improve their trees.

This constitutes Application of Classifying Microorganisms

After this activity is complete, start students discussing bacterial differences. If bacteria have metabolic differences, they probably also have physiological differences. As the notion of physical difference is uncovered, have students come up with potential physical structures in bacteria. After students create this list, supply scientific terms for applicable structures.

This constitutes Term Introduction for Physiology

This is a good time to start really talking about how different "daily bacterial life" is from our own. By this point, students should show some interest in looking at bacteria.

Give students basic Gram stain supplies. Allow them to stain and view their isolates. Different students will see pink or purple bacteria. Why should this be? Have the students ponder on this, as well as what steps in the protocol may have resulted in these final results. What conclusions do the students think they can draw from the results? Send them home and ask them to come back with hypotheses.

Notes on Teaching Procedure:. Be sure to ask students what they think caused the color changes in the media. Act puzzled. Many students think that the color change is a direct result of microbial activity, rather than due to pH indicators. Stimulating discussion on this topic should reduce the prevalence of this misconception. If necessary, refresh students' knowledge of pH indicators. Ask students why pH can be an indicator in and of itself, and try to think of references in daily life.

The Gram stain is not an intuitive technique to the novice, and if students do not understand properties of peptidoglycan it is highly unlikely they will come up with a proper protocol. Instead, supply one. Before discussing what all the steps mean, have students perform Gram stains, and give them time to look at their stains and play with different levels of microscope power. Be really clear about the special needs of the 100X lens. They will break it if they are not taught how to use it.

Learning Cycle Stages: Discussion of Physical Structures initiates term application for Learning Cycle 3: Physiology. Further Application of Classifying Microorganisms runs though the lesson as a theme.

Day Eight

Assessment 1. 10% of total grade. Have students solve pen and paper problems involving problem solving using metabolic tests, exploring their understanding of bacterial ecology, and using logical thinking to identify when it makes sense to use which laboratory techniques.

<u>Day Nine: What Else Can They Come up With?</u>

Day Nine:

Learning Goals: Understanding the difference between Gram negative and Gram positive organisms at a deep level. Understanding specific parts of bacterial physiology and their functions. Making solutions. Researching how to perform techniques.

Vocabulary Words: A variety of chemicals and compounds related to microbial stains.

Supplies Needed: Lab manuals. Ingredients to make stains from crystal violet to malachite green. Alternately, pre-made stains. Glass slides. Microscopes.

General Class Structure: Address student hypotheses from Day Seven. Have students present their hypotheses on the function of Gram staining, then go into a discussion of the bacterial cell wall/membrane. Force students to attempt to apply ideas of Gram staining to ideas of cell physiology. Allow students to come up with the conclusion regarding cell wall difference and apply this conclusion to their results.

This constitutes Application of Physiology

Ask students if this discovery is important to their tree. Have students apply the knowledge they have collected from Gram staining to revise their trees accordingly.

This constitutes Application of Classifying Microorganisms

Bring up the list of physiology terms from previous class. Go into more detail on the structure of various parts of bacteria, and have students participate in discussions relating structure to function. Have students think about how structures could be stained. Try and get them to relate the properties of the lipid bilayer membrane to permeability, etc.

By this point, students should be interested in finding out what kinds of structures their pet microbe has. Before allowing them to begin staining exploration, ask them why they want to know what they want to know. Have them create hypotheses and predictions as to how this information will impact their trees. Once students come up with some ideas for structures that could be stained, release them into lab. Supply a variety of texts and protocols related to staining. Have students find protocols that relate to their favorite structures. Students should begin studying the protocols for staining next class period. Hopefully, instead of following the protocols blindly, they will have begun wondering about the purpose of various steps. Ask students if they have found protocols that accomplish the same goal, but vary in exact steps. Again bring up the notion of science as not only a rational exercise, but involving technical arts.

