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Analysis of the Effects of Formative Assessment in Promoting Transfer of Learning in an Undergraduate General Microbiology Laboratory Course

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ANALYSIS OF THE EFFECTS OF FORMATIVE ASSESSMENT IN PROMOTING TRANSFER OF LEARNING IN AN UNDERGRADUATE GENERAL MICROBIOLOGY LABORATORY COURSE

by
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ABSTRACT

The undergraduate microbiology lab serves an important role in establishing a foundation of best practices in aseptic technique and infection control for pre-medical, pre-nursing, pre-pharmacy, or pre-allied health students. The high incidence of hospital-acquired infections (HAIs) in the US and evidence in the literature of less effective implementation of proper aseptic technique among apprentice doctors and nursing students suggests that more effective transfer of learning could improve implementation of these procedures in the clinical setting. The research described in this study aimed to assess learning transfer as it applied to aseptic techniques and infection control skills learned in the undergraduate microbiology lab from pre- and post-lab formative assessments to midterm and lab practical summative assessments. Assisting students in building connections between the aseptic techniques learned in general microbiology and their application in the clinical setting through pre-lab formative assessments and reflective practices may lead to improvements in use of aseptic techniques and infection control measures as they progress into clinical careers and may ultimately reduce infection rates and mortality rates due to HAIs.

The first major aim of this study was to explore the experiences of students with respect to learning transfer through qualitative analysis of student responses to post-lab free-response questions regarding difficulties faced in the lab and the relevance of microbiology to students' future careers. The second major aim of this study was to determine if the implementation of an in-class pre-lab formative assessment facilitates

learning transfer as evidenced by significant improvements on summative lab midterm and final lab practical exam scores.

Qualitative analysis of student responses to open-ended reflection questions indicated evidence of predominantly low-road transfer with respect to transfer of automaticity. Additionally, qualitative analysis of student responses indicated evidence of lateral transfer regarding transfer of complexity. Finally, there was evidence of an evolution from near to far transfer of context indicating that students were able to perceive the application of the knowledge gained in the microbiology lab in contexts similar to the lab as well as contexts outside of the lab. Evidence from student responses suggested that primarily students intending to pursue careers in healthcare fields were able to perceive specific applications of the microbiology lab to their future careers. Further, evidence from student responses suggested that students predominantly had difficulties with procedures, interpretation of results, manual dexterity with microbiological equipment and materials, and expressed the need to practice these procedures and techniques.

Statistical analyses provided quantifiable evidence that the implementation of pre-lab quizzes had both a statistically significantly positive impact and a practically positive impact on lab practical final scores in both of the semesters studied as compared to historical control groups with a large effect size. The statistically and practically significant impact of the pre-lab quizzes on lab practical final exams is an important finding and will add to the current literature on the importance of formative assessment in undergraduate microbiology education.

Dedicated to the life and memory of Ethan Christopher Rediske
May 5, 2002 – February 7, 2014
You are the sweetness and the light.

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LIST OF ACRONYMS AND ABBREVIATIONS

Several abbreviations, both relating to medicine and science education are used throughout this study as follows:

AAAS – American Association for the Advancement of Science

ASM – American Society for Microbiology

BA – Blood Agar

BSA – Bismuth Sulfide Agar

BSBS – Burnett School of Biomedical Sciences

CAUTI – Catheter-Associated Urinary Tract Infection

CDC – Centers for Disease Control and Prevention

C-diff – *Clostridium difficile*

CLABSI – Central Line Associated Bloodstream Infection

ECL – Extraneous Cognitive Load

EMB – Eosin Methylene Blue Agar

ER – Emergency Room

GCL – Germane Cognitive Load

GTA – Graduate Teaching Assistant

H2S – Hydrogen Sulfide (H_2S)

HAI – Healthcare-Associated Infection

HE – Hectoen Enteric Agar

IV – Intravenous Line

KIA – Kliger's Iron Agar

MCB 3030 – The UCF course code for General Microbiology

MPN – Most Probable Number

OR – Operating Room

PDA – Potato Dextrose Agar

PICC – Peripherally Inserted Central Catheter

PPE – Personal Protective Equipment

SIM – Sulfide, Indole, and Motility Medium

SS – *Salmonella Shigella* Agar

UCF – University of Central Florida

VAP – Ventilator-Associated Pneumonia

CHAPTER ONE: INTRODUCTION

Prologue

It is 7:00 am – time for shift change at the Florida Hospital Pediatric Critical Care Unit. I adjust my legs in the uncomfortable chair next to Ethan's bed and strain to hear the nurses giving report outside his door. "Pneumonia…bowel blockage…PICC (Peripherally Inserted Central Catheter) line placed in the ER (Emergency Room)." It was a rough ER visit last night. Ethan is usually a hard stick, but this time was worse. His veins were shot – the dehydration from the bowel blockage had left the IV nurse with nothing to work with, so the PICC was our only option. Shortly after we were rushed through triage in the ER, I spent about an hour holding Ethan perfectly still while the PICC team carefully threaded a catheter through a deep vein in his arm straight into his aorta so that he could receive fluids and medication. It was probably the medical procedure closest to a surgical procedure performed outside the operating room (OR) I had ever observed with my son. I sit up as the nurse comes into the room. "Hi Ethan! It's good to see you!" Ethan is a frequent flyer in the critical care unit, and most of the nurses on the floor have worked with him before. He turns his head to the sound of the nurse's voice, smiles, and lets out his Chewbacca-like howl. Ethan has a thing for blondes. I hold my breath as I observe the nurse getting ready to take his vitals. She takes a generous dollop of the hand sanitizing foam at the doorway and rubs her hands vigorously and thoroughly, covering the palms, backs of the hand, fingers front, back, and in-between, and wrists until it is dry. Before she moves to the bed, she carefully wipes the bell and diaphragm of the stethoscope that has been hanging around her neck with an isopropyl alcohol-soaked pad. Once again, my personal and professional worlds collide. The nurse hovering over my son's bed listening for bowel sounds with her now-disinfected stethoscope had to take microbiology, a pre-requisite course for nursing school that I teach. I let my breath out slowly in relief. The night nurse hadn't been as careful. "I'm judging your aseptic technique," I tell the nurse, trying to sound lighthearted. She looks up at me, startled. "I teach micro." She smiles. "That was my favorite class!" she exclaims. Again, I'm relieved. I can usually judge the quality of Ethan's nurses by how well they liked their microbiology class. Both the nurse and I know that the difference between life and death is at the hands of the nurses, doctors, technicians, and therapists that will come in and out of my son's hospital room that day. Hand washing and scrupulous attention to asepsis are critical to every patient, and even more so with a severely disabled and medically fragile child like Ethan.

As the nurse goes about her duties, assessing Ethan's vital signs, checking his PICC line, administering his medications, and getting him settled for the day, I think about my microbiology students. Most of them are pre-nursing students; some are pre-medical, pre-physical therapy, and pre-veterinary students. On the surface, the aseptic techniques I teach in the introductory microbiology lab bear little resemblance to the aseptic technique being practiced by Ethan's nurse – disinfection of bench tops, aseptic transfer between test tubes, and inoculation of petri dishes are rarely practiced in a clinical setting. However, these aseptic habits learned in my introductory microbiology course lay the foundation for the aseptic procedures the nurse is now practicing in the hospital. Students in introductory microbiology gain an awareness of the ubiquity of microbes in the environment, and the careful practice of aseptic procedures is the first step in establishing effective aseptic practices in their future careers. From my perspective, a student who develops the habit of washing their hands before and after lab, disinfecting their laboratory bench top, and carefully protecting the surface of a sterile petri dish during an inoculation may be more likely to wash their hands before and after attending to a patient, disinfecting their stethoscope, and maintaining a sterile field when changing a dressing or inserting an intravenous (IV) line. As a microbiology instructor, my purpose is to help my students learn these aseptic procedures and techniques and to facilitate transfer of these skills to their other pre-medical, pre-nursing, pre-pharmacy, or pre-allied health courses and to their future careers. As a mother, I know my son's life depends on the transfer of these skills.

Introduction

Microbiology is an essential course for many degree programs in science, particularly in the biological sciences. Moreover, undergraduate introductory or general microbiology is a vital prerequisite for health-related degree programs, including pre-medical, pre-physician's assistant, pre-pharmacy and pre-nursing programs. In addition to providing students with an overview of bacterial and viral physiology, microbial structures, disease mechanisms, and antimicrobial therapies, the laboratory section of undergraduate introductory or general microbiology lays the foundation for an understanding of aseptic technique and its necessity in the clinical setting (ASM Curriculum Recommendations, 2012). Healthcare-associated infections (HAIs), or infections acquired as a result of receiving medical treatment in a hospital or clinic, are a major threat to patient safety (Centers for Disease Control, 2015; Centers for Disease Control, 2012). It has been estimated that there are approximately 1.7 million cases of HAIs annually, resulting in healthcare costs between $28 and $33 billion and 99,000 deaths (Zilberberg & Shorr, 2012). The most common HAIs are catheter-associated urinary tract infections (CAUTIs), central line-associated blood stream infections (CLABSIs), and ventilator-associated pneumonia (VAP), the majority of which are contracted at the hands of healthcare workers using improper aseptic techniques and infection control procedures (Sickbert-Bennett, Dibiase, Willis, Wolak, Weber, & Rutala, 2016; Zilberberg & Shorr, 2012). Guidelines for prevention of HAIs include hand hygiene before and after patient contact and using sterile techniques when performing invasive procedures such as urinary catheter placement, intravenous (IV) line placement, and central venous catheter placement (Hsu, 2014). Studies suggest evidence of complacent attitudes and poor compliance with respect to prevention of hospital infection among “frontline” technicians, such as nurses, nurse practitioners, and phlebotomists, who perform these types of routine invasive procedures and are engaged with the greatest amount of patient contact (Hunt, Mohammudally, Stone, & Dacre, 2005; Preston, 2005). Other studies also suggest that there is wide variation between hospitals with respect to infection prevention (Braun, Harris, Richards, Belton, Dembry, Morton, & Xiao, 2013; Cox, Simpson, Letts, & Cavanaugh, 2014).

Aseptic techniques such as proper hand washing procedures, maintenance of sterile fields, and utilizing sterile inoculation techniques are learned in introductory and general microbiology laboratories, and attitudes toward the importance of proper aseptic technique may find their genesis in these courses. Some general aseptic techniques and skills learned in the microbiology lab include proper use of personal protective equipment (PPE), inoculation of sterile liquid media with a bacterial culture, isolation of bacterial colonies on a Petri dish, analysis of biochemical tests, Gram staining of bacterial cultures, and other staining techniques (Ambivero, Rediske, & Wilson, 2017). Additionally, students gain an awareness of the ubiquity of microbes in the environment by observing bacterial cultures contaminated with environmental microbes due to their own ineffective aseptic technique when practicing these procedures in the lab. Although the specific techniques of bacterial transfer and inoculation of sterile media are not necessarily used in a clinical setting, the manipulation and inoculation of sterile microbial media, maintenance of aseptic laboratory environments, and an awareness of the presence of microbes set the can stage for proper aseptic technique and effective infection control in hospital and clinical settings.

Because aseptic technique is such a vital component of healthcare in the hospital and the clinical setting, the learning transfer of aseptic techniques acquired in the undergraduate microbiology laboratory is essential for the prevention of HAIs. Some studies suggest that although pre-medical, pre-nursing, pre-pharmacy, or pre-allied health students are required to take microbiology as a prerequisite to their programs, there is wide variation in the training of aseptic technique and infection control measures in these courses (Cox et al., 2014). Other studies indicate that medical students lack knowledge about infection control, and many doctors who are the primary trainers of medical students are found to ignore basic hand hygiene (Al-Damouk, Pudney, & Bleetman, 2004; Jumaa, 2005; Hakko, Rasa, Enunlu, & Cakmakci, 2011; Kelcíkova, Skodova, & Straka, 2012; Mann & Wood, 2006). The lack of consistent training and knowledge of infection control measures by medical and nursing students demonstrates the need for effective learning transfer of proper aseptic techniques and infection control from the undergraduate microbiology lab to clinical settings in order to prevent HAIs and patient deaths.

Statement of the Problem

Ideally, students planning on careers in healthcare enrolled in undergraduate microbiology are able to effectively transfer knowledge and skills related to aseptic technique and infection control to their future careers in healthcare. However, HAIs are a serious issue in healthcare, mainly due to poor asepsis and infection control practices by healthcare workers who receive their initial training in aseptic technique in undergraduate microbiology laboratories. Implementation of formative assessments and reflective activities in microbiology lab may facilitate transfer of knowledge and aseptic skills to summative lab practical assessments in microbiology courses. The first steps taken in effective learning transfer of aseptic skills and knowledge gained in undergraduate microbiology courses may have future applications in the clinical setting. More effective transfer of aseptic techniques and skills may lead to a reduction in HAIs and positively impact patient outcomes in clinical settings.

In this dissertation, I will explore the theory of learning transfer as it applies to the introductory or general microbiology laboratory. Transfer of learning takes place when learning in one environment has an impact on performance in another environment (Perkins & Salomon, 1992). Learning transfer is notoriously difficult to measure and educational psychologists disagree on precise definitions and measurements of learning transfer (Gick & Holyoak, 1983; Greeno, Moore, & Smith, 1993; Perkins & Salomon, 1989; Singley & Anderson, 1989). However, this dissertation will attempt to demonstrate learning transfer of habits, techniques, and knowledge gained within the context of introductory or general microbiology among pre-medical, pre-nursing, pre-pharmacy, pre-allied health students, or students pursuing scientific research or other professional fields as measured by significant improvements in summative assessments compared to historical scores after the implementation of pre-lab formative assessments. Additionally, learning transfer will be demonstrated through students' responses to post-lab reflection questions that indicate evidence of learning transfer of automaticity, complexity, and context.

Rationale for the Study

Given the high rates of HAIs in the United States and the inconsistent training of pre-medical, pre-nursing, pre-pharmacy, or pre-allied health students in aseptic techniques and infection control measures, there is a clear need for the study of effective learning transfer of these practices from the undergraduate microbiology lab to clinical settings. The proposed study aims to address these inconsistencies and lack of learning transfer through the implementation of formative assessments (Black & Wiliam, 2009) and reflective activities (Parry, Walsch, Larsen, & Hogan, 2012) in a general microbiology laboratory at a large research university in Florida as an antecedent to learning transfer from lab activities to lab exams. Although this study does not address transfer of learning from the microbiology laboratory to the clinical setting, this study aims to elucidate a perspective on the first steps in learning transfer from formative assessment in weekly lab activities to summative assessments in lab exams. Although studies have been conducted on the effects of formative assessments (Basey, Maines, Francis, Melbourne, Wise, Safran, & Johnson, 2014; Cann, 2016; Feldon et al., 2010; Heyborne et al., 2011; Smith, 2007) and reflective activities (Basey et al., 2014;

Mackenzie, 1993; Sandars, 2009) have been studied in undergraduate science courses, these effects have not been previously studied in general microbiology laboratories at large research institutions.

Research Goals and Research Questions

Qualitative Research Questions:

1) Do student responses to open-ended post-lab questions show meaningful evidence of learning transfer over the course of the semester?
   a) What is the evidence of evolution of transfer of automaticity over the course of the semester?
   b) What is the evidence of evolution of transfer of complexity over the course of the semester?
   c) What is the evidence of evolution transfer of context over the course of the semester?"
2) How do microbiology students perceive the role of the lab in helping them to prepare for their future careers in medical, nursing, pharmacy, allied health, academic research, or industry?
3) What difficulties do students encounter when performing laboratory experiments in general microbiology?

Quantitative Research Question:

What is the effect of weekly pre-lab formative assessments on students' transfer of learning of microbiology laboratory techniques and knowledge?

Quantitative Hypothesis:

A weekly pre-lab formative assessment in a general microbiology laboratory will positively affect transfer of learning of microbiology aseptic techniques and knowledge as measured by a significant increase in post-intervention summative mid-term lab exam and final lab practical exam scores compared to historical scores.

Conceptual Framework

The conceptual framework for this study is based on theories of learning transfer and a conceptual model by Boud and Walker (1990) that illustrates a mechanism by which students learn from experience. Boud and Walker's conceptual model incorporates three aspects of learning: preparation, experience, and reflective processes. For this study, I employed an adapted form of the model that emphasizes the pre-lab quizzes as the preparation phase, the actual lab activities as the experience phase, and the post-lab quizzes with reflection questions as the reflective phase. Figure 1 below shows the original Boud and Walker diagram and Figure 2 is my adaptation for this study based on their model. The original diagram was created for a broad spectrum of learning experiences while mine is specific to the microbiology lab in the context of this study.

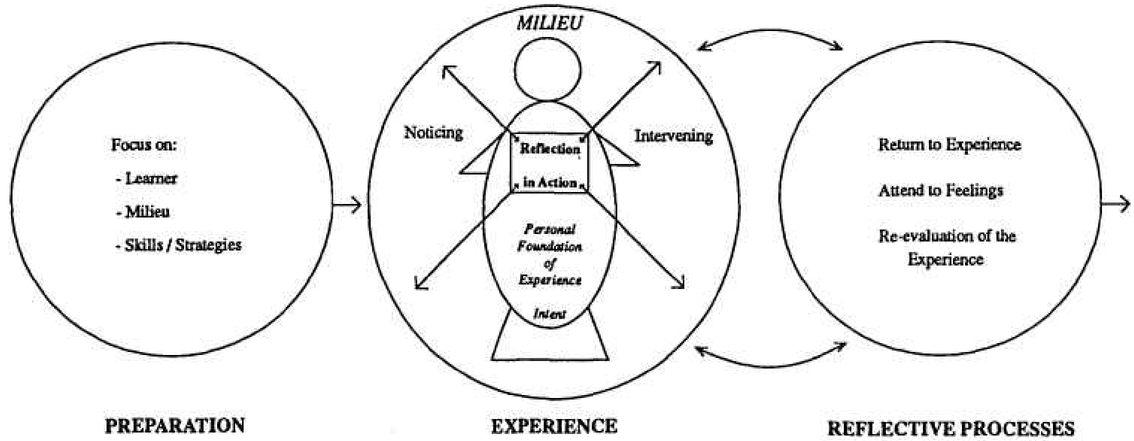


Figure 1: Original model of learning through experience by Boud and Walker.

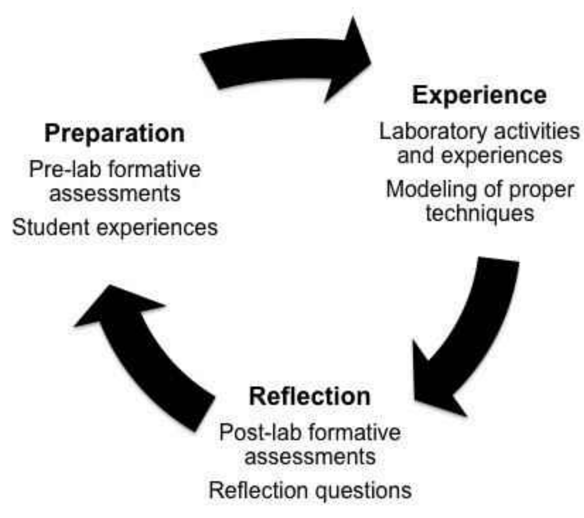


Figure 2: Adaptation of Boud and Walker model.

The adapted model is more specific to the microbiology lab experience than the original Boud and Walker model and emphasized the pre-lab formative assessments as preparation for the lab experience and the post-lab reflection questions as part of the reflective process.

Overview of Methods and Methodology

Prior to this study, students in the general microbiology course under analysis were only assessed through midterm exams and final lab practical exams that demonstrated their knowledge and skill, but formative assessments were not used to determine student progress and understanding in the laboratory that could give insight into transfer of learning from lab activities to lab practical exams. In the qualitative component of this study, students were given a short formative assessment after each lab activity comprised two free-response reflection questions designed to prompt students to consider the most difficult components of the lab and how the lab activity might apply to their future careers. In the quantitative component of this study, students were given a short formative assessment prior to each lab activity comprised of five low-level Bloom's taxonomy questions (Bloom, 1969) designed to prepare the students for the lab and to facilitate learning transfer. The research described in this study may indicate the role of formative assessment and reflection on the relevance of lab activities in the assisting transfer of laboratory skills and techniques in a general microbiology laboratory as measured by increases in scores on summative assessments. Insights gained from students' reflections on the relevance of lab activities and difficulties they had with the lab activities may also provide insights into the degree of learning transfer that occurs from the microbiology lab to summative assessments and then to potential future careers in healthcare fields and may contribute to the reduction of HAIs.

Bracketing of the Study

Although bracketing of a study is usually undertaken in qualitative phenomenological and social work studies (Tufford & Newman, 2010), I feel that it is important that I bracket my personal biases in this mixed methods study. As a trained microbiologist who has taught microbiology at the community college level for over a decade, I am invested in improving student learning outcomes in introductory microbiology classes. My personal investment in the success of my students may have lead to implicit bias in this study, as I looked for evidence of learning transfer through significant improvement in lab practical midterm and final grades in MCB 3020 students receiving the intervention of pre-lab quizzes and post-lab quizzes with reflection questions.

Additionally, since these types of formative assessments have not been historically implemented in MCB 3020 at UCF, I endeavored to demonstrate the value of these types of interventions to the MCB 3020 instructor and lab coordinator in order to facilitate further science education research with this population of students. The desire to prove that this research has value may have also introduced bias into the study.

Finally, as the mother of a disabled child and two normal, healthy children, I have seen first-hand the necessity for proper training in aseptic technique among healthcare professionals for the benefit of my family. During Ethan's lifetime, I saw both good and bad examples of aseptic technique by doctors, nurses, technicians, and therapists that worked with him. Each of the healthcare professionals that worked with Ethan had to take a microbiology course with a lab section, whether it was a prerequisite course for a professional program or a microbiology course in medical school. By improving aseptic technique practices among healthcare professionals, I indirectly benefit my family, myself, and children like Ethan with disabilities.

Assumptions

In this study, it was assumed that students responded thoughtfully and reflectively to post-lab reflection questions. It was also assumed that students received no outside assistance when answering the pre-lab or post-lab quiz questions. Further, it was assumed that all lab quizzes were graded with the same grading rubric and level of rigor. Finally, it was assumed that there were no significant differences in the content and administration of lab midterm exams and lab practical exams from Fall 2015 through Spring 2017, and this assumption was verified with the MCB 3020 instructor and lab coordinator through personal communication.

Summary

The microbiology lab is a vital component of training in principles of aseptic technique and infection control for students in healthcare programs. Effective transfer of learning of principles of aseptic technique from the general microbiology lab to the clinical setting may reduce HAIs in patients. Formative assessments in the general microbiology lab may facilitate learning transfer by assisting students in preparing for summative assessments as well as providing context for the application of lab techniques and practices to future career paths. Qualitative evidence of learning transfer based on student responses to open-ended post-lab reflection questions may provide insights into how learning transfer occurs in students longitudinally throughout the semester. Additionally qualitative evidence from these responses may shed light on difficulties students experience in the lab and if they are able to perceive future applications of the microbiology lab. Improvements on student scores on midterm lab exams and final lab practical exams may provide quantitative evidence of learning transfer facilitated by the implementation of formative assessments in the lab. Together, the qualitative and quantitative evidence of learning transfer provides a richer perspective on student experiences in the microbiology lab and may provide perspective on curricular modifications to further learning transfer in future courses.

Definitions

Allied health: A general term for career paths in various aspects of the health care field outside of medicine, pharmacy, or nursing (Association of Schools of Allied Health Professions, 2017).

Alpha hemolysis: Incomplete destruction of red blood cells by bacteria growing on blood agar (Brown, 1919).

Asepsis: In this study, asepsis will be defined as the absence of infectious organisms (Humes & Lobo, 2009).

Aseptic Technique: In this study, "aseptic technique" will be defined as skills, preliminarily learned in the undergraduate microbiology laboratory, that are essential to protecting patients from infection during invasive procedures. Aseptic techniques are aimed at removing all microbes that could potentially cause infection (Humes & Lobo, 2009; Rowley Clare, Macqueen, & Molyneux, 2010).

Beta hemolysis: Complete destruction of red blood cells by bacteria growing on blood agar (Brown, 1919).

Coliform: A group of bacterial genera including *Escherichia*, *Klebsiella, Enterobacter* and others that share similar biochemical characteristics and are indicators of fecal contamination of water (Parr, 1939).

Far Transfer of Context: Transfer of knowledge, understanding, or application of knowledge to contexts removed from the original learning context. Students use specific examples of how what they are learning can be applied to their future careers or future research endeavors (Mayer, 1975).

Fomite: An inanimate object that serves as a transmission agent of disease (Esteves, Pereira, Souza, Keller, Simões, Winkelstroter, & Rodrigues, 2016).

Formative Assessment: Formative assessments are low-stakes activities or assignments used in a classroom that provide feedback to the student (Black & Wiliam, 1998). In the context of this study, a formative assessment is defined as a short pre- or post-lab quiz used to prepare students for a laboratory activity or to assess their understanding and provide reflection after a laboratory activity. Formative assessments in the context of this study meet two the five key strategies of formative assessment, namely providing feedback that moves learners forward and activating students as owners of their own learning (Black & Wiliam, 2009, p. 8), but did not address the other three strategies proposed by Black and Wiliam.

Gram Stain: The Gram Stain is a differential staining technique developed by Hans Christian Gram in the early 1800s and distinguishes between different types of bacteria based on their cell wall characteristics (Ambivero, et al., 2017).

High-Road Transfer of Automaticity: Mindful application of learned practices and skills abstracted from the learning context. Skills have become automatic to the degree that a low-road skill is practiced in any situation (Salomon & Perkins, 2015).

Lateral Transfer of Complexity: Development and transfer of skills from one context to another that is at the same level of complexity, i.e., using skills and knowledge in other similar lab contexts (Gagné, 1965).

Learning Transfer: The theory of learning transfer is based in the idea that knowledge or skills learned in one context will be used in a different context (Greeno et al., 1993).

Low-road Transfer of Automaticity: Skills repeatedly practiced until they are mastered and can be applied to situations resembling the practice situation without effort (Salomon & Perkins, 2015).

Near Transfer of Context: Transfer of knowledge, understanding, or application of knowledge to future lab activities in MCB 3020, other labs or classes, or to other similar, yet nonspecific contexts (Mayer, 1975).

Quiz Exhaustion: For the purposes of this study, I define quiz exhaustion to be a gradual decline in the quality and specificity of student responses to reflection questions in the post-lab quizzes analyzed from the Summer 2016 semester. Students were asked essentially the same two questions in each quiz, and the qualitative evidence suggests that students had reached a point of saturation when asked questions about the application of lab knowledge, skills, and techniques to their future careers.

Summative Assessment: An assessment usually given at the end of a semester or instructional unit designed to determine students' comprehension of material (Lau, 2016). In the context of this study, summative assessments in general microbiology are lab practical midterm and final exams designed to evaluate students understanding of techniques and material learned in the laboratory section of the course. In MCB 3020, the lab practical midterm exam is given as a multiple-choice exam administered during the lecture section, with questions related to laboratory techniques, media, and test results. The lab practical final exam is given in the laboratory, with various stations set up around the room comprised of petri dishes, test tubes, or microscope slides that examine students' understanding of laboratory techniques, media, and test results.

Theoretical High-Road Transfer: Evidence of high-road transfer indicating the recognition of or observation of a habit or practice learned in MCB 3020 in a specific, yet future context. For example, students noted high-road habits of aseptic techniques while shadowing medical professionals. Because this study did not follow students longitudinally, evidence of high-road transfer was speculative at best.

Theoretical Vertical Transfer: Evidence of vertical transfer expressed by students indicating the use of a skill or technique learned in MCB 3020 in a specific, yet future context. Because this study did not follow students longitudinally, evidence of vertical transfer was speculative at best.

Transfer of Automaticity: Transfer of learning general transfer of learning that indicate specific development of a practice or habit. Comprised of low-road and high-road transfer (Salomon & Perkins, 2015).

Transfer of Complexity: Specific development of a particular skill in the lab. Comprised of lateral and vertical transfer (Gagné, 1965).

Transfer of Context: Transfer of knowledge, understanding, or application from one context to another. Comprised of near and far transfer (Mayer, 1975).

Urease: An enzyme produced by urinary-tract-infection-causing organisms (Musher, Griffith, Yawn, & Rosen, 1975)

Vertical Transfer of Complexity: Transfer of skills mastered in one situation to a more complex situation requiring application of those skills in a situation markedly removed from the practice situation (Gagné, 1965).

Organization of the Dissertation

Chapter One of this dissertation sets the stage for the context of the research conducted in this study, including the theoretical framework upon which this research is based, and my personal and professional motivations for conducting this research. Chapter Two reviews and critiques current research on the role of the laboratory in undergraduate science, theories of learning transfer, formative and summative assessment, cognitive load theory and other topics relating to improving student outcomes in undergraduate science labs. Chapter Three includes a description of the qualitative and quantitative methods used in this study. Chapter Four elucidates the results of the qualitative component of this study, and Chapter Five examines the results of the quantitative component of this study. Chapter Six concludes the dissertation with a discussion of the qualitative and quantitative results of the study, implications of its results, and recommendations for future research.

CHAPTER TWO: REVIEW OF THE LITERATURE

Constructs of Interest

The research conducted in this study builds on and contributes to earlier studies on the impact of formative assessments in facilitating transfer of learning in undergraduate science laboratories. Studies on this topic are important because they measure the degree to which laboratory skills are transferred from introductory science courses to higher-level laboratory courses, science research, or clinical applications. Although these earlier studies examined the impact of formative assessments on learning transfer in undergraduate physics, chemistry, engineering, and biology labs, they did not examine the impact of formative assessment on transfer of learning in undergraduate microbiology labs. As such, this study provides additional insight into the impact of formative assessments on improving student outcomes on summative assessments in undergraduate microbiology laboratory courses and facilitating transfer of learning of microbiology knowledge and techniques. The conceptual framework from studies on situative learning transfer and meta-communicative signaling provide additional insights to the transfer of learning from undergraduate science labs to future applications. In this section, I will examine the purpose, efficacy, and use of formative assessments in a laboratory in facilitating transfer of learning in undergraduate science courses in general and in microbiology in particular. I will also analyze formative assessments in physics, chemistry, engineering, and biology in facilitating transfer of learning. Although earlier studies on formative assessments in undergraduate science laboratories have identified improved performance on summative assessments in undergraduate laboratory courses, little analytic attention has been paid to the impact of formative assessments on improving student performance on summative assessments in undergraduate microbiology laboratory courses. Building on this analysis of prior research and scholarship, in this chapter I argue that a weekly formative pre-lab assessment will demonstrate the preliminary steps of learning transfer as measured by significant improvement in student scores on midterm and final lab practical summative assessments. I also argue that a weekly formative reflective activity will provide insight to transfer of learning through the analysis of candid student responses to open-ended questions regarding the relevance of microbiology to their future careers. Both the implementation of weekly pre-lab formative assessments and post-lab reflective activities will provide insight into the preliminary mechanisms of learning transfer among students in a general microbiology lab course at a large research university.

Research of Interest

Undergraduate Science Laboratory

The undergraduate science laboratory has historically been an essential component of the study of all aspects of science. The implementation of a laboratory section as part of science education has its foundations in the constructivist philosophies of John Dewey, who insisted that “there is an intimate and necessary relation between the processes of actual experience and education” (Dewey, 1938; p. 20). For decades the “actual experience” of science was most often encountered in the science laboratory rather than the science classroom. Unfortunately, most laboratory activities have been structured, confirmatory activities, in which students performed proscribed experiments of already well-established scientific knowledge (Hofstein & Lunetta, 1982; Kirschner &

Meester, 1988; Labov, 2004; Tobin, 1990). The undergraduate laboratory continues to be the norm in undergraduate science education despite criticisms that freshmen level science laboratories have changed little from the 1960s "cookbook" style confirmatory labs, and inquiry-based or authentic research-based lab activities are seriously neglected (Adams, 2009: DeHaan, 2005; Feisel & Rosa, 2005; Handelsman et al., 2004; Hodson, 1993; Hofstein & Lunetta, 2004; Hofstein & Manlok-Naaman, 2007; Kirschner & Meester, 1988; Labov, 2004; Laws, 1996; Toothacker, 1983). However, the microbiology laboratory is unique when compared to chemistry, biology, and physics laboratories because the nature of the microbiology lab, whether it be confirmatory, cookbook-style, or inquiry-based, necessarily requires students to be aware of microbes in the environment, to maintain sterility, and to inoculate media carefully and correctly to avoid contamination with unwanted microbes (Aruscavage, 2013; Baker & Verran, 2004; Rowley et al., 2010). The requirement for scrupulous attention to aseptic technique must be practiced by students who will one day be required to maintain sterile fields, prepare a patient for invasive procedures, observe proper hand washing, and use of PPE to prevent transmission of infection between patients.

Partially in response to the continued criticism of undergraduate introductory science labs, the American Academy for the Advancement of Science (AAAS) published recommendations for improving undergraduate biology education entitled, "*Vision and Change in Undergraduate Biology Education: A Call to Action*" (AAAS, 2011). *Vision and Change* outlines mechanisms for reforming undergraduate biology education through student-centered classrooms, which are "interactive, inquiry-driven, cooperative, collaborative, and relevant" (AAAS, 2011, p. 6). In response to the AAAS initiative, the

American Society for Microbiology (ASM) developed curricular guidelines to address the core concepts elucidated in *Vision and Change*, adding "The Impact of Microbes" as a core concept (Baker, Chang, Hung, Merkel, Siegesmund, & Smith, A, 2012). Additionally, ASM elucidated microbiology lab skills necessary for students to gain the knowledge and techniques necessary for proper aseptic technique and infection control in the research and clinical setting (ASM Curriculum Recommendations, 2012; Merkel, 2012). The purpose of these curricular guidelines in undergraduate microbiology courses is to address the shortcomings of most undergraduate science courses and more effectively prepare students in effective aseptic techniques and infection control practices.

While the guidelines suggested by the ASM are valuable and pertinent, they have yet to be universally applied in all undergraduate microbiology laboratory courses. Studies suggest that there is a deficit in knowledge of effective aseptic technique and infection control and in the ability to apply this knowledge and these techniques in practice (Cox et al., 2014; Jennings-Sanders & Jury, 2010; Kelcíkova et al., 2012; Wu, Gardner, & Chang, 2009). Respondents to semi-structured interviews regarding the efficacy of undergraduate microbiology labs indicated there was a gap between their theoretical knowledge obtained in prerequisite microbiology courses and their practice in the clinical setting. Respondents also reported a disconnect between the knowledge and techniques learned in the university and their real-world application in the clinical setting (Cox et al., 2014). An emphasis on the transfer of learning of aseptic techniques and knowledge from undergraduate introductory or general microbiology may reduce the gap between the theoretical knowledge of asepsis and its application in the clinical setting.

General Learning Transfer

Transfer of learning is a psychological educational construct that suggests that the training of students in one context will improve their ability to demonstrate that training in other contexts. Since the early 20th century, educational psychologists have endeavored to establish and measure transfer of learning, which has proven to be an elusive challenge. Yet, the theory of learning transfer is the root of all education – that a student will be able to apply the concepts and skills that they learned in primary, secondary, and post-secondary education in real-life circumstances. In the past 100 years, psychologists and educators have found that evidence of learning transfer is not only uncommon, it can be challenging to measure effectively. In the 1900s, the prevailing attitude among educational psychologists and theorists was that the mind was comprised of several general capabilities such as attention, discrimination, observation, and reasoning, and education trained these skills, making them stronger and more effective (Singley & Anderson, 1989; p. 3). In other words, general training in one area, such as the study of Latin, will improve learning or skill in another area, such as the study of mathematics. Edward L. Thorndike and Robert S. Woodworth conducted the earliest studies of learning transfer following the prevailing theories of the day, asserting that rigorous study of one subject would develop a student's "faculties of mind" and improve their performance or proficiency in other subjects (Woodward & Thorndike, 1901). However, Thorndike found no benefit in taking Latin on improving performance in any other academic subjects (Thorndike, 1923). Thorndike's theory of identical elements asserted that training in one area would only transfer to another area if elements were highly similar, eliciting a type of stimulus-response reaction (Singley & Anderson, 1989). John Dewey also refuted the idea of "mind as muscle" and training in one subject area for transfer into another subject area, asserting instead that when a general topic is learned, becoming skilled in activities that are “broad in scope” is the result, rather than actual transfer of learning (Dewey, 1916).

Because educational scholars continue to disagree about the nature of classical learning transfer, the degree to which it occurs, how it occurs, and how it is measured (Barnett & Ceci, 2002; Bransford & Schwartz, 1999; Packer, 2001; Royer, 1979), other theories of learning transfer must be explored to explain the transfer of learning of aseptic techniques in microbiology to other contexts, including clinical settings. In contrast to Woodward and Thorndike, Charles Judd asserted that any educational experience undertaken by students had the capacity to be transferred or generalized to other contexts (Judd, 1908). In a series of experiments in which students were taught how to hit an underwater target with a dart, Judd demonstrated that the students were able to transfer their understanding of compensating for refraction in calculating hitting underwater targets when the targets were presented at varying depths of water. Judd’s experiments indicated that meaningful training, rather than rote learning facilitated learning transfer effectively (Judd, 1908). Gestalt theorists such as Max Wertheimer distinguished between rote learning as an exercise of the mind and meaningful learning occurs when an individual sees clearly the interrelatedness between two situations (King, Wertheimer, Keller, & Crochetière, 1994). While Thorndike’s theory of identical elements focused mainly on training the mind as one would a muscle, Judd’s experiments and Wertheimer’s gestalt theory insisted that meaningful connections between similar situations were necessary for learning transfer to occur.

Types of Learning Transfer

While the early studies in learning transfer failed to definitively demonstrate learning transfer through rote memorization or exercise of the faculties of mind in educational settings, later researchers have identified different mechanisms by which transfer is theorized to occur. Robert Gagné theorized that there were two levels of learning transfer – lateral and vertical transfer. Lateral transfer occurs when a student is able to generalize learning from one context to another that has the same level of complexity (Gagné, 1965, cited in Royer, 1979; Singley & Anderson, 1989). Vertical transfer is the transfer of learning from low-level to high-level skills, but only occurs when low-level learning skills had been mastered (Singley & Anderson, 1989).

Another dichotomy of learning transfer was put forth by Richard Mayer was that of near and far transfer. Near transfer in this context refers to application of knowledge or skill that is very similar to the original learning context. Far transfer refers to a transfer situation in which the application of knowledge or skill is very different than the original learning context (Mayer, 1975; Royer, 1979).

Dreyfus and Deyfus (1980) proposed a five-stage process of skill acquisition that details the progression from novice to expert in a particular field, which in itself is a type of learning transfer. Progression from novice to expert can be observed in the behaviors as well as the expressions of the individual at each stage of development. As an individual progresses through a training program, they begin in a novice state in which they are given rules to follow in order to learn a task. The next stage in the progression is competence, in which the individual recognizes patterns, or "aspects" (Dreyfus & Dreyfus, 1980, p. 8) within the context in which they work. Next, the individual achieves proficiency in performing a task, and can do so in different contexts or from different perspectives. The fourth step in novice to expert progression is expertise, in which an individual can intuitively and appropriately respond to a task, regardless of the situation. Finally, an individual achieves mastery, in which,

> "…the expert, who no longer needs principles, can cease to pay conscious attention to his performance and can let al.l the mental energy previously used in monitoring his performance go into almost instantaneously the appropriate perspective and its associated action" (Dreyfus & Dreyfus, 1980, p. 14).