Notes on Teaching Procedure:

- Be sure to talk about how physical properties and metabolism tie back to ecology- encourage students to think and discuss on this topic

-Remind students to wear lousy clothes for doing staining experiments and check MSDS info on their dyes and stains for safety!

<u>Learning Cycle Stages</u>: The above discussions initiate Application of Learning Cycle 1:Ecology, and Learning Cycle 3: Physiology. As usual, Application of Classifying Microorganisms binds the lesson together.

Days Ten, Eleven, Twelve and Thirteen Theme: Discovering Structures

Days Ten, Eleven, Twelve and Thirteen:

Learning Goals: Learning to work without instructor guidance. Performing stain techniques.

Vocabulary Words: No new except as students find in manuals.

Supplies Needed: Stains made previous period. Slides. Staining protocols. Microscopes

General Class Structure: Using texts as resources, allow students to explore other stains of interest to learn more about their particular bacteria. Keep up the pressure to apply knowledge, and to collect knowledge in a meaningful way! Make sure students are staying busy. Every student should have the time to learn at least four staining techniques during these lab sessions. Encourage students to work together so that not everybody has to make everything. Point out that planning before acting can increase success. Have students figure out their own distribution of labor- only get involved if things get particularly hairy. Encourage daily revision of each group's tree.

This lab involves Application of Classifying Microorganisms, Technical and Safety Skills, and Physiology.

Notes on Teaching Procedure: These lab periods should be spent without any lecture or class discussion. It is time for students to experience guiding themselves. You should move about assisting groups as necessary. Encourage students to do as much as they can, but do not allow them to get too frustrated. Point out that it takes experienced technicians many trials to learn advanced techniques. Have students with successful stains share with the class. They like showing off their work.

Learning Cycle Stages: Lab activities continue Application of Learning Cycle 3: Physiology.

Day Fourteen Theme: What do we know now?

Day 14:

Learning Goals: Applying knowledge learned during staining exercises. Using this knowledge to understand bacterial differences on a deeper level. Using this knowledge to construct more meaningful trees.

Vocabulary: Review taxonomy vocabulary from previous classes.

Supplies Needed: Lots of colorful markers and paper

General Class Outline: In this class, students will share the results of their staining exercises. They will explain them in terms of results and conclusions. Each student will write on the board what they have now learned about their pet microbe. Each group will utilize this information to improve their tree. Have students spend a good amount time on this- this is a lot of new information to absorb!

When groups are beginning to wrap up tree revisions, have each group present their revised tree to the class. Have the class discuss the best parts of each tree. Have the class work together and compromise to construct one group tree that encompasses all the information they have gathered in the class so far. Make sure students review ideas of ecology, metabolism, and physiology. At the end of the class period, point out that students have not only learned a lot of things, but they have managed to address a lot of hypotheses about how bacteria look, live, and behave. They have used this information to create a good classification system. Did all their hypotheses end up supporting any particular theory? What could that theory be?

Notes on Teaching Procedure: Make sure students are doing a really thorough review of the knowledge they have gained. Don't let anybody get off easy. This process not only allows students to review for the midterm, it allows them to review their knowledge in a meaningful, structured way. It can be hoped that this will allow for deeper understanding and long-term retention, rather than simple memorization. Most students will probably remember the most about their pet microbe, as they have spent the most time working with this organism, and have been busy actively discovering things about it. However, when placed in context of the tree, every student must also understand at least some of the impact of every other student's work.

Learning Cycles: This class period requires a synthesis of all knowledge gained from all learning cycles experienced so far in the course.

Day Fifteen: Technique Olympiad

-Have students as individuals demonstrate dilution, quadrant streak, colony isolation, and inoculation techniques. Successful demonstration equals 10% of grade

Day Sixteen: Midterm Assessment

-Administer midterm exam worth 20% of grade. Do not give students back their grades for the practical portion of the exam before administering the midterm. These results would not provide them with information that would be useful to them in the midterm examination. Also, a bad result could cause a student to become more nervous and perform more poorly than otherwise expected. The kind of free and creative thinking that is desired in the assessments given in this class can be very difficult to accomplish when nervous or stressed; all efforts must be made to keep the mood of the class peaceful and positive during assessment.

Chunk 2: Guided major projects

First Mini-Freedom: Helpful Bacteria

Days One through Four:

Learning Goals: Beginning to research, design, and execute longer-term experiments. Applying technical, procedural and declarative knowledge learned earlier in the course to solving real problems.

Vocabulary Words: None except those introduced by students.

Supplies Needed: Allow students to use any materials, such as loops, needles, nutrient agar, etc, that have been previously available to them. If students require particular media for metabolic testing, have them make it from powdered form. If students desire exotic supplies not available in University Lab Stores, and require these supplies, allow them to look at the budget for the course with you. If the money is there, order desired supplies. Particularly in the independent major project, students should design their protocols and know their material needs well in advance. Last minute requests will, by and large, be denied. This approach will allow students to start to realize the costs of science, and will encourage responsibility in future laboratory members.

General Class Structure: Give back Technique Olympiad and midterm results; allow discussion. Initiate "Helpful Bacteria". Detailed instructions for the "Helpful Bacteria" lab are available by request from ASU. Request "Yogurt Lab: Instructor Version."

Have the students come up with hypotheses and predictions related to Yogurt Lab questions. Have them come up with a protocol and use it to answer your question. This will be turned in as a lab report. Discuss with the class how to write up a lab report. On D4 have students hand in a report on their findings and potential future directions worth 10% of their total grade.

Notes On Teaching Procedures:

-As all groups in the course will be working on this and the following project at the same time, inter-group communication is to be encouraged. Allow student groups to help each other. The instructor should have very little to say regarding design of protocols, as these two labs are both applications of concepts students learned in the first half of the semester.

-The only instructor-led discussion that should occur will deal with the expectations involved in the writing of lab reports. Multiple examples should be provided, both of good and bad lab reports. Offer students the opportunity to turn in drafts before producing the final report. Many students at ASU appear to have very weak writing skills. By allowing draft production and scheduling time with problem writers during office hours, many students' skills can be improved dramatically with minimal effort. Do everything you can to provide a supportive environment; avoid any sort of "shaming" behavior or tone. This tends to do very little to improve writing skills or to encourage students to come to you for individualized attention.

Second Mini-Freedom: Harmful Bacteria

Days Five Through Eight:

Learning Goals: Gaining understanding of microbial life through increasingly confident, skilled problem solving.
Vocabulary Words: Only as presented by students.
Supplies Needed: As requested by students, as per days one through four.
General Class Structure: Initiate "Harmful Bacteria". On D5, give students an overview of bacteria and disease. Remind them of Koch from the "Using Brain Tools" case studies. Then give them a diverse collection of rotting fruits and vegetables with corresponding fresh specimens as well as other common micro supplies. Point out to the students that you gave them questions to answer in the last lab. This time they need to come up with their own questions and design their own experiments in order to answer them. Do not give students questions or ideas. They will come up with some within fifteen minutes; it is normal for the process to generate initial anxiety. "A" students often become particularly worked up. As with the Helpful Bacteria lab, reassure them that there aren't any right answers. They will be graded on the quality of their design and arguments.

They must answer the question in the form of a lab report. On D8, students will turn in their lab report on their findings and potential future directions worth 10% of their total grade.

Notes on Teaching Procedures:

. -Again, allow students to turn in drafts before the final version of their lab reports. Try to help students, especially those requiring private sessions, to understand the differences between scientific and other forms of writing. Attempt to stress the importance of clarity in communication.

Chunk 3: Armed for Exploration

Into the Wild: An Exercise in Exploration

Days One through Seven:

Learning Goals: Applying declarative, procedural and technical knowledge learned during course. Applying practiced skills related to research, design, and execution of protocols. Most importantly, learning that questions students ask are important, interesting, and can be answered

Vocabulary Words: None other than those brought up by students.