The Dreyfus and Dreyfus five-step novice-to-expert progression model has been studied in the medical and nursing professions as an effective training method for novices in these professions (Benner, 1984; Gentile, 2012; Hoffman, Aitken, & Duffield, 2009; Sisson, 1991; Quick, 2016; Wouda, & van de Weil, 2012). The majority of the student population studied as part of this research were in pre-medical, pre-dental, pre-nursing, and pre-physician's assistant degree programs and were primarily at the novice stage of the Dreyfus and Dreyfus model. The procedures and aseptic guidelines implemented in a general microbiology class paved the way for learning transfer through progression from novice to competence.

A final theory of learning transfer is proposed by Salomon and Perkins, who explore low-road and high-road transfer. Low-road transfer occurs when certain skills repeatedly practiced until they are mastered and become nearly automatic. These skills can then be applied to situations resembling the practice situation without effort (Perkins & Salomon, 1992; Salomon & Perkins, 2015; Singley & Anderson, 1989). Low-road transfer is mainly reflexive and is triggered by similarities in stimuli in different situations (Perkins & Salomon, 1989). High-road transfer involves the mindful application of learned practices and skills to situations abstracted from the learning context (Bassok, 1990; Gick & Holyoak, 1983; Salomon & Perkins, 2015; Salomon & Perkins, 1989). High-road transfer involves a level of application beyond simple stimulus and requires the student to apply basic principles or skills learned in one setting to unrelated environments.

An example of low-road transfer of skills from the microbiology lab would be washing one's hands and disinfecting surfaces upon entry to a laboratory. Hand washing and disinfecting surfaces is practiced every time a student enters the microbiology lab, and according to the theory of low-road transfer, this habit would become automatic and would easily transfer to a very similar clinical setting. An example of high-road transfer would be the application of surgical aseptic techniques used by the PICC team to insert a central line into a patient. The principles of aseptic technique learned in a microbiology laboratory are applied in a scenario completely removed from the original learning environment. Perkins and Salomon (2015) suggest that individuals use both low-road and high-road transfer, and the dual use of transfer may explain why earlier studies of learning transfer have failed.

> Not enough time is allocated for practice for the former [low-road], and not enough attention is given for mindful abstraction for the latter [high-road]. As a consequence, neither near automatic transfer on the basis of easily recognized common elements, nor farther transfer on the basis of metacognitively guided mindful abstraction can be attained (p. 98).

Lateral/vertical transfer, near/far transfer, novice to expert, and low-road/high-road transfer are similar to each other in that they express dichotomies or transitions of learning transfer situations. However, each explains a different aspect of learning transfer. As outlined in the table below, lateral vs. vertical transfer is concerned with learning transfer in differing levels of complexity of skill. Near vs. far transfer is concerned with the transfer of skills in different contexts. Novice to expert learning transfer explains a progression of skill acquisition. Finally, low-road vs. high-road learning transfer are concerned with the automaticity of skill.

Table 1: Progression of Learning Transfer

Type of Transfer		Explanation	Researcher(s)
Lateral	Vertical	Transfer of complexity	Gagné, 1965
Near	Far	Transfer of context	Mayer, 1975
Novice	Expert	Transfer of expertise	Dreyfus & Dreyfus, 1980
Low-Road	High-Road	Transfer of automaticity	Salomon & Perkins, 2015

The study described in this dissertation primarily explored the preliminary stages of learning transfer in terms of how the intervention of pre- and post-lab quizzes facilitated transfer of microbiology knowledge and laboratory skills from the laboratory activities to the lab practical midterm and final exams. Pre- and post-lab quizzes encouraged lateral, low-road, near, and novice-to-competent transfer because they required students to review laboratory knowledge and skills prior to their practice in each lab activity in order to be successful on the quiz. Pre-lab quizzes focused mainly on low-level Bloom's taxonomy learning such as remembering and understanding, and promoted transfer between similar circumstances of complexity. (See Appendices H and I for the pre-lab quizzes implemented in Fall 2016 and Spring 2017 semesters). Learning transfer was demonstrated through improvements in midterm and lab practical exam scores, because although lab practical exams are a summative assessment of laboratory knowledge and skills, the level of complexity is similar to that found in the weekly lab activities, and therefore encourages lateral, near, or novice-to-competent transfer. Since the lab practical and midterm exams did not require students to apply their knowledge to different contexts or laboratory applications; the transfer of skill in this context was mainly lateral transfer. The general microbiology lab encouraged low-road skills such as aseptic transfer between test tubes, aseptic inoculation of petri dishes, and other aseptic habits such as hand washing before and after the lab and disinfection of surfaces. The development of these skills and practices helped students to develop an awareness of microbes in the environment and laid the foundation for aseptic skills and practices in future laboratory settings and for some students, in the clinical or research setting. It was beyond the scope of this study to determine novice-to-expert transfer of learning, and this component of learning transfer was not considered in this study.

Situated Transfer of Learning

Another theory that may explain the transfer of learning from the microbiology lab to other settings is the theory of situated transfer, which suggests that the social context in which learning occurs improves transfer of learning (Forman & Ansell, 2001; Greeno et al., 1993; Lave, 1996; Lave, 1991). Greeno et al. (1993) suggest that situated transfer of learning "…occurs as people engage in activities, and the meanings and significance of objects and information in the situation derive from their roles in the activities that people are engaged in" (p. 100). Lave emphasizes the apprenticeship model as an important aspect of social learning stating that apprenticeship facilitates mastery of skill without didactic instruction (Lave, 1991; p. 64). However, other authors insist that the educational benefits of situative learning are overstated (Anderson, Reder, & Simon, 1996).

In general, the undergraduate general microbiology laboratory serves as one social context for learning of aseptic technique as best practices are taught and modeled to students who practice these techniques in a low-stakes environment. Ideally, lab instructors model effective aseptic techniques to the students, and students pick up on these social cues by copying these techniques as they perform laboratory exercises. The social structure carries over to the clinical context, as apprentice doctors and nurses take their cues from their trainers with respect to proper aseptic techniques. In fact, Lave asserts that the apprenticeship model facilitates learning through "demonstration, observation, and mimesis" (Lave, 1996). Other researchers suggest that in professional apprenticeship settings "'experts' initiate 'novices' into particular worlds of cultural and social competence" (Jacoby & Gonzalez, 1991; p. 150). Apprenticeship models are frequently utilized in clinical training settings in which medical doctors or senior nursing staff train medical students or novice nurses through demonstration of specific techniques followed by observation and critique of novice performance. Additionally, apprenticeship models are also found in non-clinical research settings as well, where senior researchers train novice researchers in bench lab techniques (Latour & Woolgar, 1979).

Unfortunately, some social settings may have an adverse effect on the transfer of learning from the microbiology lab to the clinical setting. In one study, medical students on rounds with doctors were less likely to wash their hands between patients if the rounding physician did not wash their hands (Cox et al., 2014). However, the same study noted the positive influence of "good clinical leadership" in reinforcing good infection control practices and modeling appropriate practices. The theory of situated transfer of learning must be further explored to determine how the social context of learning impacts transfer of learning in the microbiology lab, however, the study of situated learning transfer is beyond the scope of this study and is an area of future research. Nevertheless, because MCB 3020 is a type of situated learning where Graduate Teaching Assistants (GTAs) or course instructors serve as mentors, situated learning transfer may have indirectly occurred and influenced the outcomes of this study.

Contexts for Learning Transfer

A facet of situative learning known as "intercontextuality" occurs when two or more contexts are connected with each other (Engle, 2006; Greeno, 2006). Intercontextuality of transfer occurs when two related contexts are similar enough to each other such that students will see the relationship between the two contexts and thus learning transfer occurs. For example, the microbiology lab is a highly structured environment, in which students are expected to maintain PPE, maintain or protect sterile fields, and be conscious of the microbes in their environment. In the clinical setting, healthcare professionals are also expected to maintain PPE, protect sterile fields, and be conscious of microbes in the environment when performing invasive procedures on patients. There is a high degree of similarity between these two contexts, and this intercontextuality may facilitate transfer of learning from the microbiology laboratory to the clinical setting. The study of learning transfer from an instructional laboratory setting to a clinical setting is beyond the scope of this particular study and is an area of future research. However, because this contextual similarity exists, it may indirectly contribute to learning transfer in this study.

Additionally, utilizing meta-communicative signals within a learning context assists students in transfer of learning (Goffman, 1974; Gumperz, 1982). Goffman emphasized two types of frameworks that assist learning transfer: natural frameworks and social frameworks. Social frameworks in particular guide individuals to what can be considered “guided doings” (Goffman, 1974, p. 22). Additionally, Goffman theorized that social frameworks involve specific rules and expectations for individuals to follow. The idea of social frameworks can be translated to the microbiology lab, which is a type of a social setting with strict rules that students must follow in order to function in that social setting. Meta-communication informs students what they are doing in a given context, why they are doing it, and why the activity may be important to them (Floriani, 1993; Tapper, 1999). In this way, meta-communication forms a context for learning that also facilitates learning transfer. An example of meta-communicative signaling in microbiology laboratory context could occur when an instructor utilizes an example from a current laboratory exercise and explains how a specific principle can be applied to a clinical setting. The lab instructor could remind the students that the surface of the Petri dish is sterile, and exposure of the sterile surface should be limited to prevent contamination from microbes in the air. The instructor could liken the sterile surface of a Petri dish to a surgical scar covered in sterile dressings and discuss how care should be taken when changing the dressings to avoid contamination from airborne microbes. The preceding example may or may not occur during the instruction portion of the microbiology lab and is a personal example of a technique that I practice in my own instructional experience. Meta-communication creates intercontextuality by linking the social context of the microbiology lab with the future clinical setting in which students will be required to transfer learning of aseptic techniques and infection control. However, establishing situative learning, creating intercontextuality, and providing meta-communication is contingent on the instructor of the course using these techniques regularly and consistently. Because GTAs or lab instructors with limited clinical experience primarily teach MCB 3020, they may not have established situative learning, created intercontextuality, or provided meta-communication as they instructed students in the context of this study. The use of meta-communication and creating intercontextuality is another area for future research in order to determine if these techniques facilitate learning transfer to clinical practice from MCB 3020. However, if GTAs or lab instructors utilized any of these situative learning, intercontextual, or meta-communicative techniques, they may have indirectly contributed to learning transfer in this study.

Cognitive Load Theory

Another important consideration when studying the difficulties students encounter in the microbiology lab is cognitive load theory. Cognitive load theory is based on the hypothesis that the short-term, or working memory of students has a limited capacity (Baddeley, 1992; Bannert, 2002; Sweller, 1998 Weinberg & Berg, 2007). In learning situations, Bannert (2002) suggests that there are three types of cognitive load that impact working memory: a) intrinsic cognitive load (ICL) related to the nature of the material to be learned; b) extraneous cognitive load (ECL) that does not relate to learning, but is related to the constructs of the learning environment; and c) germane cognitive load (GCL), in which free working memory can be allocated for more profound and meaningful learning. In an introductory undergraduate laboratory situation, students' focus on manual dexterity in manipulating test tubes and lab instruments or organization of lab materials can lead to high ICL, and can detract from deep understanding of the concepts being learned, or GCL. Introductory laboratory situations often have both high ICL and high GCL, in which students are simultaneously required to master laboratory techniques and skills at the same time as they are required to understand and internalize the outcomes of laboratory experiments. High ICL may interfere with leaning transfer in the MCB 3020 lab as students are require to learn and master techniques such as aseptic technique two-tube transfer, the three-zone streak technique, the Gram stain, and other techniques unique to microbiology.

The demands of high ICL in the laboratory can detract significantly from GCL in introductory laboratory situations. Research suggests that the introduction of pre-lab activities can help reduce ICL and allow students to focus on deeper understanding in the lab. For example, Weinberg and Berg (2007) implemented a computer-based pre-lab titration simulation in an introductory chemistry course. The titration simulation assisted students in qualitative understanding of titration and data gathering strategies. After completing this exercise, students performed a titration activity in the class. Qualitative results of the study indicated that students who performed the online titration simulation demonstrated greater theoretical concept knowledge than students who had not completed the exercise. Other studies indicate that pre-lab activities and lab simulations can improve student learning outcomes and theoretical concept knowledge by reducing ECL (Gregory & Trapani, 2012; Scharfenberg & Boger, 2013; Srisawasdi & Panjaburee, 2015). Studies such as these suggest that pre-lab activities reduce ECL and can facilitate learning transfer in introductory science courses. Cognitive load theory may have an impact on learning transfer in the context of the MCB 3020 lab as effective and meaningful transfer of automaticity, transfer of complexity, and transfer of context may be impacted by high ECL in lab exercises.

Transfer of Learning from Coursework to Clinical Practice

A number of studies explore the transfer of learning from educational settings such as the classroom and laboratory to clinical practice. Feldman (1969) attempted to determine whether programmed instruction in a nursing program translated to “motor behavior” demonstrated as proper asepsis in a clinical setting. Students were given a paper-and-pencil pre- and post-achievement test to determine their understanding of programmed instruction. Students were then exposed to six situations that simulated common scenarios in the clinical setting and rated on the degree to which they followed the procedures they were taught in their course. In this study, researchers determined that the curriculum of programmed instruction transferred to proper practice of aseptic technique in clinical practice based on improvement on posttest scores. Other studies have shown success in transfer of aseptic technique (Yoder, 1993), basic nursing skills (Gomez & Gomez, 1987), hand washing (Larson & Lusk, 2006), clinical procedures (Kneebone, Kidd, Nestel, Asvall, Paraskeva & Darzi, 2002; Maginnis & Cruzon, 2010), and infection control (Goldrick, Appling-Stevens, & Larson, 1990) through the use of programmed instruction prior to clinical practice. However, all of these studies were conducted with pre-nursing or pre-medical students. There is a dearth in the literature with respect to the learning transfer based on programmed instruction and assessment of learning transfer in prerequisite microbiology courses for pre-medical, pre-nursing, pre-pharmacy, or pre-allied health students. Additionally, learning transfer must be assessed in order to confirm that it has occurred, and assessment of learning transfer can be challenging, especially with respect to aseptic techniques learned in the microbiology laboratory.

Role of Formative Assessment in Encouraging Learning Transfer

Learning assessment in undergraduate science laboratories can take many forms, but the most common assessment measures employed are "practical" exams, usually given at midterm and at the end of the semester. High-stakes summative assessments such as these are less effective methods to assist learning transfer because the volume of material is so great, cannot address individual students' learning needs, and does not give feedback on specific learning difficulties (Black, 1993; Black & Wiliam, 1998; Black & Wiliam, 2009; Boston, 2002; Bryce & Robertson, 1985; Sadler, 1989). Some researchers suggest that summative assessments or terminal examinations in science courses only give a limited perspective on student achievement, and that continuous formative assessments may afford greater gains in student outcomes (Bryce & Robertson, 1985). Black and Wiliam suggest five key strategies of formative assessment:

1. Clarifying and sharing learning intentions and criteria for success;
2. Engineering effective classroom discussions and other learning tasks that elicit evidence of student understanding;
3. Providing feedback that moves learners forward;
4. Activating students as instructional resources for one another; and
5. Activating students as the owners of their own learning. (Black & Wiliam, 2009, p. 8)

The formative assessments utilized in this study primarily address Black & Wiliam's third strategy of providing feedback that moves students forward. However, this study may also have a secondary effect of activating students as the owners of their own learning, which is the fifth strategy proposed by Black and Wiliam. Further research may be necessary to measure how formative assessments in this context activate students as owners of their own learning.

The research on the impact of formative assessment on summative assessments is mixed. Harlan & James (1997) insist that formative and summative assessments are often conflated and that neither provide effective assessment of students' abilities. Tarras (2005) cites Scriven (1967) in asserting that formative assessments are merely summative assessments with feedback, and that formative assessments are simply summative assessments in a different context (p. 471). Knight (2002) suggests that summative assessments used in higher education are in "disarray" and that the implementation of formative assessments promote student learning through feedback about their work (p. 284). Other researchers claim that frequent testing through formative assessment only results in modest gains by students (Crooks, 1988). Still other researchers assert that in order to improve their performance, students need to have feedback on their progress, but that it must be qualitatively judged (Sadler, 1989). In particular, some researchers suggest that although teachers implement formative assessments, most do not reflect on what is being assessed (Black & Wiliam, 1998, p. 17).

Research in the K-12 setting shows the utilization of formative assessments benefits low-achieving students and enhances their learning through the frequent feedback provided to the student and allows the instructor to adapt the curriculum based on results of formative assessments (Fuchs, Fuchs, Karns, Hamlett, Katzaroff, & Dutka, 1998). Further, formative assessment has not been studied extensively in higher education, and theories underpinning the use of formative assessment in higher education are not fully developed (Boud, 2000; Yorke, 2003). Regardless of these disparate findings on the benefits of formative assessment, the general consensus among education researchers is that formative assessment of students provides meaningful feedback to students with respect to their progress and improves achievement on summative assessments in the K-12 setting (Black, 1993; Black & Wiliam, 2009; Boston, 2002; Bryce & Robertson, 1985; Crooks, 1988; Etkina et al., 2006), yet there is a dearth in the literature of the positive effect of formative assessments on summative assessments in higher education. Additionally, the large class sizes and laboratory sections frequently found in higher education make immediate alterations to curriculum based on results of formative assessments challenging.

In addition to the dearth of literature demonstrating the efficacy of formative assessment in higher education, there is even less evidence of the use of formative assessments in science laboratories in general and a paucity in the literature on formative assessments in microbiology labs in particular. Formative assessments have been utilized in virtual engineering laboratories to improve higher-order thinking skills (Koretsky, Maatore, Barnes, & Kmiura, 2008). Other studies explore the use of performance-based lab assessment technique (PBLAT) to assess the psychomotor domain of learning and improve students' manipulation skills (Chabalengula, Mumba, Hunter, & Wilson, 2009). Another study explored the use of online pre-lab assessments as formative assessments to prepare students for lab practical exams in introductory biology courses (Cann, 2016). Basey, et al. (2014) explored the use of pre-lab activities and post-lab reports in a plant biodiversity lab to promote higher-order learning skills in undergraduates and improve student engagement. Green (2007) demonstrated correlations between improvements in exam scores and frequent formative assessments in the form of pre-lab online quizzes in geoscience courses. Yet, none of these studies explore the use of pre-lab formative assessments to encourage transfer of learning in introductory microbiology courses.

The Role of Reflection in Facilitating Transfer of Learning

Another important, yet neglected aspect of the undergraduate science laboratory is reflection on the activities performed and the discoveries made in the lab. John Dewey advocated reflective practices in education as early as 1933, and reflection has been a common theme among education researchers as a mechanism for exploring and framing their learning experiences (Boud, 1999; Boud & Walker, 1991; Dewey, 1933; Hébert, 2015; Mezirow, 1981; Schön, 1983). Kolb's theory of experiential learning suggests that reflection is vital in connecting abstract topics with hands-on activities (Kolb, 2015). Tobin suggests that, "Time for reflective thinking is crucial, even when psychomotor skills are the main goals of an activity" (Tobin, 1990; p. 407). Several studies suggest that incorporation of a reflective component in postsecondary science laboratory education may assist students in creating connections between the abstract concepts in the lecture and hands-on activities in the lab. For example, some studies explore the benefits of implementing reflective practices in engineering education (Abdulwahed & Nagy, 2009), medical technology education (Archavarungson, Saengthong, Riengrojpitak, Panijpan, Ruenwongsa, & Jittam, 2011) agricultural education (Baker, Robinson, & Kolb, 2012), computer engineering education (Botelho, Marietto, Ferreira, & Pimentel, 2016), geology education (Healey & Jenkins, 2000), and physics education (Dounaz-Frazer & Reinholz, 2015). The studies cited above all demonstrate the benefits of reflection in undergraduate science laboratories, yet the literature demonstrating the benefits of reflection in undergraduate microbiology laboratories is lacking. Additionally, a number of studies explore the need for reflective practices in healthcare professions (Mann, Gordon, & MacLeod, 2009; Hargreaves, 2016; Sanders, 2009). Given the research on the utilization of reflective practices in healthcare professions, it is important to establish these reflective practices in pre-medical, pre-nursing, pre-pharmacy, or pre-allied health prerequisite courses, such as microbiology, to foster reflective learning in healthcare professionals. The research conducted in this research study aimed to address these deficits in the literature on reflective activities in undergraduate microbiology labs.