Supplies Needed: As requested by students.

General Class Structure: Have students come up with a question they find interesting and potentially answerable with their new skills within their groups. Examples include "what is the frequency of antibiotic resistant organisms in the environment" "can a more meaningful taxonomic tree be produced with current data", etc.

Notes on Teaching Procedure:

-Some groups will almost certainly have difficulty coming up with a big idea to explore. Do not give them ideas! Instead, encourage inter-group communication on Day One very strongly, and let the class brainstorm a variety of project ideas. Write this list on the board. If more than one group wants to do a similar project, let them- with the caveat that they may not form one giant group, and that projects must have significant differences. Groups should not exceed five students, to encourage meaningful participation of all individuals.

-Ask questions of all groups, every day, to find out what it is they are doing. Have them explain to you the importance and rational behind their study. By allowing students to teach you, you can allow them to strengthen and clarify their own understanding.

-Observe groups to make sure all students are active, thoughtful participants.

-Allow students to turn in drafts of their individual lab reports. This method, while time-consuming, is necessary if weak writers are to be able to develop their skills to enable them to show their level of understanding.

Day Eight:

-Have students turn in a lab report on the morning of D8 covering their explorations; this paper will be worth 20% of the total grade. For the remainder of the class period, students will take their final. This will be worth 10% of their total grade and will be based on problem-solving pen and paper questions that review their understanding of metabolism, physiology, reproduction, and the role of microbial life in society.

-The remaining 10% of the total grade will be assigned on the basis of attendance, participation, and improvement throughout the semester.

111 APPENDIX C

THE THREE EXAMS

Assessment One 55 pts

Name___________________

1. Describe 3 specialized traits you think would likely be found in bacteria that colonize crevices in rocks in Antarctica. Explain why you think the bacteria would have those traits. (5pts)

2. Describe 3 specialized traits you think would likely be found in bacteria that colonize the throat of pigs. Explain why you think the bacteria would have those traits. (5pts)

3. Why do you think bacteria bother having different metabolic properties? Wouldn't it make more sense just to be able to digest everything? Argue why or why not. (5pts)

4. We have discussed in class that different bacteria can have different oxygen requirements. Please list three potential oxygen requirements bacteria can have and an environment in which these bacteria might live. (5pts)

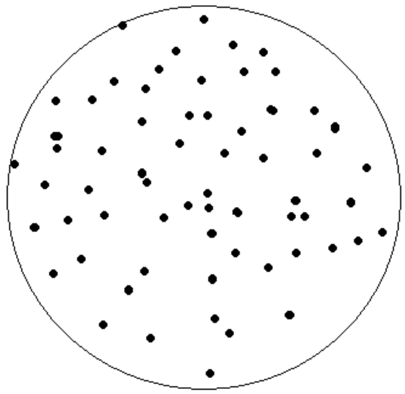
5. When you collect bacteria in the field using nutrient agar and incubate the plates overnight, the bacterial colonies you see the next day may not be representative of bacterial populations in the field. Why is this? Give three potential reasons and explain them clearly. (5pts)

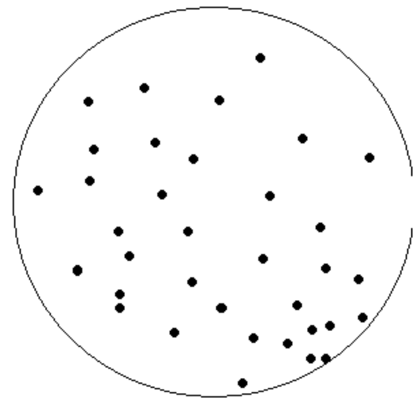
6. Both quadrant streaking (we did this in class) and dilution series (we talked about this: you put the bacteria in liquid and make 1:10 dilutions until you have a solution with very few bacteria in it) can have the same effect; generating isolated colonies of bacteria. Which do you think is the better technique to get this done? Why? What are situations where you might prefer one over the other? (5pts)

7. Give three examples of tests we have done in class. Describe what each test looks like when it is uninoculated, and how it can look after the bacteria grow on it. Tell me what each test tests for. (5pts)

8. During the course so far you have worked on making a tree with which to classify everybody's pet microbe. In your group's tree, what determines where the tree branches? Do you think these are good reasons? What other kinds of information would you like to have to improve your tree? Write a hypothesis, make a prediction, and give a rough protocol to try and figure out the problem of how to improve your tree. (10pts)

9.


LB plate


Mystery plate

These two plates were made from the same dilution tube. Each plate was made by pipetting 100 microliters of liquid, diluted culture from the same tube.

a. You can count and see how many bacteria / 100 microliters grew on each plate. Accordingly, how many bacteria / 1 ml should be in the tube according to the LB plate? How many bacteria / 1 ml should be in the tube according to the mystery plate? (4pts)

b. The difference in the number of colonies between these two plates is puzzling. Remember, they were inoculated from the same tube of bacteria. It's weird that the numbers are different on the two plates! Come up with two possible hypotheses to explain this observation. Then tell me how you could test those hypotheses. (6pts)

Midterm Assessment (10 pts each) Name:____________

1. List five things that could go wrong with a Gram stain, and tell me whether they would make a Gram positive organism look negative (false negative), a Gram negative organism look positive (false positive), or neither.

2. I made some dilution plates the other day. To do this, I made a series of 1:10 dilutions. That means that each time I made a dilution the solution became ten times more dilute. If there were 20 bacteria/ml and I made a 1:10 dilution, in the resulting dilution there would be 2 bacteria/ml.
I made four 1:10 dilutions in a row. Then I put 1 ml of the last dilution onto a plate and let it grow. 8 colonies grew.
How many colonies/ml were in my original sample?

3. Tell me why and how the capsule stain works, as well as what an organism with a capsule would look like in a good stain.

4. You have been caring for your microbes for quite a while. Tell me eight specific things you have learned about your microbe through our explorations in class. What is your microbe's name? 5pts

5. Why and how does an acid fast stain work? What color will "acid-fast" bacteria stain?

6. At this point in class you have made a pretty good tree showing the traits of you and your classmates' organisms. You know a great deal about these organisms! But we did spend a lot of time gathering this information. What we have done to identify these organisms more quickly? Give me two possible strategies and your reasoning behind them.

7a. Please explain how one performs a nitrate test. Tell me all three things that can happen to the nitrate, how one would discover these, and what you would see in the tube for each case. 6pts

7b. Explain what an MR test tests for and what a VP test tests for. Also, why do they use the same broth? 4pts

8. The time for final projects is fast approaching! As you recall, the last month of class will be spent answering a question you and your group have about the microbial world.

I have a friend who has many, many pets. She has chickens, dogs, cats, and ferrets. Because of this, sometimes her house is very gross. If I were doing a final project, I might ask this question:

"Which type of pet is the most gross?"

Please come up with two hypotheses to address these questions, with accompanying predictions. You may need to clarify the question before you can do this!

9. We have done lots of tests to look at bacterial metabolism/digestion. Some of the tests change colors depending on the properties of the bacteria. Name three color-changing tests, tell me what they test for, and explain why they change color.

10. Everyone has heard about antibiotic resistant bacteria. We know that they can make people sick and are very difficult to kill. However, we know that there are many bacteria in the environment that do not make people sick. Do you think any of these bacteria are antibiotic resistant? Tell me why or why not, and if you do think they are, explain where their antibiotic resistance may have come from.