The research in this study will address the deficits in the literature with respect to learning transfer of skills learned in the microbiology laboratory to other contexts, specifically to midterm and final lab practical summative assessments. Additionally, this study aims to observe and measure the effects of the first small step in low-road, lateral, and near learning transfer in microbiology labs from weekly lab formative assessments to midterm and final lab practical summative assessments with the ultimate goal of facilitating learning transfer of skills learned in the undergraduate microbiology lab to clinical practice. Finally, the research described in this study will address deficits in the literature with respect to students' experiences in undergraduate microbiology laboratory and how students perceive the application of the microbiology lab to their future careers through analysis of responses to open-ended reflection questions.

CHAPTER THREE: RESEARCH METHODOLOGY

The study described in this dissertation was a mixed-method quasi-experimental design with historical control group (Creswell & Plano-Clark, 2011; Edmonds & Kennedy, 2013). The quasi-experimental design was chosen due to the difficulty of implementing a strict randomized selection of control and test subjects in a large lecture section with individual lab sections and implementing an intervention among students in the same semester cohort.

Research Design Overview

Context of the Study and Research Population

The research design for this study was based on the implementation of formative assessments in the laboratory section of a general microbiology course (MCB 3020) at UCF. MCB 3020 was comprised of a single large lecture section with multiple lab sections. In the Summer 2016 semester of the course, there was one lecture section comprised of approximately 350 students and seven laboratory sections comprised of approximately 50 students each. In the Fall and Spring semesters of the course, there was one lecture section comprised of approximately 650 students and 13 laboratory sections comprised of approximately 50 students each. This population represents a convenience sample of participants participating in MCB 3020 at UCF during the study period.

Intervention Design

The intervention design for this study had two components: a post-lab formative assessment in the form of a post-lab quiz administered online through the UCF learning management system and a paper-based free-lab formative assessment administered at the beginning of each lab activity. The post-lab formative assessment was composed of three low-level Bloom's taxonomy questions with two open-ended reflection questions that probed students on their experiences in the lab and difficulties that they faced during each week's lab activity. The post-lab quizzes were designed both by the lab manager of the course and myself prior to their implementation. The post-lab formative assessments were implemented during the Summer 2016 semester (see Appendix B for post-lab quiz questions with reflection questions). The second intervention for this study was the implementation of pre-lab formative assessments in the form of paper-based pre-lab quizzes comprised of five low-level Bloom's taxonomy questions designed by the lab manager of the course. Pre-lab quizzes were implemented in the Fall and Spring semesters of the 2016 school year. (See Appendix F for pre-lab quiz questions for the Fall 2016 semester and Appendix G for pre-lab quiz questions for the Spring 2017 semester).

Research Design

The research design for this study was a mixed methods quasi-experimental design with historical control group. The mixed methods quasi-experimental design was chosen due to the difficulty in implementing a strict experimental design with a large lecture section divided into individual lab sections. Additionally, experimental designs with individuals who are aware that they are a part of an experiment may suffer from the Hawthorne effect and the novelty and disruption effect, resulting in a change in behavior or performance that affects the outcome of the experiment (Gall et al., 2007; p. 390-391). A quasi-experimental design eliminates the Hawthorne effect and the novelty and disruption effect because all individuals in the intervention group are compared with a control group not associated with the intervention group. In this study, the pre- and post-lab formative assessments were implemented as part of the curriculum for MCB 3020, which necessitated comparison of student scores during the intervention implementation with a historical control group that had no such intervention. Grades from summative lab practical midterm and final exams from the Fall 2015 and Spring 2016 semesters were compared with grades from post-intervention summative lab practical midterm and final exams from the Fall 2016 and Spring 2017 Semesters.

The qualitative component of this study was an embedded mixed methods design in which the supplemental qualitative aspect is inserted within the larger quantitative study, with the qualitative aspect enhancing and elaborating on the quantitative component (Creswell & Plano-Clark, 2011; Creswell & Plano-Clark 2007). Because the data on the qualitative component of the study was collected before implementation of the quantitative component of the study, student responses to the open-ended reflection questions in the post-lab assessments provided insight to student experiences in the lab prior to the quantitative intervention. The embedded mixed methods design was chosen because the researcher has limited experience with qualitative research design, and the post-lab open-ended reflection questions were designed to support and augment the quantitative aspect of the study.

Threats to Internal Validity

The quasi-experimental design with historical control group suffers from the following threats to internal validity: history, maturation, statistical regression, and selection bias (Edmonds & Kennedy, 2013; p. 34; Gall, Gall, & Borg, 2007). The historical threat to validity was ameliorated due to the fact that the comparison of summative assessments occurred between similar semesters that are one year apart (Fall 2015 compared to Fall 2016 and Spring 2016 compared to Spring 2017), and because the lecture section of each semester was taught by the same instructors, the curriculum was similar in all respects except for the pre-lab intervention and post-lab reflection questions (Gall, et al., 2007; p. 384). However, there was some variation in instruction in each lab section because each of the lab sections was taught by different graduate teaching assistants (GTAs) and lab instructors.

Maturation is defined as "physical or psychological changes in the research participants [that] are likely to occur" (Gall, et al., 2007; p. 385). Maturation was a factor in the research design described in this study, and any gains on lab midterm and final exam may be due to changes within the research participants rather than the transfer of learning. However, because students in both the historical control group and the test group will have the same rate of maturation from lab practical midterm to lab practical final, maturation was not a significant threat to validity in this study.

Statistical regression is the "tendency for research participants whose scores fall at either extreme to score nearer the mean when the variable is measured a second time" (Gall, et al., 2007; p. 385). Statistical regression may occur if students score a high grade on the lab midterm exam but score closer to the mean on the lab practical final exam. Selection bias has a major effect on this study due to the fact that the groups under study are not randomized, represent a convenience sample within a limited population, and may not be representative of all general microbiology students within the US. However, since all students in each semester were involved in the pre-lab formative assessments and post-lab reflection questions, the sample will represent the entire population of students in MCB 3020 during the semesters sampled. Additionally, propensity score analysis statistical procedures reduced sampling bias during data analysis (Bai, 2011b).

Clarification of Personal Bias

As the primary researcher for this study, I have extensive experience as a microbiology instructor and have a personal investment in positive student experiences in microbiology, as well as improvement of asepsis and infection control practices in clinical settings. As a final validation strategy, I will clarify and elucidate my personal biases in the qualitative data collection process, utilize a second coder in the coding process, and subject the results of the qualitative data interpretation to an external review (Creswell, 2013; p. 251).

Data Collection Procedures

After application for Internal Review Board (IRB) approval for this study, it was determined that since students' identifying information was scrubbed from all data analysis, IRB approval was not necessary for this study. See Appendix A for the IRB Outcome Letter for this study. The UCF Office of Institutional Knowledge Management (IKM) provided the anonymized student grades and demographic information for statistical analysis. Anonymized pre- and post-intervention scores on lab practical midterm and final exams were statistically matched using propensity score analysis (Bai, 2011a; Bai, 2011b; Guo & Fraser, 2015; Olmos & Govindasamy, 2015; Pan & Bai, 2015) to determine the effects of the formative pre-lab quiz summative midterm and final lab practical exams. Additionally, open-ended reflection questions from post-lab reflection questions given during the Summer 2016 semester were coded to determine emerging themes as described below.

Data Analysis

Qualitative analysis procedures

The implementation of post-lab quizzes with reflection questions occurred during the Summer 2016 semester. Thematic content analysis was utilized to study anonymized student responses to open-ended questions using NVivo software (Altheide, 2007; Altheide, 1987; Braun & Clarke, 2006; Creswell, 2013; Sandelowski & Barroso, 2003; Vaismoradi, Turunen, & Bondas, 2013). Thematic content analysis was chosen for the qualitative component of this study because it is a dynamic approach to qualitative data analysis that can be employed in various theoretical frameworks to describe the experiences of individuals (Braun & Clarke, 2006). *A priori* codes were developed based on the literature review on learning transfer. Codes of emergent themes were organically developed during the coding process. The most salient codes emerging from the students' experiences from each free response post-lab assessment were included in the analysis (Creswell, 2013; p. 186).

Three forms of triangulation were employed to assure validation and reliability of themes emerging from the qualitative data. First, one other researcher along with the primary researcher was employed to provide dual perspectives on the codes developed for open-ended reflection questions. Both researchers collaborated regularly to identify and clarify emerging themes. Each coder worked independently, and regular intercoder agreement checks were conducted to assure reliability of the coding process (Creswell, 2013; p. 254). Second, an outside peer review group was utilized to provide an “external check of the research process” (Creswell, 2013; p 251). During the coding process, preliminary results were presented students in the Spring 2017 Ethnography course (EDF 7473). These peer reviewers provided perspective and debriefing in emerging themes as well as assisting to revise qualitative research questions based on new perspectives on the themes emerging from the data. Finally, an external audit of the qualitative findings was conducted by an individual not related to the study to provide an assessment of the accuracy of the findings and determine if the findings are supported by the data (Creswell, 2013; p. 252).

Quantitative analysis procedures

Propensity score analysis was chosen for data analysis for this study because it is an effective statistical analysis method that controls for bias in non-randomized samples or non-standard experimental designs (Bai, 2011b; Guo & Fraser, 2015; Hahs-Vaughn & Onwuegbuzie, 2006; Luellen, Shadish, & Clark, 2005; Pan & Bai, 2015; Shadish & Steiner, 2010; Thoemmes, 2012). In an experimental design, individuals are randomly assigned to an intervention and a control group to assure that each group is identical in every possible way such that if a difference is found between the groups, the difference can be attributed to the intervention. Bias is eliminated in experimental designs because each individual in the study has an equal probability of being selected for the treatment or control group (Gall, Gall, & Borg, 2007). Additionally, in a randomized experiment, all data collected includes all covariates that are possibly related to the outcome of the experiment (Rosenbaum & Rubin, 1983).

However, the study described here is a quasi-experimental design with a historical group of students assigned as the control groups (Fall 2015 and Spring 2016) and with an intervention conducted during two cohorts (Fall 2016 and Spring 2017). Unfortunately, quasi-experimental designs may not be unbiased due to covariates that impact the historical control group and intervention group, and any differences between the two groups may be due to the non-random assignment to treatment and control groups and may not be due to the intervention (Luellen, Shadish, & Clark, 2005). Propensity score matching has been used in many studies when random assignments to control and treatments are not practical or ethical, such as in medical studies where the control group would suffer inordinately due to lack of treatment.

To conduct propensity score matching, individuals were assigned a propensity score, which is a conditional probability that an individual will be in the control group or the experimental group, based on a set of covariates used to predict whether the individual is in the control or intervention group (Luellen et al., 2005; Rosenbaum & Rubin, 1983; Rosenbaum & Rubin, 1984; Shadish & Steiner, 2010). Logistic regression using a SAS logistic regression program was the method used in this study to create propensity scores for the students in the historical control groups and intervention groups (Lanehart, Rodriguez de Gil, Kim, Komrey, & Lee, 2012) as well as statistically comparing the matched groups. In quasi-experiments, propensity scores range from 0 to 1, depending on an individual's propensity for being in a particular group based on the prediction of the covariates. An individual with a propensity score close to 0 is more likely to be in the control group while an individual with a propensity score close to 1 is more likely to be in the intervention group. In contrast, each individual in a randomized experiment has a propensity score of 0.5, or a 50 per cent chance of being in the control or intervention group. A caliper, or maximum allowable difference between to individuals, was utilized if a one-to-one match could not be performed (Luellen et al., 2005; Shadish & Steiner, 2010; Thoemmes, 2012). For this study, the caliper was set to allow a ten per cent difference in propensity scores in order to perform a match between individuals. Propensity scores were then used as weights to balance the historical and intervention groups and to create equivalent groups that could be compared statistically. Finally, a paired t-test analysis was performed to determine if there were significant differences between the control and intervention groups.

CHAPTER FOUR: QUALITATIVE RESULTS

Introduction

Student responses to post-lab reflection questions were collected during the Summer 2016 semester in MCB 3020 at UCF. Ten post-lab quizzes were implemented over the course of the semester that were comprised of three low-level Bloom's (Bloom, 1969) multiple choice questions and two free response questions that related to the lab activities of the previous week. Each of the free response reflection questions was worded similarly. The first free response reflection question was, "What aspect(s) of lab exercises x and y were most challenging for you? Explain your answer in the space below." The second free response question was, "What aspect(s) of lab exercises x and y were most important for you in preparing for your future career? Explain your answer in the space below." See Appendix B for each of the post-lab quizzes with their respective reflection questions. Between 260 and 300 students responded to each of the free response questions in ten post lab quizzes, resulting in nearly 6000 responses available for qualitative coding. Because of the volume of potential responses, initially quizzes one, five, and ten were chosen for coding to represent the beginning, middle, and end of student experiences in MCB 3020. However, it became clear during the coding process, and based on feedback from peer reviewers, that these three quizzes were not a representative sample of student responses and experiences in the lab. Therefore, a total of six quizzes (quizzes one, three, five, seven, nine, and ten) were chosen as representative samples of student responses that would describe the longitudinal arc of student experiences in MCB 3020. Finally, it was noted that students were experiencing "quiz exhaustion" by post-lab quiz 10; many responses were short, did not contain meaningful reflection, and were coded as "nonsense," therefore, quiz nine was included to represent an end point to the arc of student reflective experience in this study. Each coder selected a random sample of 100 responses to code, resulting in a total of 200 samples from each lab quiz and approximately 1200 total samples from the quizzes in the study to reach a level of saturation. The remaining quizzes (two, four, six, and eight) will be analyzed in future studies.

Because each quiz covered different laboratory skills and techniques, these skills and techniques were taken into consideration when coding for Transfer of Automaticity and Transfer of Complexity. For example, in lab exercise one, students learned how to use the pipette. In lab exercise 15, part one, use of the pipette skills were revisited in the water testing activity, and students were assumed to have achieved a level of competency with using the pipette when they reached this lab exercise based on their experience with the pipette in lab exercise one. Table 2 elucidates the lab skills and techniques learned or used in each lab activity in the lab quizzes coded for this component of the qualitative analysis.

Table 2: Lab Skills and Techniques Learned in MCB 3020 in Summer 2016

Lab Quiz	Lab Activities	Skills or Techniques Learned or Used
1	Exercise 1	Lab Safety
		Lab Attire and Personal Protective Equipment
		Aseptic Technique
		Two-Tube Transfer
		Pipette Use
		Use and Sterilization of Inoculating Loop
		Use of Bunsen Burner and Microincinerator
		Inoculation of Media
	Exercise 2	Smear Preparation: from broth and plated cultures
		Dyes Used in Staining
		Simple Stain
		Negative Stain

Lab Quiz	Lab Activities	Skills or Techniques Learned or Used
		Microscopy: parts of the microscope, use of oil immersion lens, illumination, magnification, resolution
3	Exercise 5	Pure culture techniques Pour Plate Isolation Technique Organization of Materials: labeling test tubes Inoculation of Petri Dishes Two-Tube Transfer Three-Zone Streak Plate Method
5	Exercise 8	Inoculation of Petri Dishes Two-Tube Transfer Inoculation of Broth Cultures Inoculation of Agar Slants Interpretation of Media: Milk Agar, Starch Agar, Litmus Milk, Phenol Red Broth, Kliger's Iron Agar
7	Exercise 10, part 2	Identification of *Streptococcus* species on Blood Agar Inoculation of Petri Dishes Inoculation of Broth Cultures Throat Swab
	Exercise 11, part 1	Inoculation of Petri Dishes
9	Exercise 11, part 3	Interpretation of Sulfide, Indole, and Motility Media Interpretation of Kliger's Iron Agar Interpretation of Urea Broth Identification of *Salmonella* and *Proteus* based on interpretation of media above
	Exercise 15, day 1	Pipette Use Inoculation of Broth Media
10	Exercise 13, part 1	Inoculation of Petri Dishes Placement of Antiseptic-Soaked Discs on Inoculated Petri Dishes Placement of Antibiotic-Infused Discs on Inoculated Petri Dishes Three-Zone Streak Plate Method
	Exercise 15, day 2	Observation of bacterial growth in lactose tubes Interpretation of results using the Most Probable Number (MPN) chart

Lab Quiz	Lab Activities	Skills or Techniques Learned or Used
		Inoculation of Petri Dishes

Each quiz covered different microbiology knowledge and understanding as well, and these concepts were taken into consideration when coding for Transfer of Context in both near and far transfer. For example, in lab exercise one, students were taught principles of negative staining and in lab exercise two, students were taught the Gram stain. The concepts of bacterial staining were taken into consideration when coding for Transfer of Context in terms of knowing, understanding, or applying knowledge for lab quiz one. See Table 3 for the major microbiology concepts learned in the MCB 3020 lab in Summer 2016.

Table 3: Microbiology Concepts Learned in MCB 3020 in Summer 2016

Lab Quiz	Lab Activities	Microbiology Concepts Learned
1	Exercise 1	Lab Safety Guidelines Principles of Asepsis
	Exercise 2	Principles of simple staining Principles of negative staining Principles of bright field microscopy, refractive index, purpose of the oil immersion lens, illumination, magnification, and resolution
3	Exercise 5	Microbial growth conditions Principles of pure culture and isolation
5	Exercise 8	Principles of bacterial aerobic respiration, anaerobic respiration, and fermentation.
7	Exercise 10, part 2	Physiological characteristics of *Staphylococcus* Physiological characteristics of *Streptococcus* Characteristics of selective and differential media in culturing *Staphylococcus* and *Streptococcus.*
	Exercise 11, part 1	Further characteristics of selective and differential media and their use in culturing *Salmonella, Shigella,* and *Proteus*

Lab Quiz	Lab Activities	Microbiology Concepts Learned
9	Exercise 11, part 3	Properties of *Salmonella* Properties of *Shigella*
	Exercise 15, day 1	Most Probable Number (MPN) water testing
10	Exercise 13, part 1	Properties of antibiotics, antiseptics, and disinfectants and their use.
	Exercise 15, day 2	Analysis of the MPN test results

Development of Qualitative Codes

First, utilizing the literature on learning transfer and knowledge (Gagné, 1965; Mayer, 1975; Perkins & Salomon, 1989; Singley & Anderson, 1989) of the laboratory skills and techniques learned in each lab exercise (See Table 1), *a priori* codes were developed as a framework for the coding process. The novice-to-expert theory of learning transfer was not considered while developing *a priori* codes because students in MCB 3020 are considered to be novices with respect to microbiology skills and techniques. Students progress from novice to competent at best in the MCB 3020 lab, but this progression was not studied in this context because the novice-to-expert transition is based on observation of skill utilization, and these observations were not made in this study. The progression of novice-to-expert with respect to microbiology skills and techniques is an area for future work. NVivo software (NVivo for Mac, QSR International, version 11.4.0) was used to organize and analyze the qualitative data.

As the coding process began, other codes emerged as student responses were analyzed qualitatively by two coders using NVivo software to record assignment of codes to phrases in student responses to reflection questions. Coders frequently communicated during the coding process as these emergent codes were discovered, and lab quizzes previously coded with *a priori* codes were re-analyzed with emergent codes. The iterative process of re-analyzing early quizzes continued as emergent codes were discovered in the later quizzes to determine if these later emergent codes had been missed in the process of coding early quizzes. Table 4 elucidates *a priori* and emerging codes along with a description of each grandparent, parent, and child code developed through the iterative coding process.