Final Assessment 100 pts

Name_________________

1. One horrible morning, you wake up to find your pet bunny covered in ugly, oozing sores. From the smell, you deduce they are harboring bacteria. Unfortunately for you, you cannot take your bunny to the vet. Fortunately, you have an extensive supply of many kinds of veterinary antibiotics, and access to the MIC206 lab. Please describe a protocol that would allow you to figure out how best to treat your bunny. 20 pts.

2. You have performed three experiments during the second half of the semester: the milk experiment, the fruit experiment, and your final project. Please answer the following questions as related to your favorite experiment. 20 pts total.
-What experiment are you using to answer this question?

-Where in your experiment could your group have improved accuracy or precision in your measurements?

-Where in your experiment did your group tend to make mistakes? How could these be improved?

-Is there a way your experimental design could have been improved to better answer your questions? How could you have done this?

-What do you feel is the most important thing you learned during the course of your study?

3. Some cultures enjoy producing and consuming foods that involve bacterial fermentation, such as kim chee, sauerkraut, and fermented fish heads. To make all of these foods, the ingredients are placed in a jar which is then tightly sealed for a lengthy period. What do you think happens to this sealed environment with food and bacteria? How does the environment change? What factors important to bacterial growth will change as the environment changes? Try to explain the process of food fermentation using your understanding of bacterial life gained through this course. 20 pts.

4. I have discovered a photo-luminescent strain of bacteria. They glow in the dark. Now I want to know WHY these bacteria do this. Propose three hypotheses to explain the purpose of glowing in these bacteria. Use the scientific method to devise ways to test all these hypotheses. Write these hypotheses and their accompanying predictions and protocols below. Then state what conclusions you could reach if your hypotheses were supported or failed to achieve support. 20 pts.

5. I did an experiment in which everything went wrong- or at least turned out differently from how I thought it would. Help me troubleshoot my experiment- at each step tell me **TWO** things that might have happened, and how to test these ideas. Human error, while frequently responsible for these sort of things, is not a good reason to write down. Try to come up with deeper reasons.

STEP ONE- The experiment I did was with rotting broccoli. I wanted to find out what was making the broccoli rot. I rubbed the rotting broccoli on some nutrient agar plates, expecting bacterial growth. But nothing grew! **Why would nothing grow?**

STEP TWO- One of my friends managed to get some growth. I used her bacteria to inoculate fresh broccoli, expecting that to make the broccoli rot. But it didn't rot! **Why didn't it rot when I thought it would?**

STEP THREE- Since the bacteria didn't make the broccoli rot I put the broccoli in the refrigerator, expecting it to keep the broccoli fresh so I could study it more later. But when I came back the broccoli had rotted! **Why did it rot when I thought it wouldn't?**

20 pts.

APPENDIX D
PRE AND POST-COURSE SURVEYS

An identical knowledge assessment was administered pre and post-course.

Microbiology Knowledge Assessment Name: ________________

Please circle the answer you think is best.

1. Gram staining gives you information about a bacteria's
   a) metabolism/oxygen requirements
   b) cell wall/membrane
   c) motility
   d) ability to cause disease

2. "After diluting, 45 colonies were observed."
   This statement is a:
   a) prediction
   b) conclusion
   c) result
   d) hypothesis

3. A bacterial capsule protects against
   a) dehydration
   b) heat
   c) high levels of salts
   d) cold

4. A bacterium consists of
   a) one cell containing ribosomes and a nucleus
   b) two cells containing ribosomes and genetic material
   c) one cell containing mitochondria and endosomes
   d) one cell containing ribosomes

5. Bacteria metabolize food by
   a) passively bringing food molecules across their cell wall/membrane
   b) bringing food particles into themselves via phagocytosis
   c) passively and actively moving food molecules across their cell wall/membrane
   d) growing on the food and absorbing it

6. Good aseptic technique is important in microbiology because
   a) it helps prevent contamination
   b) it keeps your work area neat and clean
   c) it kills all the bacteria in your work station
   d) it keeps you from getting sick