Table 4: *A priori* Codes and Emerging Codes[1]

Grandparent Code	Parent Code	Child Code	Description
Factors Affecting Learning			Codes related to the student experience and student success in the lab.
	Food or Drink in Lab		Student comments about eating or drinking in the MCB 3020 lab.
	Interpretation of Results		Students expresses issues with interpreting lab results.
		Identification of Bacteria	Student expresses difficulties with identifying bacteria.
		Interpretation of Media	Student expresses issues with interpretation of media.
	Learned Something New		Student expresses an “aha!” moment in the course of the lab activity.
	Manual Dexterity		Student comments about issues with manual manipulation of laboratory equipment.
	Microscopy Skills		Student comments about issues related to using the microscope in MCB 3020.

Grandparent Code	Parent Code	Child Code	Description
	Need practice		Student comments about the need to practice laboratory skills or techniques.
	No issues		Student indicates that they didn't have any problems with the lab activity.
	PPE or Lab Attire		Student expresses an opinion about using personal protective equipment, or proper lab attire in MCB 3020.
	Procedural Skills		Student comments about issues related to lab procedures in MCB 3020.
		Streak Plate Skills	Student expresses difficulties with aspects of the streak plate procedure: slashing the agar, inoculating the zones in the three-zone streak plate method.
	Time Constraints		Student comments about time constraints in MCB 3020 impacting their ability to complete the lab activity.
Future Career or Field			Student either explicitly expresses a future career or field or implies a future career or field in their response.
	Higher Education and Research		
	Other Professional Field		
	Pre-Dental		
	Pre-Medical		
	Pre-Nursing		

Grandparent Code	Parent Code	Child Code	Description
	Pre-Physician's Assistant		
	Pre-Veterinary		
Misconceptions			Student demonstrates misconceptions of material learned in the lab.
Nonsense			Student response doesn't relate to the question, doesn't answer the question, or the response just seems to be "filler."
Section			Codes for sections 11 – 18.
Transfer			Codes related to learning transfer of any type.
	Transfer of Automaticity		Codes relating to transfer of automaticity that indicate development of a practice or habit.
		Low-Road	Skills repeatedly practiced until they are mastered; can be applied to situations resembling the practice situation without effort.
		High-Road	Mindful application of learned practices and skills abstracted from the learning context. Skills have become automatic to the degree that a low-road skill is practiced in any situation.
	Transfer of Complexity		Codes relating to transfer of complexity that indicate a type of skill developed in the lab.
		Lateral Transfer	Transfer of skills from one context to another that is at the same level of complexity, i.e.

Grandparent Code	Parent Code	Child Code	Description
			using skills and knowledge in other similar lab contexts.
		Vertical Transfer	Transfer of skills mastered in one situation to a more complex situation requiring application of those knowledge or skills in a situation markedly removed from the practice situation.
	Transfer of Context		Transfer of knowledge, understanding, or application from one context to another.
		Near Transfer	Transfer of knowledge, understanding, or application of knowledge to other future lab activities in MCB 3020, other labs or classes, or to other similar, yet nonspecific contexts.
		Far Transfer	Transfer of knowledge, understanding, or application of knowledge to context removed from the original learning context. Students use specific examples of how what they are learning can be applied to their careers or future research.

[1]Codes that emerged during the coding process are indicated in italics.

Analysis of Qualitative Data

Thematic content analysis was employed when analyzing student responses to post-lab reflection questions (Altheide, 2007; Altheide, 1987; Creswell, 2013; Sandelowski & Barroso, 2003; Braun & Clarke, 2006; Turunen, & Bondas, 2013) to identify themes representing student experiences in MCB 3020 as expressed in responses to post-lab reflection questions. In the analysis of the qualitative data from this study, each of the qualitative research questions was considered separately. Student responses demonstrating evidence of answers to each research question were utilized in the analysis. Research question one was related to transfer of learning, research question two addressed applications of laboratory knowledge and techniques to future careers, and research question three addressed difficulties the students encountered in MCB 3020.

Analysis of Research Question One and Sub-Questions A, B, and C

The first qualitative research question was: Do student responses to open-ended post-lab questions show meaningful evidence of learning transfer over the course of the semester? Accompanying sub-questions were: a) What is the evidence of evolution of transfer of automaticity over the course of the semester? b) What is the evidence of evolution of transfer of complexity over the course of the semester? and c) What is the evidence of evolution transfer of context over the course of the semester? Observing the data as a whole, meaningful differences in learning transfer were observed in student responses to open-ended post-lab questions. Specifically, students demonstrated evidence of low-road transfer with respect to transfer of automaticity. Evidence from student responses suggested that there was an evolution of student habit and practice within the low-road transfer as students expressed certain skills becoming “second nature” to them. Evidence based on student responses also indicated primarily lateral transfer with respect to transfer of complexity. Any evidence of vertical transfer was theoretical in nature, as students imagined how particular lab techniques would be used in more complex contexts. Finally, there was evidence of an evolution from primarily near transfer of context at the beginning of the semester to predominantly far transfer of context from the beginning to the end of the semester. Student responses to post-lab reflection questions evolved from a basic near transfer of knowledge and understanding of microbiological concepts to future lab activities to a more sophisticated far transfer of application of knowledge and understanding of these concepts to contexts abstracted from MCB 3020.

Table 5 below indicates the overall response frequencies for each of the types of learning transfer by quiz. Two hundred student responses were randomly selected to be coded for each quiz, representing 1200 of the nearly 6000 student responses for all quizzes in the qualitative component of this study. As indicated by the table below, overall coding volumes for transfer of automaticity and transfer of complexity were low compared to coding volumes for transfer of context. Although some evidence of transfer of automaticity and transfer of complexity were noted, overall evidence was low compared to transfer of context.

Table 5: Learning Transfer Frequencies for All Quizzes

		Quiz 1	Quiz 3	Quiz 5	Quiz 7	Quiz 9	Quiz 10	Total
Transfer of Automaticity	Low-Road	46	14	15	16	10	7	108
	High-Road	5	1	3	1	0	2	12
Transfer of Complexity	Lateral	84	45	29	21	33	25	237
	Vertical	16	11	8	3	21	18	77
Transfer of Context	Near	104	77	107	78	71	71	508
	Far	49	52	62	61	77	98	399

The following sections will address each of the sub-questions of qualitative research question one.

Research Question One, Sub Question A: Transfer of Automaticity

Response frequencies and overall percentages of codes for transfer of automaticity indicated that on average, there was greater evidence of low-road transfer as compared to high-road transfer among the responses sampled for each quiz (see Table 6 for response frequencies and overall percentages of low- and high-road transfer). Compared to transfer of complexity and transfer of context, student responses related to transfer of automaticity were in the minority, representing only a small fraction of total responses coded, yet a meaningful progression of learning transfer of automaticity was observed in student responses. Specifically, an evolution within low-road transfer indicated that students had developed habits based on skills and techniques learned in MCB 3020. Any evidence of high-road transfer was theoretical; that is, students recognized that the practices and habits they learned in MCB 3020 could be used in specific future contexts but were not actually using these habits and practices in contexts outside of the lab.

Table 6: Response Frequencies and Percentages for Transfer of Automaticity

	Total Low-Road Responses	Total High-Road Responses	Percent Low-Road Responses	Percent High-Road Responses
Quiz #1	46	5	90.2	9.8
Quiz #3	14	1	93.3	6.7
Quiz #5	15	3	83.3	16.7
Quiz #7	16	1	94.1	5.9
Quiz #9	10	0	100.0	0.0
Quiz #10	7	2	77.8	22.2
Average:	18	2	89.8	10.2

During the coding process, students indicating the application of a practice or habit in a non-specific context were coded as “low-road transfer.” If students indicated a specific example of how a habit or practice could be used in a context outside of MCB 3020, it was coded as "high-road transfer." Student quotations exemplifying low-road or high-road transfer do not necessarily represent low- or high-road transfer in the student population as a whole; on average, evidence of transfer of automaticity was only noted in nine percent of the responses analyzed. See Appendix C for exemplary student quotations regarding transfer of automaticity for each lab quiz analyzed.

In the first three lab quizzes, student responses that showed evidence of low-road transfer indicated that students "needed to practice" or that the skills and techniques learned in MCB 3020 had "not yet become habit" for them. However, it was interesting to note that students were aware that habits of aseptic techniques, two-tube transfer, the three-zone streak technique, and other laboratory practices would eventually become habits, which is an element of low-road transfer (Salomon & Perkins, 2015). For example, in lab quiz three, a student remarked, "This exercise was important for preparing myself for the future as it is an essential step in microbiology dealing with bacteria. There are some basic steps that will be used over and over again." Another student recognized that certain practices and habits learned in the lab would be essential for passing the class, "Also, a 3 zone streak method is a test we have to master in order to pass the class so it is very important that I learn how to do it correctly." One student noted that certain techniques were essential because they had been used so often by stating, "Each lab, we practice the aseptic technique more and more and it shows why its so important." Finally, one student remarked, "I think the two tube transfers in this lab allowed me to practice and perfect that technique which will most definitely be used in a lab environment if I am to work in research in the future." Evidence of low-road transfer is exemplified by student quotations such as these indicating that students can see the value of certain practices and techniques becoming habits. See Appendix C for student quotations exemplifying transfer of automaticity for each lab quiz.

As the semester progressed, students expressed that they had developed certain habits in the laboratory, including habits of aseptic technique, pipetting skills, two-tube transfer, and the three-zone streak, which exhibit low road transfer (Salomon & Perkins, 2015). A distinct shift in the type of low-road transfer was noted as students began expressing sentiments that certain skills or techniques had become habit or second nature to them. For example, one student noted, "We have performed the isolation techniques multiple times before, therefore I did not find that challenging." Another student stated, "Doing this over and over again made it seem like second nature by the time I left the lab, and I no longer needed the template when drawing out the three sections on my petri dish." Finally, in the last lab quiz, one student said, "I do not think anything in this lab was too challenging, because it was all things that we have had a good amount of practice with." Student expressions such as these indicate that practices and habits taught in lab exercises early in the semester had become habits in the later lab activities, suggesting an evolution of low-road transfer of automaticity from the beginning to the end of the semester.

Among student responses related to transfer of automaticity, was a paucity of evidence of high-road transfer, or the application of learned practices and skills abstracted from the learning context. However, a number of students recognized in nearly every quiz that habits and practices learned in MCB 3020 could be utilized in contexts abstracted from the lab context. Evidence of high-road transfer was mainly theoretical or observed by students who were currently shadowing doctors. For example, one student had an insightful comment after a recent physician-shadowing opportunity:

> For example, yesterday I saw an injection in the back, and the doctor carefully made sure not to contaminate the needle. He kept it in the sterile wrapper until the last minute, when he needed to use it, and also made sure to wipe everything down with an alcohol wipe before and after use.

Another student recognized how practicing the three-zone streak would be beneficial to them in their future career as a surgeon:

> The precision that comes with gently using your sterilized loop against the agar was most important for my future career. This is because in a surgery you need to have a steady hand, and for the 3-zone streak you also need a steady hand, so this was good practice for the future.

The lack of evidence of high-road transfer throughout student responses was logical, because this study did not follow students from the relatively low-road environment of the MCB 3020 lab to high-road contexts where they would be using the habits gained in MCB 3020 to other environments such as an upper-level microbiology class or clinical setting. Given the paucity of student expressions of high-road transfer, it can be surmised that students were aware of the practices and habits they would need to develop in the MCB 3020 lab, but they were not yet using these practices and habits in contexts outside the lab. It was outside the context of this study to observe high-road application of practices and habits learned in MCB 3020 to more complex situations, but this is an area for future research.

In the analysis of research question one with respect to transfer of automaticity, there was little evidence of evolution from low-road transfer to high-road transfer over the course of the semester based on student responses to open-ended reflection questions. The majority of student responses were centered on low-road transfer, and evidence of high-road transfer was primarily theoretical. The evidence based on student responses indicated that there was an evolution within low-road transfer indicating a greater degree of mastery of techniques and skills. In lab quizzes one through three, the prevailing responses indicated that certain skills and techniques were "not yet habit," that they were "basic steps to be used over and over," or that students were "practicing efficiency" in the lab. In quizzes seven, nine, and ten, there was greater evidence of mastery of lab skills and techniques. Students expressed that techniques such as the three-zone streak had become "second nature" to them, that lab techniques were "not challenging because [they] have practiced them multiple times," or that the "lab techniques [were] getting easier" with practice, or that these techniques had become "second nature." Although these expressions do not indicate transfer of automaticity from low-road to high-road, student responses suggest an evolution within low-road transfer through the course of the semester. With respect to high-road transfer, students recognized that they may be using habits used in MCB 3020 in future contexts, but there was little specific evidence of how these habits will be used. Students who were shadowing doctors or working in a clinical environment expressed specific examples of high-road transfer of automaticity, but this type of evidence was in the minority. Compared to other types of learning transfer, evidence of transfer of automaticity was low, with only a small fraction of overall student responses coded for transfer of automaticity among the responses sampled.

Research Question One, Sub Question B: Transfer of Complexity

Based on the evidence from student responses, students progressed from demonstrating primarily lateral transfer of skills and techniques learned in MCB 3020 in the first four exercises to a more balanced demonstration of lateral and vertical transfer at the end of the lab experience in the last two lab quizzes. In the first four lab quizzes, evidence of lateral transfer ranges from 78 percent to 87 percent while in the last two lab quizzes, lateral transfer represents 61 percent and 58 percent in lab quizzes nine and ten respectively. While there is some increasing evidence of vertical transfer in the last two lab quizzes, the evidence of vertical transfer is mainly theoretical in this study. The term "theoretical vertical transfer" is used to describe evidence that students were not actually performing skills and techniques in a more complex situation; rather, students were able to recognize that skills and techniques learned in the MCB 3020 lab could be applied in more complex situations (Gagné, 1965). Because this study did not follow students in MCB 3020 longitudinally, it is unclear whether students will be able to apply skills learned in this context to other, more complex contexts. Hence, any evidence of vertical transfer was theoretical at best. Initial analysis of overall lateral and vertical responses coded from the responses sampled and the percentage of each type of transfer of complexity can be found in Table 7.

Table 7: Response Frequencies and Percentages for Transfer of Complexity

	Total Lateral Responses	Total Vertical Responses	Percent Lateral Responses	Percent Vertical Responses
Quiz #1	84	16	84.0	16.0
Quiz #3	45	11	80.4	19.6
Quiz #5	29	8	78.4	21.6
Quiz #7	21	3	87.5	12.5
Quiz #9	33	21	61.1	38.9
Quiz #10	25	18	58.1	41.9
Average	39.5	12.8	74.9	25.1

The skills and techniques learned in MCB 3020 were relatively new to students, and many students expressed that these techniques were novel, foreign, or difficult to them. In the first four lab quizzes, student responses indicated however, that they recognized that the skills and techniques used in these lab exercises would be necessary in the short term and the long term. For example, one student noted that mastery of the two-tube transfer would be necessary for them to pass the class. Another student recognized that, "…being able to successfully use the coarse and fine focus to get the correct resolution of a picture is going to be the most beneficial not only for my career but for this class as well." Students recognized the importance of proper performance of basic lab techniques and organization of their laboratory materials. For example, one student noted, "It is really important to measure out the precise amount of water to put it into the tube," demonstrating lateral transfer of pipetting skills. See Appendix D for student quotations exemplifying transfer of complexity for each lab quiz.

Considerable overlap exists between transfer of automaticity and transfer of complexity with regard to aseptic technique. Aseptic technique requires very specific skills to be utilized such as maintaining a disinfected lab bench, washing hands, sterilizing inoculating loops, aseptically transferring bacteria between test tubes, and maintaining a sterile field on a petri dish. These aseptic techniques, once learned, eventually become unconscious habits as students utilize them. For this reason, aseptic technique is considered both a skill to be learned when analyzing transfer of complexity and a habit to be developed in analyzing transfer of automaticity. Student responses indicated the importance of aseptic techniques, with responses such as, "If I did not sterilize properly, my results could be contaminated." Comments such as this one were evident in each lab quiz as students recognized the importance of aseptic technique in MCB 3020, both as a skill to be learned and a habit to be practiced.

Students also recognized that a skill they needed to improve on was working with their lab partner. Although this isn't necessarily a laboratory skill or technique, working with laboratory colleagues is an important professional skill to develop in any field. One student noted, "The aspect I can take away from lab 8 was trying to work well with my partner. Sometimes the person you work with isn't as good or at the same skill level, so you have to rewind, and slow it down for them. You can say this lab has taught me to try to work well with others." While working with lab partners is not necessarily unique to MCB 3020, it could be considered a skill requiring lateral transfer, as students gradually came to work more effectively and cooperatively with their lab partner.

The Kirby-Bauer antibiotic sensitivity test was one lab technique that elicited evidence of both lateral and theoretical vertical transfer from students. Students were able to recognize that the Kirby-Bauer antibiotic susceptibility testing method was a "standard for testing the effectiveness of antibiotics" in a nonspecific, lateral context as well as a more specific, theoretical vertical context by noting, "With this test, health care professionals can decide which antibiotic works best for a person infected with an unknown bacteria." Indeed, the Kirby Bauer test is one method by which clinical labs determine bacterial susceptibility to antibiotics, and quotes such as the one above indicate that students can discern at least a theoretical vertical transfer of complexity for this test. One student was able to see a more specific application of the Kirby Bauer test in a clinical setting:

> The most important aspect that helps prepare me for my future career was the Kirby-Bauer test using the Mueller-Hinton plates. With this test, health care

> professionals can decide which antibiotic works best for a person infected with an unknown bacteria [sic]. The results are really clear and it is not difficult to determine which antibiotic works and which one does not.

This student will likely not be prescribing antibiotics to patients in the near future, but demonstrates the understanding that the Kirby Bauer test may aid physicians in prescribing the most effective antibiotic.

A number of other instances of theoretical vertical transfer were noted in the analysis of student responses with respect to transfer of complexity. For example, one student stated, “Even though most places have people who prepare slides for the doctors to read it is still important to know how it is done…” Also, it was interesting to note that some students expressed that they wouldn’t use the specific techniques learned for this lab quiz per se, but that they would use the concepts of “thinking quickly” or “following tasks correctly” in future, more complex situations. Expressions such as these indicate some theoretical evidence of vertical transfer, and demonstrate that some students were beginning to consider how they could apply the skills and techniques learned in MCB 3020 to more complex situations outside the learning context. At least one student recognized that the precision learned in the lab exercises could be applied in the future in surgical techniques, noting “The patience and care it took not to scratch the agar in the three zone streak plate reminded me of the care a physician has to have when doing anything in the medical field.” This student may not be performing surgery for several years, yet they recognized that they would need to take patience and care when performing procedures.

In the last two lab quizzes, more evidence of theoretical vertical transfer was noted as well as some minor evidence of true vertical transfer. For example, one student remarked, “If I were to suspect that my patient was infected with Salmonella, I would be able to use Hektoen Enteric (HE) agar as a means of isolating and differentiating salmonella [sic] from other enterics infecting the gastrointestinal tract.” Evidence of theoretical transfer such as this indicates that students have an idea of how they might apply the skills and techniques learned in MCB 3020 to more complex situations, despite not knowing exactly what procedures would be involved in detecting *Salmonella.* One student was able to identify a real-world application of lab skills and techniques learned in MCB 3020:

> I aspire to be an environmental biologist as a future career path, and considering that, being able to test water samples for the concentrations of bacteria that exist within them is extremely imperative in my field of choice. From drinking water, to ocean water, lake water, etc. Having the knowledge of these tests and being able to correctly run and analyze the results could lead to breakthrough knowledge in a certain environmental research study.