7. An example of a protein bacteria might metabolize is
   a) lactose
   b) casein
   c) tryptophan
   d) glucose

8. Bacteria move through use of
   a) cilia
   b) pseudopods
   c) fimbria
   d) flagella

9. "After applying alcohol to the culture, the number of microbes will decrease."
   This statement is a
   a) prediction
   b) hypothesis
   c) conclusion
   d) result

10. Staining allows one to determine
    a) a bacteria's species
    b) what a bacteria metabolizes
    c) how a bacteria moves
    d) what structures the bacteria possesses

11. "Of the agents tested, iodine was the most effective microbicide."
    This statement is a
    a) prediction
    b) hypothesis
    c) conclusion
    d) result

True or False

12. Most bacteria cause disease. T/F

13. A hypothesis states what you expect to find in an experiment. T/F

14. Bacteria can be found in diverse environments all over the Earth. T/F

15. Through good hygiene, a person can be free from bacteria. T/F

16. Bacterial cells are fundamentally different from our own cells. T/F

Separate pre and post course reasoning tests were administered. Items were appropriately illustrated by hand before photocopying.

MIC 206 Reasoning Pretest

Name:________________

1. Six square pieces of wood are put into a cloth bag and mixed about. The six pieces are identical in size and shape. However, three pieces are red and three are yellow. Suppose someone reaches into the bag without looking and pulls out one piece.

*What are the chances the piece is red?

*Please show or explain how you arrived at your answer.

2. You have two cylinders filled to the same level with water. The cylinders are identical in size and shape.

You have two marbles. They are identical in size and shape. One is made of glass and one is made of steel. The steel marble is much heavier than the glass marble.

When you put the glass marble in the first cylinder, it sinks to the bottom. The water level rises by three units.

If the steel marble is put into the second cylinder, the water will rise

a) to the same level as cylinder 1
b) to a higher level than in cylinder 1
c) to a lower level than in cylinder 1

*Please show or explain how you arrived at your answer

3. You have three strings hanging from a bar. The strings have metal weights attached to their ends. Strings 1 and 3 are the same length. String 2 is shorter. String 1 has 10 grams attached to the bottom, as does String 2. String 3 has 5 grams attached to the bottom.

The strings and their weights can be swung back and forth. The time they take to swing can be measured.

Suppose you want to find out whether the length of string has an effect on the time it takes to swing back and forth.

*Which strings would you use to find out?

*Please explain why you chose the string(s) you did.

4. A farmer observed the mice in her barn. She discovered that the mice were all either fat or thin. They all had either black or white tails. She wondered if there was a link between fatness and tail color, so she captured all the mice in the barn. Here they are below:

*Do you think there is a link between mouse size and tail color?

*Please show or explain how you arrived at your answer.

<u>MIC 206 Reasoning Posttest</u>

Name:_________________

1. Eight square pieces of wood are put into a cloth bag and mixed about. The eight pieces are identical in size and shape. However, two pieces are red and six are yellow. Suppose someone reaches into the bag without looking and pulls out one piece.

*What are the chances the piece is red?

*Please show or explain how you arrived at your answer.

2. You have two cylinders filled to the same level with water. The cylinders are identical in size and shape.

You have two marbles. They are identical in size and shape. One is made of aluminum and one is made of lead. The lead marble is much heavier than the aluminum marble.

When you put the aluminum marble in the first cylinder, it sinks to the bottom. The water level rises by three units.

If the lead marble is put into the second cylinder, the water will rise

a) to the same level as cylinder 1
b) to a higher level than in cylinder 1
c) to a lower level than in cylinder 1

*Please show or explain how you arrived at your answer

3. You have three strings hanging from a bar. The strings have metal weights attached to their ends. Strings 1 and 3 are the same length. String 2 is shorter. String 1 has 10 grams attached to the bottom, as does String 2. String 3 has 5 grams attached to the bottom.

The strings and their weights can be swung back and forth. The time they take to swing can be measured.

Suppose you want to find out whether the length of string has an effect on the time it takes to swing back and forth.

*Which strings would you use to find out?

*Please explain why you chose the string(s) you did.

4. While observing a pond, a researcher noticed that the fish inside were all either large or small, and either white or black in color. The researcher wondered if size and color were linked, so he caught all the fish in the pond. They are pictured below.

*Do you think there is a link between size and color?

*Please show or explain how you arrived at your answer.

Separate pre and post course impressions surveys were administered.

<u>MIC206 Pre-Course Impressions</u>

Name:__________________

Choose the number that best suits your reaction to the statement

	1. Not at all 3. No opinion 5. Definitely
1. I find the sciences interesting/enjoyable	1 2 3 4 5
2. I find biology interesting/enjoyable	1 2 3 4 5
3. I plan to take another microbiology course.	1 2 3 4 5
4. I am only taking this class because it is required	1 2 3 4 5
5. Science courses require too much memorization	1 2 3 4 5
6. I plan to take another biology course.	1 2 3 4 5
7. I plan to take another science course.	1 2 3 4 5
8. I plan to work in the biological sciences.	1 2 3 4 5
9. I remember most of what I learn after tests	1 2 3 4 5
10. Science knowledge applies to my daily life	1 2 3 4 5

MIC 206 Post-Course Impression

Name:________________

Choose the number that best suits your reaction to the statement

1. Not at all 3. No opinion 5. Definitely

1. I find the sciences interesting/enjoyable.	1	2	3	4	5
2. I find biology interesting/enjoyable.	1	2	3	4	5
3. I plan to take another microbiology course.	1	2	3	4	5
4. This course taught me information I can use.	1	2	3	4	5
5. I enjoyed this course.	1	2	3	4	5
6. I plan to take another biology course.	1	2	3	4	5
7. I plan to take another science course.	1	2	3	4	5
8. I plan to work in the biological sciences.	1	2	3	4	5
9. I remember most of what I learn after tests	1	2	3	4	5
10. Science knowledge applies to my daily life	1	2	3	4	5
11. I would have preferred a standard course.	1	2	3	4	5
12. I learned a lot in this course.	1	2	3	4	5

APPENDIX E
SUMMATION OF HYPOTHESES AND PREDICTIONS

Bold = Evidence matches prediction.

Hypotheses:	English Proficiency	Cultural Dynamic	**Applied Neurobiology**
Predictions: Diverse Group	-**Anglicized exam scores should be significantly higher than Classical** -**No differences should occur on cultural questions of impressions survey** -Lower upper-level course grades should occur for Anglicized group No Procedural/Declarative knowledge differences should be observed	-**Anglicized exam scores should be significantly higher than Classical** -Anglicized impressions surveys should be significantly higher than Classical -**Higher upper-level course grades should occur for Anglicized group** No Procedural/Declarative knowledge differences should be observed	-**Anglicized exam scores should be significantly higher than Classical** -**No differences should occur on cultural questions of impressions survey** -**Higher upper-level course grades should occur for Anglicized group** **Procedural/Declarative knowledge differences should be observed**
Predictions: Homogeneous Group	-Anglicized exam scores should be similar/same as Classical -**No differences should occur on cultural questions of impressions survey** No Procedural/Declarative knowledge differences should be observed	-Anglicized exam scores should be similar/Same as Classical -**Anglicized impressions surveys should be similar/same as Classical.** No Procedural/Declarative knowledge differences should be observed	-**Anglicized exam scores should be significantly higher than Classical** -**No differences should occur on cultural questions of impressions survey** **Procedural/Declarative knowledge differences should be observed**

Please note that upper-level course follow-up was not possible for the homogenous group. As they were all non-majors, they did not take upper-level microbiology courses.

From current evidence, the best supported hypothesis is the Applied Neurobiology hypothesis.

140

140