Again, this quote indicates theoretical vertical transfer of learning, in that the student is able to see the application of the water testing procedures used in MCB 3020 in a career in environmental biology, but is not actively applying these techniques in that scenario. An example of true vertical transfer of learning came from a student who was planning on a career in veterinary medicine and who worked in a veterinary office:

> The water testing is most important. If a dog comes into the office with an odd infection, I would ask the owners if he's recently been to a dark park and if that dog park had a lake. If so, I might ask for a water sample to see if the lake was a reservoir for the patient's symptoms.

Evidence such as this demonstrating vertical transfer of a technique performed in MCB 3020 directly translating to a student’s current experience was sparse. Few students in MCB 3020 work in a medical, veterinary, or other type of clinical setting and therefore developed only a theoretical understanding of how skills and techniques learned in MCB 3020 could be applied to more complex contexts.

In the analysis of research question one with respect to transfer of complexity, there was little evidence of transfer of complexity from lateral to vertical transfer based on evidence from student responses. The majority of student responses were focused on lateral transfer of skills and techniques to other, similar contexts to the lab or to the lab practical exam. In the last two lab quizzes, there was evidence of greater balance toward lateral and vertical transfer as students began to recognize how they could use skills and techniques learned in MCB 3020 in future contexts. However, the evidence of vertical transfer was mainly theoretical, as students did not actually apply these skills in more complex situations. Rather, students recognized how they could use these skills and techniques in more complex situations. Overall, the evidence of transfer of complexity was moderate compared to other types of learning transfer observed in this study. About one-quarter of the total student responses coded indicated evidence of transfer of complexity, with the majority of these indicating lateral transfer.

Research Question One, Sub Question C: Transfer of Context

Unlike evidence of transfer of automaticity and transfer of complexity, a distinct shift from near transfer to far transfer of context was noted from the beginning to the end of the semester. Initially, the total number of responses with respect to near vastly outnumbers responses relating to far transfer (See Table 8). As the evolution of near to far transfer progressed, there was evidence of an increase in specific examples of how the MCB 3020 curriculum could be applied to students' future work as well as current scenarios removed from the MCB 3020 lab. For example, a number of pre-medical students were shadowing medical doctors and expressed applying principles of antibiotic susceptibility and resistance to their work with medical doctors. The shift from near to far transfer suggested that students could apply knowledge and understanding gained in the MCB 3020 other contexts.

Table 8: Response Frequencies and Percentages for Transfer of Context

	Total Near Responses	Total Far Responses	Percent Near Responses	Percent Far Responses
Quiz #1	104	49	68.0	32.0
Quiz #3	77	52	59.7	40.3
Quiz #5	107	62	63.3	36.7
Quiz #7	61	78	43.9	56.1
Quiz #9	71	77	48.0	52.0
Quiz #10	71	98	42.0	58.0
Average	81.8	69.3	54.1	45.9

To distinguish near transfer from far transfer in the coding process, both coders agreed on the following guidelines for identifying transfer of context: If a student expressed utilizing knowledge or understanding in "the future" without a specific context, their response was coded as near transfer. If a student used a specific example of how what they learned, understood, or applied could be used in their future careers or future research endeavors, such as in a research laboratory or as a physician, their response was coded as far transfer. See Appendix E for exemplary student quotations relating to transfer of context for each laboratory quiz.

Evidence of near transfer was manifest in student responses regarding how the knowledge and understanding they gained in early labs could be applied to later lab activities or exams. One student specifically noted, "I think the most important aspect of this lab would be to understand what [reaction] each medium produces, what its reaction are [sic], its purpose, etc. especially for the lab midterm and practical." Another student stated, "Working on unknowns has been extremely beneficial for me. This is allowing me to have full control of the tests I do in order to determine my organisms, which is the first applicable thing I feel like we've done so far." Student responses such as these indicated evidence of near transfer as they were able to apply knowledge gained in the lab to future lab exercises.

Aseptic technique was again noted in transfer of context as a concept students needed to understand for future applications. For example, in an early quiz, one student remarked,

> Aseptic technique is definitely the most important concept I learned this week because if I ever wish to work for a laboratory it is imperative that I maintain a sterile environment because no experiment of mine will be considered valid if it has been conducted without the use of aseptic technique.

Previously, aseptic technique has been coded as a habit in transfer of automaticity and a skill in transfer of complexity. Because of its vital application in health care fields, the habit, use, and understanding of aseptic technique is essential for students to learn in MCB 3020, as was evident from student responses to post-lab reflection questions.

As the semester progressed, there seemed to be a mixture of specific and nonspecific examples of application of knowledge and understanding in responses coded for far transfer; some students clearly expressed specific applications in future fields, while others expressed a nebulous idea of "using [knowledge] in my job as a [profession]." For example, one student expressed, "My goal is to become a veterinarian and I have seen many clinics that do their own microbiology testing. This will serve me well in the future." Another student had a definitive goal of going into forensic science, yet their comment about using what they learned in MCB 3020 was nonspecific:

> With forensics, I can use the methods I learned in this lab for observation and collecting data. Using collected samples from a crime scene that's provided to me, I would be able to use these techniques to help identify what was given to me and relate it to the crime and even cause of death.

The student did not give a specific application of how the methods learned in MCB 3020 would be used, but just that they would be helpful to them in a future context. Interestingly, one student noted that they wanted to become a Biology teacher, and they used this lab exercise to practice teaching a fellow student who was having trouble with the lab. They stated, “Being a teacher I will also have to help kids understand what it is they are doing and why it is important.” Statements like these in the early quizzes of the semester seem to indicate that students are beginning to see practical applications of knowledge and understanding gained in the lab, but don’t yet have an idea of specific instances in which they can be applied.

The majority of students in MCB 3020 in the period studied anticipated a career in the medical or research field, and given their responses regarding near transfer, many of them were able to make the connection between knowledge and understanding gained in MCB 3020 and a nonspecific future application in their careers. An example of this is the following student response, “Sterilizing my tools helps me in the future because in the future, the environment I will be working in needs to be sterile.” Many students expressed that they would use knowledge gained in MCB 3020 in a “medical field,” but few expressed specific applications. For example, one student noted, “I feel as though both labs have given me a better understanding of how important it is to prevent cross-contamination in a medical setting.” Another student noted, “Knowing how to properly isolate bacteria is essential in the healthcare field for identification, cure and treatment,” but did not give a specific example of how they might do this. Some students were able to recognize that the concepts they were learning in MCB 3020 would be useful in their future medical careers, and that they may not be necessarily be performing the specific lab procedures as a medical doctor. For example, one student expressed, "As a future physician. I probably will not be presented with many times when I would personally have to look at a culture but when I send the samples to the labs (Urine, a swab, etc.) it is important to know exactly what they do in the labs and this teaches me that." Nevertheless, some students were shadowing physicians as part of their undergraduate work, and were able to see specific applications of MCB 3020 in a clinical setting. For example, "While I was at the hospital this weekend shadowing, they had to run some lactose tests and the physician was asking the nurse about the patients blood work and she responded they sent the work back to be tested..." Evidence such as this was scarce, however, as many students did not have the opportunity to work in a clinical setting or shadow physicians.

Evidence of far transfer began to exceed evidence of near transfer in quiz seven and continued through lab quiz ten. Based on the analysis of total responses between near and far transfer, lab quiz seven seemed to be the tipping point in the evolution from near to far transfer in this study. In the lab activities covered by lab quiz seven, students identified *Staphylococcus* and *Streptococcus* as well as *Salmonella* and *Shigella* based on their growth patterns and hemolysis on blood agar (BA). Because students took samples from their own noses and fomites, this lab had great personal application. For example, one student stated, "Seeing how much bacteria was growing on my fomite (which was my own personal cell phone) was a reminder about how easily bacteria can transfer and grow on personal belongings." Many students expressed that they understood principles of disease transmission more completely after they interpreted the results of their swabs on Blood Agar (BA). One student noted, “Exercise 11 part 1 helped me how to distinguish between Salmonella and Shigella by using a Hektoen Enteric agar plate. This can help me as a physician in the future when a patient comes in sick with foreign bacteria in their GI tract.” Another student noted the importance of identifying particular organisms in the diagnosis of infections:

> The aspects of this lab that were most important for me in preparing for my future career was definitely getting to learn the ins and outs of different types of bacteria. Having an extensive knowledge of bacteria and pathogens can only prepare me for my future career in medicine! I think being able to isolate staph, strep, or other pathogens such as the intestinal pathogens that we will be working with is very exciting and can only serve me well in any of my potential future careers in medicine.

The diagnosis of both staphylococcal and streptococcal infections is very common in the healthcare field; therefore it is logical that students in pre-medical, pre-nursing, pre-pharmacy, or pre-allied health fields would be able to see application of the knowledge and understanding gained in this lab to their future careers.

In the final lab quizzes, it seemed that students were beginning to see the real-world applications of the knowledge they had gained in MCB 3020. Students may also have started to see the arc MCB 3020 lab curriculum as a whole and were able to relate the knowledge and understanding they had gained in the lab more specifically to their future careers. One student noted, “This lab showed how microbiology is easily applied to our everyday lives. It shows how important it is for things that we don't even think about on a regular basis…” The lab activities covered by lab quiz ten had to do with antibiotics, disinfectants, antiseptics, and water testing for fecal coliforms. As mentioned previously, each of these topics have real world applications, primarily to pre-medical, pre-nursing, pre-pharmacy, or pre-allied health students who will be diagnosing and treating patients, as was evidenced by the abundance of far transfer codes. Specifically, evidence from student responses suggested that the Kirby-Bauer disk diffusion assay was meaningful to students in terms of their future medical careers. An example student response regarding the Kirby-Bauer test was, "By knowing the action of the antibiotics, I will be able to determine the effect the antibiotic could have on a patient and obviously the side effects caused by the prescribed antibiotic…" The distinct shift from near to far transfer seemed to be closely related to more real-world applications of concepts studied in the last few lab activities, where students began to identify disease-causing organisms and see first-hand the effects of antibiotics and disinfectants *in vitro*. The greatest evidence of the evolution from near to far transfer seemed to be among students planning on entering a medical field (dentistry, medicine, nursing, pharmacy, physician's assistant, or veterinary), where there would be day-to-day interaction with the diagnosis and treatment of infectious disease. Overall the evidence of transfer of context was highest compared to the other types of learning transfer. More than three quarters of the student responses sampled showed evidence of far transfer of context with the majority of these responses indicating evidence of near transfer of context.

<u>Summary of Meaningful Evidence of Learning Transfer in MCB 3020</u>

The clearest evidence of the evolution of student responses to post-lab reflection questions was with transfer of context. Evidence of a shift from total numbers of responses for near transfer to far transfer with lab quiz seven suggested that students were evolving in their understanding of the applications of knowledge and understanding of the material learned in MCB 3020. Additionally, student responses indicating specific applications of the knowledge and understanding gained in the MCB 3020 lab in outside contexts furthers the evidence of evolution of transfer of context from near to far. Unlike the theoretical shift from low-road to high-road transfer with respect to use of habits developed in the lab or lateral to vertical transfer of applications of skills and techniques in other contexts, the evolution from near to far transfer represents meaningful transfer of learning. Students were able to cite specific contexts in which what they learned, understood, or applied could be used in their future careers or future research endeavors. The evolution of evidence of near transfer to far transfer represents one of the main goals of education, which is to help students understand how the knowledge they gain in the classroom or laboratory setting can be applied in other contexts. The evolution of responses from near to far transfer was noted primarily among students who identified themselves as going into a medical field (dentistry, medicine, nursing, pharmacy, physician's assistant, or veterinary medicine), indicating that perhaps the curriculum of the lab was focused primarily on medical applications rather than a global focus on all aspects of microbiology. The shift of student responses from predominantly near to primarily far transfer from the lab quizzes at the beginning of the semester to the end of the semester suggests that learning transfer with respect to transfer of context may have occurred among students in MCB 3020 during the Summer 2016 semester.

Analysis of Qualitative Research Question Two

The next major theme explored in post-lab reflections was how students viewed the MCB 3020 lab as it related to their future careers. Qualitative research question two asked, "How do microbiology students perceive the role of the lab in helping them to prepare for their future careers in pre-medical, pre-nursing, pre-pharmacy, pre-allied health, academic research, or industry?" Evidence based on student responses indicated that a small percentage of the students were able to perceive how the lab could prepare them for future careers, but there was not clear or conclusive evidence that students could determine how MCB 3020 applied to their future careers (see Table 9). Several issues hampered definitive evidence to answer research question two, however. First, many students were non-specific in their responses and referred to "medicine" or "research" but did not state a specific future career, and this trend continued as the semester progressed. As noted in table 8, all future career fields were represented in the coding process for quiz one, but this was not the trend throughout the semester. Second, several career fields were underrepresented in student responses. Specifically, there was a dearth of specific indications of pre-nursing or pre-pharmacy careers among the students surveyed. It is unclear if students in pre-nursing or pre-pharmacy career tracks dropped out of the course, if they didn't see how the course applied to their future careers, or if they chose not to specifically mention these career tracks in their responses. Finally, because students were asked about application of lab exercises to their future careers in every quiz throughout the semester, they may have experienced "quiz exhaustion" by answering similar questions in every lab quiz. "Quiz exhaustion" is evidenced by the decreasing number of specific responses regarding future careers in Table 8, with a significant drop-off at quiz seven.

Table 9: Total Responses Related to Future Careers by Lab Quiz

Field	Quiz 1	Quiz 3	Quiz 5	Quiz 7	Quiz 9	Quiz 10	Total
Higher Education and Research	21	9	5	1	7	1	44
Other Professional Field	20	6	6	1	6	6	45
Pre-Dental	4	1	2	1	2	2	12
Pre-Medical	23	18	12	15	13	14	95
Pre-Nursing	1	0	0	0	0	0	1
Pre-Pharmacy	3	1	1	0	0	6	11
Pre-Physician's Assistant	9	4	5	2	1	1	22
Pre-Veterinary	3	2	1	0	2	1	9
Total:	81	39	32	20	31	31	

Among those who noted specific references to future careers, a number of students made insightful comments about the application of MCB 3020 to future careers. For example, a student planning on a career as a microbiologist noted,

> "Many Microbiologists jobs are to research about and ensure we can prevent the spread of pathogenic microbes that harm the population. Salmonella and other pathogenic bacteria are important to study and are extremely relevant to a large sector of possible jobs I may have researching pathogens. Seeing how we can isolate them from healthy bacteria is important if we encounter infection."

Expressions such as this one are not uncommon in their lack of specificity. As noted in the analysis of learning transfer, the undergraduate students involved in this study may not be able to recognize specific applications of what they are learning in MCB 3020 to their future careers.

Another student indicated that they were planning on a career in chemistry, and made the following comment regarding design of pharmaceuticals:

> "As a chemist, understanding and being able to characterize a bacteria based on it's physiological characteristics will allow for the design of effective drugs that may interfere with certain metabolic pathways that the bacteria possess."

Again, this student refers to "certain metabolic pathways," but does not indicate specifically how understanding of these pathways could be inhibited in drug development.

A pre-dental student recognized the importance of bacterial biofilms in their future career in dentistry:

> "The aspects used in this lab are good to be able to observe how bacteria form, in dentistry, biofilms are one of the most common grouping of bacteria. It is interesting to see how these processes occur and how they can apply to real life situations."

A "real life situation" was mentioned with respect to a future career in dentistry, but again, the response was non-specific.

The following pre-medical student was able to relate the patience and care they were required to take in the lab to a future scenario in surgery:

> "The fact that everything requires such care and precision to do will help me out in a future of surgery, considering everything has to be calculated and near perfect to not harm anyone. The patience and care it took not to scratch the agar in the three zone streak plate reminded me of the care a physician has to have when doing anything in the medical field."

While it is doubtful that this student will be performing surgery in the near future, they were able to recognize that the habits and skills they are developing in MCB 3020 will serve them in the future.

A pre-nursing student noted,

> "I hope to become a nurse and it will be important for me to know how different bacteria look in a microscope and which type of stain I should use to see the bacteria. I can cut down the time the lab needs if I can tell them what type of bacteria I think it is."

In some clinical settings outside the hospital, nurses are required to observe samples taken from patients under the microscope in order to assist with diagnosis of infection. Perhaps this pre-nursing student has had experience working in a clinic where this type of microscopy was performed and was able to relate their experience in the clinic to their experience in the lab. Regardless, this was the only response coded for pre-nursing among the responses sampled.

A pharmacy student expressed that one of the MCB 3020 lab activities was very relevant to their future career:

> "This has probably been the most relevant lab to my future, as we actually used chemicals that helped to fight and prevent bacterial infections and saw their effect on living and growing microorganisms. It will be important for me to understand and know the differences between different medicines and what they do to microorganisms as a pharmacist."

Given the dearth of specific comments related to future careers in pharmacy, students in the pre-pharmacy track may not be able to see the application of MCB 3020 to their future careers.

Unlike pre-nursing and pre-pharmacy students, a number of students were able to relate lab activities to their future careers as physician's assistants:

> "Being able to differentiate proteus from salmonella actually applies to the PA profession. Proteus is a bacteria that is often the cause of UTIs, so it will be important to be familiar with its traits and chemical characteristics."

This student recognized that *Proteus* species is an organism implicated in many urinary tract infections (UTIs) and also that as a physician's assistant, they would have to identify and diagnose these types of infections regularly.

Finally, this pre-veterinary student recognized that bacterial isolation techniques learned in the lab would help her in diagnosing animals in a veterinary clinic

> "Again, everything I am doing is in hopes of having some sort of career in the veterinary medicine field. Learning how to isolate the bacteria of a sick animal is going to be a useful technique when trying to figure out why animals are getting sick, and moving on to trying to make them better. Is it a single microbe, multiple microbes?"

Comments by pre-veterinary students were in the minority, but those who did make specific reference to their future career were insightful. See Appendix F for more exemplary student quotes regarding application of MCB 3020 to future careers.

<u>Summary of Student Perceptions of Application of MCB 3020 to Future Careers</u>

Research question two addressed how microbiology students perceived the role of the lab in preparing them for their future careers in pre-medical, pre-nursing, pre-pharmacy, or pre-allied health, academic research, or industry. Evidence from student responses suggest that students who plan on a career in medicine and those who are planning on a career in some type of scientific research perceive the role of the lab as helpful to them in preparing for their future career. The evidence from students planning on careers in other professional arenas, nursing, pharmacy, and veterinary medicine that perceived MCB 3020 as helping them prepare for their future career was lacking. Future careers noted in the qualitative analysis for this research section were organized as higher education and research, other professional fields, pre-dental, pre-medical, pre-nursing, pre-physician's assistant, and pre-veterinary. Analysis of early quizzes indicated specific references to each of the fields above; however, it became evident as the semester progressed that students were experiencing “quiz exhaustion” with respect to discussing how the lab would apply to their future careers. The volume of responses for specific references to each career field dropped off significantly over the course of the semester. The highest volume of responses was among students planning on going into medicine, pre-physician’s assistant, and research or academia, while there were few to no responses specifically referencing the nursing, pharmacy, or veterinary fields. One reason why there was a paucity of references to the nursing field is that pre-nursing students are primarily enrolled in the Microbiology for Health Professionals (MCB 2004C) course that has a pre-nursing focus. Qualitative analysis of student experiences in MCB 2004C may indicate student recognition of this course to their future careers in nursing.

Analysis of Qualitative Research Question Three

Research question three focused on student perceptions of difficulties they encountered in the MCB 3020 lab by asking, “What difficulties do students encounter when performing laboratory experiments in general microbiology?” Based on the evidence from student responses, the primary difficulties students encountered with laboratory were in difficulties with procedural skills, difficulties with interpretation of data, issues with manual dexterity, students expressing they “need practice” with lab skills and techniques, difficulties with using the microscope, and time constraints. See Table 4 for a list of *a priori* and emergent codes developed in the coding process. “Manual dexterity” and “need practice” were the predominant codes that emerged when considering difficulties students had in the lab. Table 10 indicates the number of codes related to difficulties encountered by students in each lab quiz.

Table 10: Difficulties Encountered by Students in MCB 3020

Quiz	Procedural Skills	Interpretation of Data	Manual Dexterity	Need Practice	Microscope	Time	No Issues
1	132	0	33	28	67	2	25
3	195	2	60	27	0	1	7
5	86	170	9	10	3	3	3
7	56	114	6	6	0	2	7
9	46	108	46	5	0	3	25
10	66	72	45	3	4	4	30
Total:	581	466	199	79	74	15	97

The following sections will analyze each of the types of difficulties encountered by students in MCB 3020 with representative student quotes that illustrate the difficulties students encountered. See Appendix G for exemplary student quotes for each of the lab quizzes studied in each of the categories listed in Table 10.

Issues with Procedural Skills

Many students were unfamiliar with the laboratory procedures learned in MCB 3020, and there was significant evidence of student difficulties with these procedures. Table 2 summarizes the major procedures for each of the lab quizzes. Of all of the issues affecting student learning coded in the qualitative analysis of student responses, issues with procedural skills had the highest number of coded items. However, the overall volume of codes relating to procedural issues significantly declined over the course of the semester, indicating that students were becoming more familiar with standard procedures in the MCB 3020 lab over the course of the semester. Emergent codes related to issues with procedural skills will be discussed below.

Difficulties with procedural skills were primarily seen in the first two laboratory quizzes, but remained significant throughout the semester. It is likely that the majority of students in MCB 3020 had little to no experience with the manipulation and staining of microbes, and it is unsurprising that students encountered difficulties with these procedures. Some of the difficulties with procedural issues overlapped – for example, if a student had a problem with performing a staining technique, they also had difficulties with microscopy. One student noted,

> "I also realized while doing the lab that if you don't do it 100% correctly, there can be some issues. For the staining, I didn't leave the purple dye on for a full minute and a half due to timing issues, and that affected my results while trying to look under the microscope."

A steep learning curve exists for students in the first few weeks of MCB 3020, as students attempt to internalize aseptic skills and techniques while simultaneously learning to manipulate microbes for staining and culturing. In lab quiz three, "streak plate skills" emerged as a code as students expressed their struggles with the three-zone streak technique, designed to isolate individual bacterial colonies. One student noted,

> "The aspect of lab exercise 5 that was most challenging was getting the technique down for a proper three-zone streak. It was generally difficult at first to not scratch the agar too much, angle the loop properly, and judge how many times to streak each zone. Overall, it was just an issue of not being familiar with the technique/not having done it before, etc."

Bacterial agar of all types is somewhat difficult to work with – it has a soft surface, not unlike gelatin, and it can be easily cut into with the inoculating loops used to manipulate bacteria. The three-zone streak technique designed to achieve isolation of bacterial colonies (See Figures 3 and 4; Ambivero et al., 2017) was an essential skill taught and assessed in MCB 3020.

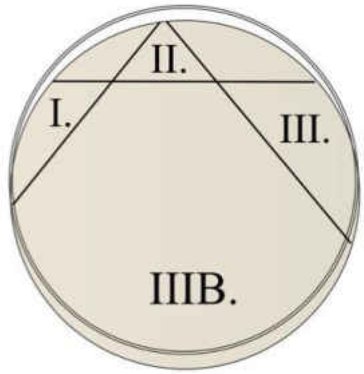


Figure 3: Three-zone streak diagram learned in MCB 3020 (Ambivero et al., 2017).

Figure 4: Example of the outcome of the three-zone streak technique (Ambivero et al., 2017).

Issues with streak plate skills remained a constant difficulty throughout the semester as students learned to master this essential technique.

Unfortunately, there was still some evidence of students having problems with streak plate skills in the last few lab exercises in the semester. One student complained, "Also I slashed the Agar when we did the three zone streak plate. Even now, so that was kind of frustrating." Because streak plate skills are practiced throughout the semester, students should have achieved some level of proficiency with streaking agar plates. Perhaps more practice with this skill earlier in the semester may benefit students as they progress to more challenging lab exercises later in the semester.

Coincident with streak plate skills, "isolation of bacteria" emerged as a code in later labs, as students were required to isolate and identify different species of bacteria based on their colony morphology on an agar plate. One student noted,

> "The most challenging part of this lab was isolating staph and strep from the original blood agar plates because I was not sure how to tell them apart. Also, it was hard to remember where the species come from (staph on the fomite but strep in the throat). it was confusing."

Because the exercises covered by lab quiz seven involved selecting appropriate colonies of *Staphylococcus* or *Streptococcus* for further plating and analysis, the balance of codes between "isolation of bacterial colonies" and "streak plate skills" was nearly equal due to the crossover between these two lab procedures.

In the later lab activities, students performed the Most Probable Number (MPN) method for identifying coliform bacteria in water. Regarding the MPN test, one student expressed difficulties with dilution procedures, noting:

> The aspects in exercise 13 that were most difficult for me technique wise were pipetting the exact amount of water into the lactose broth tubes and making sure that no more of no less came out of the pipettes. Pipetting was only a technique that we did about once before in lab and sometimes the holders would not always work. But for me a few extra drips of water kept sneaking out!

The quote above is exemplary of many student responses indicating difficulties with pipetting and dilution procedures in the MPN test.

<u>Issues with Interpretation of Results</u>

An important aspect of MCB 3020 is not merely performing procedures and inoculating media correctly, but interpreting the results correctly as well. The volume of responses expressing student difficulties significantly increased as the semester progressed, with the final three quizzes showing the highest volume of responses.

Students were primarily concerned with learning procedures and techniques in the early stages of the semester, so it is logical that the difficulties with interpretation increased in later lab activities. For example, there were no results to interpret in the lab exercises covered by lab quiz one, so this code was not applied to the first quiz, but the specificity and volume of responses regarding interpretation of results significantly increased in later quizzes.

As indicated by Table 9, issues with interpretation of results did not begin to emerge until lab quiz five. The lab exercise covered by lab quiz five was primarily concerned with inoculation of and interpretation of different biochemical tests and differential media. As a result, “identification of bacteria” and “interpretation of media” emerged as codes. “Identification of bacteria” was noted to be distinct from “isolation of bacteria” in the previous section in that “isolation of bacteria” referred to the physical isolation of bacterial colonies on an agar plate, whereas “identification of bacteria” refers to the identification of bacterial species based on their reaction to different biochemical tests. Students encountered difficulties with interpreting the results of bacterial fermentation of sugars, results of the litmus milk test, and bacterial growth in selective and differential media. The following student quote exemplifies difficulties with identification of bacteria:

> The aspect of lab exercise 8 that was the most challenging for me was learning about how to differentiate bacteria based on their characteristics, such as the production of exoenzymes and the ability to ferment sugar.

Interpretation of results was a consistent difficulty for students throughout the semester, especially in lab activities that required interpretation of biochemical tests. A frequent complaint was that there was a great deal of media with specific ingredients, pH indicators, and results that needed to be learned. Another student expressed difficulties with interpretation of the different types of media used in the lab:

> The most challenging part was learning why all the reactions happened. Every media was different in its own unique way. There were differences that are hard to understand why it happens. There is a reason all the media reacts differently and finding out why was challenging.

One reason for some of the difficulties with interpretation of results may have been due to the availability of curricular materials explaining biochemical test results. The curricular materials in the MCB 3020 lab were primarily distributed through PowerPoint presentations to illustrate how each bacterial species reacted to the different biochemical tests performed in lab activities. These presentations were the only reference point students had for the “correct” interpretation of their results, and students expressed difficulties with remembering all of the media types and the different outcomes. One student noted, “It would have been helpful if as a class we did one of the plates together in order to have some sort of consensus on what each looks like on the plate, rather than the pictures on the slides.” Difficulties such as these remained constant after the third lab quiz, although evidence of difficulties with interpretation of results declined somewhat in the later lab quizzes.

Issues with Manual Dexterity

Manual dexterity emerged as a code in the analysis of lab quiz one. The two-tube transfer was taught as an essential lab skill, and students struggled with manipulation of two test tubes, aseptically removing test tube caps, and sterilizing the inoculating loop. Students expressed difficulties with holding and manipulating test tubes, manipulating the inoculating loop, using the micro-incinerator. For example, one student noted after the first lab activities, “In the lab 1 exercise, I found getting use to holding the tube caps while holding the loop challenging because it was a new technique I've never used before in a lab.” Evidence of issues related to manual dexterity overlapped significantly with the emergent “need practice” code discussed in the next section. Students recognized that they needed practice with their difficulties with manual dexterity. Another student noted, “I had a little trouble holding the test tubes and caps right in my hands. But nothing I couldn't do with more practice.” Given the relatively high number of coded responses relating to manual dexterity, the manipulation of test tubes, inoculating loops, and petri dishes seemed to be a constant issue throughout the semester.

Evidence of issues with manual dexterity was primarily seen in the first two lab quizzes and surprisingly in the last two lab exercises. Students experienced difficulties in the early lab activities when they were learning the three-zone streak plate method, the two-tube transfer, and pipetting skills. They also experienced difficulties with these same techniques as they were revisited in the later labs. In lab quiz seven, one student expressed, “My hands are very unsteady, so all the streak plates were incredibly challenging to pull off sans agar slashing and so on.” At this point in the semester, students have had numerous encounters with the three-zone streak technique, yet students still express difficulties with slashing the agar. Future research may be necessary to determine how to assist students with the three-zone streak technique early in the semester to ameliorate these difficulties later in the semester.

Students Expressing that They “Need Practice”

The issue of students needing practiced will be explored next because due to the fact that codes for “manual dexterity” and “need practice” overlap significantly.

Generally speaking, student comments regarding needing practice are positive. Initially, they express that they struggle with a certain technique or skill, but recognize that they will get better with practice. For example, in quiz one, a student noted, "The more I use the microscope, the better I will get at it." Regarding preparation of slides for staining and observation, another student noted, "The aseptic smear preparation was most challenging for me but I strongly believe I will become significantly better at it as the semester goes on." Despite evidence of difficulties with the three-zone streak, one student expressed,

> The most challenging part of lab five for me was streaking zone 3b on the streak plate. I found this challenging because I kept cutting into the agar with the loop. I think with more practice this motion will get easier and I will become better at it.

Positive expressions regarding the need for practice on skills and technique are consistent throughout all lab quizzes. Additionally, the volume of student expressions about needing practice is concentrated in the first two lab quizzes, with a significant drop in coding volume related to "need practice" in quizzes five through ten.

<u>Issues with Microscopy Skills</u>

Use of the microscope tends to be a challenge for students, regardless of any prior experience they have had with the microscope in previous classes. Challenges with using the microscope in MCB 3020 mainly stem from the fact that students are required to use the oil immersion lens with the 100x objective to view microbes. Use of immersion oil with the 100x objective reduces refraction of light by air and improves resolution of microscopic cells that are approximately 1.0 µm in length. As noted in the previous section, it takes practice to adjust the coarse and fine focus of the microscope to view bacterial cells at this magnification, and there is significant overlap between codes for "need practice" and "microscopy skills." One of the main issues noted regarding use of the microscope is the fact that some students had little to no previous experience with viewing bacteria under the microscope. For example, one student noted, "Adjusting the microscope to the proper setting to see the culture. I have not used a microscope in quite a while, which made it more difficult using the microscope at first." Another student remarked, "Although I have high-school experience with microscopy from biology classes, my familiarity with the microscope functionality was rusty." Compared to the other codes related to student difficulties in the lab, the overall volume of codes related to use of the microscope was relatively low. However, there were several lab exercises in which the microscope was not used at all (lab exercises covered by lab quizzes three, seven and nine). Use of the microscope was used more heavily in the lab exercises covered by lab quiz two. Further study will be needed to explore issues with using the microscope in student responses in lab quiz two.

Issues with Time Constraints

"Issues with time constraints" emerged as a code early in the coding process. However, very few students expressed issues with time constraints with completing the lab exercises in the time allotted for the lab period throughout the semester. Additionally, students expressed difficulties with time constraints regarding the speed with which they needed to complete a particular procedure. For example, students expressed difficulties with the pour plate procedure, noting, "The most challenging part of the lab was the pour plate method because everything needed to be done quickly before the molten agar solidified." In this procedure, students inoculate molten agar with bacteria and pour it into a sterile petri dish. Students must work expediently and with careful attention to detail when inoculating the bacteria and pouring the molten agar into the petri dish before it solidifies. Other students noted difficulties with large numbers of inoculations of different types of media in the lab period, stating, “And also the hard part for me was when we had to inoculate multiple things, and we had very little time, since we started doing skills test. So I had to make sure I do my work very fast. Since time was an issue.” Finally, at the end of the semester, students noted difficulties with time management while performing lab activities and simultaneously identifying an unknown organism, “The unknowns were the most challenging part for me simply for the fact that my time management skills were tested. Leaving me with no time left for confirmation tests.” The relatively low number of responses regarding issues with time constraints may indicate that the time allotted for MCB 3020 labs is sufficient to accomplish all of the lab activities. However, indications of time constraints may relate to transfer of automaticity and students’ inability to develop habits that allow them to accomplish lab procedures with efficiency and accuracy.

Summary of Difficulties Encountered by Students in MCB 3020

The difficulties encountered by students in MCB overall were not unexpected, nevertheless, emergent themes in the coding process brought to light specific difficulties students encountered in the course. Difficulties encountered by students were primarily with procedural issues, interpretation of results manual dexterity, and the need for practice. To a lesser extent, students experienced difficulties with using the microscope and time constraints.

Based on coding volumes, by far, students had the most difficulties with procedures in MCB 3020, with the highest volumes of responses regarding procedural issues occurring in the first two lab quizzes, and representing the early phases of the course when students are learning procedures. However, student responses expressing difficulties with general lab procedures remained consistent throughout the semester. Difficulties with procedural issues may be due to the progression of the lab from less demanding procedures in the beginning of the semester when students are becoming accustomed to the lab to more demanding procedures in later lab exercises, resulting in a continuum of difficulties with lab procedures throughout the semester.

The volume of responses regarding interpretation of results steadily increased from the beginning to the end of the semester, as expectations for interpretation and analysis of results. In the semester in which this study was conducted, lab materials consisted primarily of a short, general lab manual, PowerPoint presentations shared in class and online with students, results tables filled out in class, and students' own notes taken during explanation of lab procedures at the beginning of each lab exercise. After the Summer 2016 semester, a new lab manual (Ambivero et al., 2017) was published that had more extensive explanations of lab procedures, expected results with accompanying pictures, tables for recording results, and other materials designed to encourage reflection and improve students' lab experience. Further study is necessary to determine if the implementation of this lab manual with its augmented lab materials will alter students' experiences with respect to interpretation of lab results.

As an emerging theme, issues with manual dexterity remained constant throughout the semester. Students encountered problems with manipulating the inoculating loop, test tubes, inoculating petri dishes, inoculating test tubes, and preparing bacterial stains. While the issues with manual dexterity were not surprising in the early responses, it was unfortunate to note that student still faced problems with manual dexterity in the final lab quizzes. Practicing manual dexterity may be an area for future research in MCB 3020.

Coincident with manual dexterity, students expressed that they needed practice to master certain techniques and procedures. The evidence of students expressing that they needed practiced was greatest in the early lab quizzes and dropped off significantly in the later lab quizzes. Generally, students expressed a positive outlook on the need for practice, and most responses seemed confident that they would be able to master certain techniques with practice.

It was heartening to note that students' difficulties with using the microscope sharply declined after the first lab quiz. However, this analysis did not include lab exercises covering lab quiz #2, where the majority of staining techniques requiring heavy microscope use were explored. Further analysis of student responses regarding issues with microscope use in lab quiz #2 is warranted for future work. However, the sharp decline in issues related to the microscope indicates that students gained experience with the microscope after these lab activities.

The dearth of student comments regarding time constraints in the lab was also a positive result. Personal experience with teaching labs similar to MCB 3020 and observation of the MCB 3020 lab over the Summer 2016 semester suggested that this may have been an area of difficulty for students. However, the evidence for time constraints being a problem is low, indicating that the time allotted for MCB 3020 is adequate to complete all lab activities for this course.

Finally, the number of students indicating that they had “no issues” was relatively high for lab quizzes 1, 9, and 10, suggesting that least a minority of students had relatively few problems with the first lab and that more students felt comfortable with lab exercises at the later stages of the lab.

The number and type of difficulties encountered in the MCB 3020 lab expressed by students may be due to extraneous cognitive load. Specifically, the simultaneous difficulties with procedural issues, manual dexterity, and needing practice may directly contribute to issues with interpretation of results. Students may be focusing so much on correctly performing procedures that they are unable to focus on the theoretical aspects of the lab and understanding how microbes react to different media. Further research on the extraneous cognitive load encountered by students in the lab may be necessary in order to ameliorate difficulties students encounter in the MCB 3020 lab.

Conclusion

In this chapter, student responses to post-lab reflection questions from the Summer 2016 MCB 3020 laboratory course have been qualitatively analyzed. Although nearly 6000 responses were recorded, only 1200 total responses were sampled for qualitative analysis, and the qualitative data analyzed here may not give a full picture of the student experience in the MCB 3020 lab. However, representative student responses analyzed from lab quizzes one, three, five, seven, nine, and ten give some insight into transfer of learning and difficulties students encountered in the lab, and the results of this study may be helpful in planning future curriculum and lab activities. Evidence from student responses indicated that some degree of learning transfer occurred, students perceived application of MCB 3020 primarily to pre-medical, pre-nursing, pre-pharmacy, or pre-allied health fields, and the majority of student difficulties centered on procedural issues an interpretation of results.

Qualitative Research Question One, Parts A, B, and C

The greatest evidence of learning transfer was among student responses related to transfer of context. Two types of evidence demonstrate that learning transfer of context occurred. First, the total of number of responses relating to transfer of context shifted from the majority of responses coded for near transfer in quizzes from the first half of the semester to the majority of responses coded for far transfer at the last half of the semester. Second, the content of exemplary student quotes shifted from primarily near transfer responses to primarily far transfer responses based on qualitative analysis. Students were able to give specific examples of how the concepts they were learning in MCB 3020 to contexts outside of the learning environment.

Further, there was some evidence of transfer from lateral to vertical transfer of skills, although evidence of transfer of complexity was significantly lower than transfer of context. Evidence from student responses mainly indicated lateral transfer of skills learned in MCB to future lab activities or the unknown activity. Any evidence of vertical transfer was theoretical – students were unable to demonstrate the use of skills learned in the lab to more complex contexts outside the lab. They were, however able to theorize how these skills and techniques could potentially be used. Regardless, there was no significant evidence of evolution from lateral to vertical transfer of complexity in MCB 3020.

Transfer of automaticity had the lowest level of coding frequency compared to the other two types of learning transfer. However, there was some evidence of evolution of transfer of automaticity within low-road automaticity. Exemplary student quotes from lab quizzes early in the semester indicated that they recognized that there were some habits and practices that needed to be learned. Toward the end of the semester, students expressed that certain techniques had become habitual for them. However, there was no evidence of significant transfer from low-road to high-road automaticity.

Qualitative Research Question Two

The qualitative evidence of students' perceptions of how MCB 3020 related to their future careers was slight. Several factors impacted student responses to research question two. First, the question was somewhat leading, and asked students to determine specific application of ten lab quizzes to their future career. The lack of specific references after lab quizzes one and three indicates a level of "quiz exhaustion" in which students grew weary of answering the same question every week. Additionally, the evidence based on student responses indicated that the majority of students responding to the question had either a career in medicine or research, with fewer responses related to nursing, pharmacy, veterinary medicine or other professional fields.

Qualitative Research Question Three

Evidence from student responses to research question three indicate that students had the greatest difficulties with procedures in the lab, interpretation of results, manual dexterity in handling lab equipment, and needing practice with certain lab skills. To a lesser extent, students also struggled with use of the microscope and time constraints in the lab. These results suggested that high intrinsic cognitive load in undergraduate microbiology labs may impede germane cognitive load (Baddeley, 1992; Bannert, 2002; Sweller, 1998 Winberg, 2007)

CHAPTER FIVE: QUANTITATIVE RESULTS

Introduction

The research question for the quantitative component of this study was, "What is the effect of weekly pre-lab formative assessments on students' transfer of learning of microbiology laboratory techniques and knowledge?" The hypothesis for this research question was that weekly pre-lab formative assessment in a general microbiology laboratory will positively affect transfer of learning of microbiology aseptic techniques and knowledge as measured by a statistically significant increase in post-intervention summative mid-term lab exam and final lab practical exam scores compared to historical scores. Statistically significant improvements in mean lab practical final scores were noted in both the Fall 2016 and Spring 2017 intervention groups as compared to historical control groups. There was a statistically significant yet practically insignificant increase in mean lab midterm scores in the Spring 2017 intervention group compared to the historical control group. However, there was a statistically significant decrease in mean lab midterm scores in the Fall 2016 intervention group as compared to the historical control group.

Historical control groups in Fall 2015 and Spring 2016 were compared to Fall 2016 and Spring 2017 groups after the intervention of pre-lab formative assessment. Propensity score matching was utilized to match students from the historical control group to reduce bias, balance unequal sample sizes, and accurately determine the effect of the pre-lab formative assessments (Luellen et al., 2012; Shadish & Steiner, 2010; Thoemmes, 2012). Propensity scores were developed based on covariates of gender, race, age, degree program, academic level, semester, score on the lab midterm exam and score on the lab practical final exam. The covariate of honors section as explored in the Fall semesters as well. Honors sections are not offered in the Spring semesters, therefore, this covariate was not included in the comparison of Spring 2016 and Spring 2017 scores.

Quantitative Study Overview

Intervention Design

The intervention design for the quantitative component of this study is based on the implementation of pre-lab quizzes in MCB 3020 in the Fall 2016 and Spring 2017 semesters. Pre-lab quizzes were comprised of five low-level Bloom's (Bloom, 1969) multiple-choice questions given prior to the start of each lab activity. A total of 19 pre-lab quizzes were given in the Fall 2016 and a total of 21 pre-lab quizzes were given in the Spring 2017 semester. Slight variations existed between the two sets of lab quizzes based on curricular adjustments to the lab curriculum between the two semesters. See Appendices H and I for pre-lab quizzes implemented in the Fall 2016 and Spring 2017 semesters. The MCB 3020 midterm consisted of a multiple-choice exam comprised of 50 questions and worth 100 points. Midterm exam questions pertained specifically to lab concepts, techniques, and media taken during the class session. No significant changes in the content of the lab midterm exam were made during the study period. The MCB 3020 lab practical final exam was worth 75 points and was comprised of stations set up around the classroom with different biochemical tests, petri dishes, specimens under the microscope, and other questions related to the MCB 3020 lab. Students were allotted one minute per station to answer the questions and were not allowed to review the questions at the stations after the exam was completed. No significant changes were made to the content of the final lab practical exam during the semesters studied. The pre-lab formative assessment intervention was designed to act as a formative assessment that would help students prepare for the lab midterm and lab practical summative assessments.

Initial Data Transformation and Cleaning

Anonymized student demographics and scores on midterm lab exams and final lab practical exams were received from Institutional Knowledge Management (IKM) at UCF. Personally identifying information such as student name and ID was stripped from the data and replaced with a randomized code. Demographic data such as gender, race, degree program, honors status in the Fall semesters, academic level, and academic career were transformed into nominal and ordinal codes using SPSS software version 24. Gender codes included male and female. Race codes included Asian, Black/African American, Hispanic/Latino, Multi-racial, Native Hawaiian/Other Pacific Islander, Non-resident Alien, Not Specified, and White. Over 25 different degree programs were coded, but the majority of degree programs were Biology BS, Biomedical Sciences BS, Biotechnology BS, Chemistry BS, and Health Sciences – Pre-Clinical BS. Academic codes included Sophomore, Junior, Senior, Non-Degree-Seeking, and Second-Degree Seeking. Academic Career codes included Undergraduate and Graduate. In the course of the analysis, it was determined that all Sophomores, Juniors, Seniors, and Second-Degree Seeking were also coded as undergraduates, while all but one Non-Degree-Seeking students were also coded as graduate students. Therefore, one case was eliminated from the data set that was coded as both undergraduate and non-degree seeking, while all other cases of students who were non-degree seeking were also coded as graduate students. Although final course grades were not included in the analysis of the impact of pre-lab quizzes on lab midterm and lab practical final grades, students receiving a Withdrawal (W) or an Incomplete (I) grade in MCB 3020 were removed from the data set. After these adjustments were made, no missing data was noted in the data sets for Fall or Spring semesters, indicating that all students included in the study took all of the pre-lab quizzes.

Analysis of Fall Scores

Lab Practical Final Exams

An initial comparison of Fall 2015 lab practical exam scores to post-intervention Fall 2016 exam scores indicated a statistically significant difference between the mean scores of the two groups. However, there was an unequal distribution of scores between the Fall 2015 control group and the Fall 2016 intervention group of lab practical final exams as well as unseen bias in the non-randomized control and intervention groups. It was unclear if differences between the two groups were due to the implementation of the pre-lab quiz intervention or some other confounding variable. Figure 5 below indicates the differences in these two groups before the propensity score matching procedure was performed.

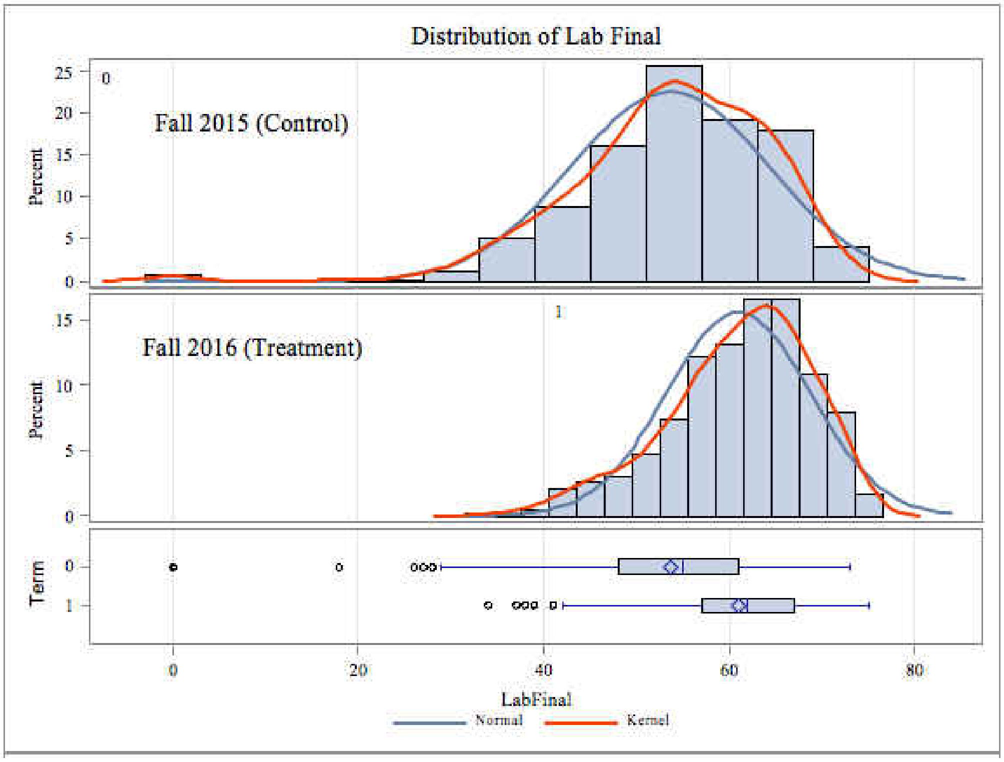


Figure 5: Comparison of the distributions of final lab practical exam scores between Fall 2015 (top) and Fall 2016 (bottom).

Logistic regression analysis was performed to create propensity scores based on the covariates academic level, honors standing, gender, race, age, and degree program so that the two sets of scores could be analyzed more accurately. See Appendix J for analysis of maximum likelihood estimates for each of the covariates included in the model, odds ratios estimates, and the propensity score classification table. The Hosmer-Lemeshow Goodness-of Fit Test was non-significant (χ^2 = 3.0090, *df* = 8, *p* = 0.9338), indicating a good model for the propensity score logistic regression and assignment of propensity scores to the two groups.

Propensity score matching accurately paired student populations in the historical control group with students in the intervention group, creating equal-sized groups of 507 matched pairs between the two groups. See Figure 6 for the distribution of scores after the propensity score matching procedure.

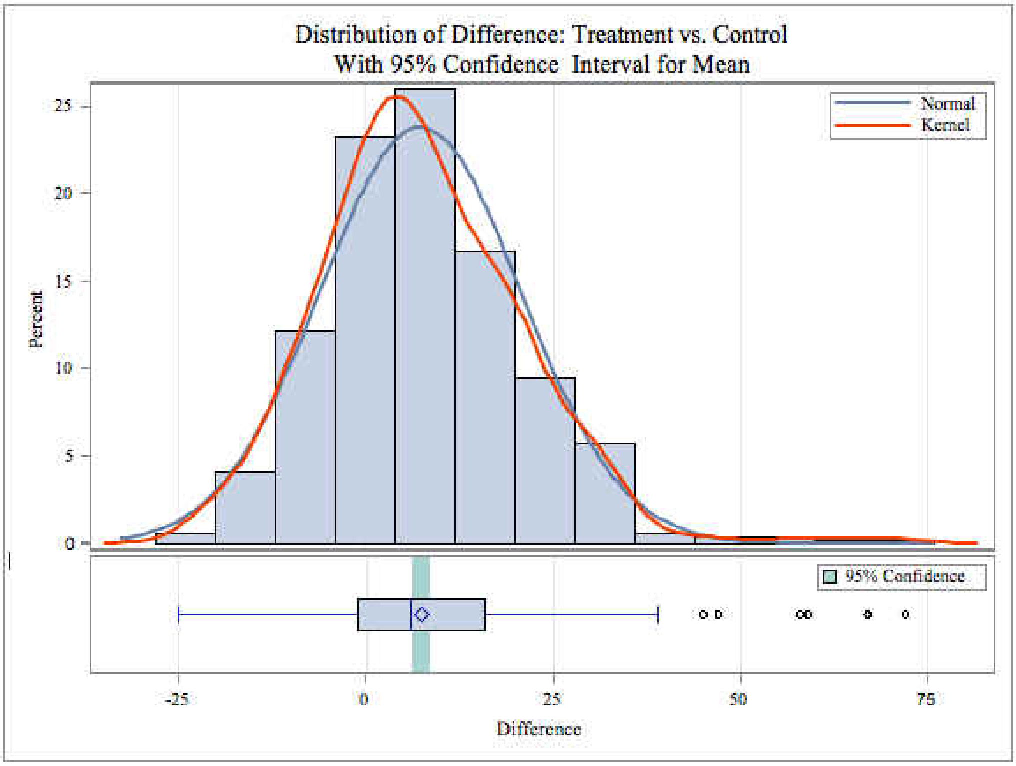


Figure 6: Distribution differences of Fall 2015 and Fall 2016 lab practical exam scores after the propensity score matching procedure.

After scores were matched, an independent t-test was performed to determine if statistical significant differences existed between the Fall 2015 control group and the Fall 2016 intervention group. Results of the independent t-test indicated a statistically significant improvement in mean lab practical final scores in the intervention group (M = 60.98, SD = 7.76) as compared to the historical control group (M = 53.58, SD = 10.67; $t(506) = 12.43$, $p < 0.0001$). Cohen's d was calculated to be 0.797, indicating a large effect size (Field, 2013). Upon further inspection, it was noted that there was also a practically significant increase in lab scores as well. The lab practical final was worth a total of 75 points, therefore the mean increase in scores indicated an increase from an average of 71.44 per cent on the final exam to 81.31 percent, or a nearly ten percent increase in student scores on the lab practical final.

Lab Midterm Exams

Initial comparison of the Fall 2015 lab midterm exam scores to post-intervention Fall 2016 lab midterm exam scores indicated a statistically significant difference between the mean scores of the two groups. However, there was an unequal distribution of scores between the Fall 2015 control group and the Fall 2016 intervention group of lab midterm exams as well as unseen bias in the non-randomized control and intervention groups. It was unclear if differences between the two groups were due to the implementation of the pre-lab quiz intervention or some other confounding variable. Figure 7 below indicates the differences in these two groups before the propensity score matching procedure was performed.

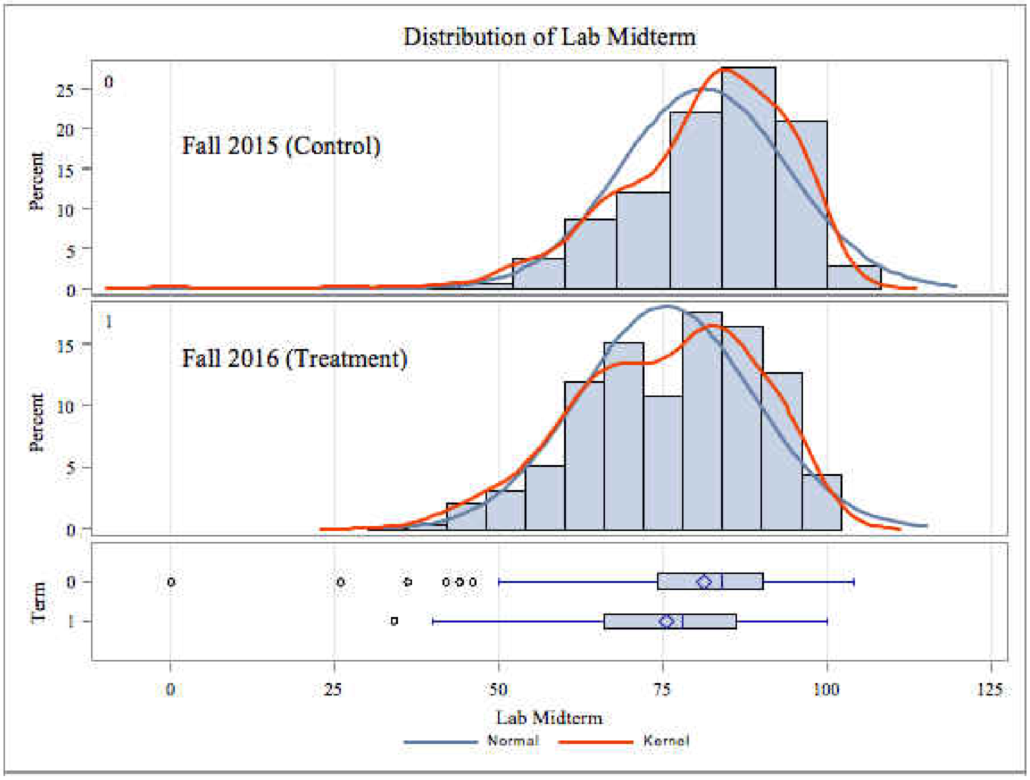


Figure 7: Comparison of the distributions of final lab midterm exam scores between Fall 2015 (top) and Fall 2016 (bottom).

Logistic regression analysis was performed to create propensity scores based on the covariates academic level, honors standing, gender, race, age, and degree program. See Appendix K for analysis of maximum likelihood estimates for each of the covariates included in the model, odds ratios estimates, and the propensity score classification table. The Hosmer-Lemeshow Goodness-of Fit Test was non-significant ($\chi^2 = 3.0090$, $df = 8$, $p = 0.9338$), indicating a good model for the propensity score logistic regression and assignment of propensity scores to the two groups.

Propensity score matching accurately paired student populations in the historical control group with students in the intervention group, creating equal-sized groups of 507 matched pairs. See Figure 8 for the distribution of scores after the propensity score matching procedure.

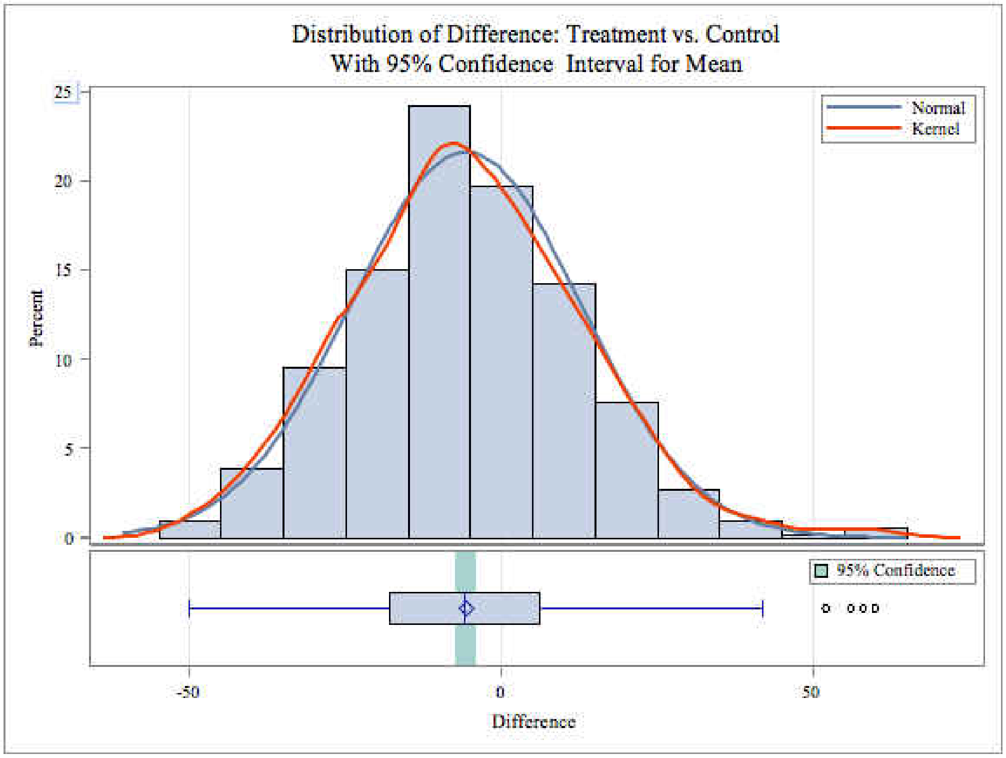


Figure 8: Distribution differences of Fall 2015 and Fall 2016 lab midterm exam scores after the propensity score matching procedure.

After scores were matched, an independent t-test was performed to determine if statistically significant differences existed between the Fall 2015 control group and the Fall 2016 intervention group. Results of the independent t-test indicated a statistically significant decrease in mean lab midterm scores in the intervention group (*M* = 75.69, *SD* = 13.29) as compared to the historical control group (*M* = 81.29 SD = 12.85; $t(510) = -6.88$, $p<0.0001$). Cohen's d was calculated to be 0.430, indicating a low to moderate effect size (Field, 2013). Upon further inspection, it was noted that there was a practically significant decrease in mean scores as well. The lab practical midterm was given as a multiple-choice exam administered in the classroom rather than the laboratory and was worth 100 points. The decrease in mean scores indicates 5.6 per cent decrease in lab midterm exam scores in the post-intervention group.

Analysis of Spring Scores

Lab Practical Final Exams

Initial analysis of the Spring 2016 lab practical exam scores to post-intervention Spring 2017 exam scores indicated a statistically significant difference between the mean scores of the two groups. However, there was an unequal distribution of scores between the Spring 2016 control group and the Spring 2017 intervention group of lab practical final exams as well as unseen bias in the non-randomized control and intervention groups. It was unclear if differences between the two groups were due to the implementation of the pre-lab quiz intervention or some other confounding variable. Figure 9 below indicates the differences in these two groups before the propensity score matching procedure was performed.

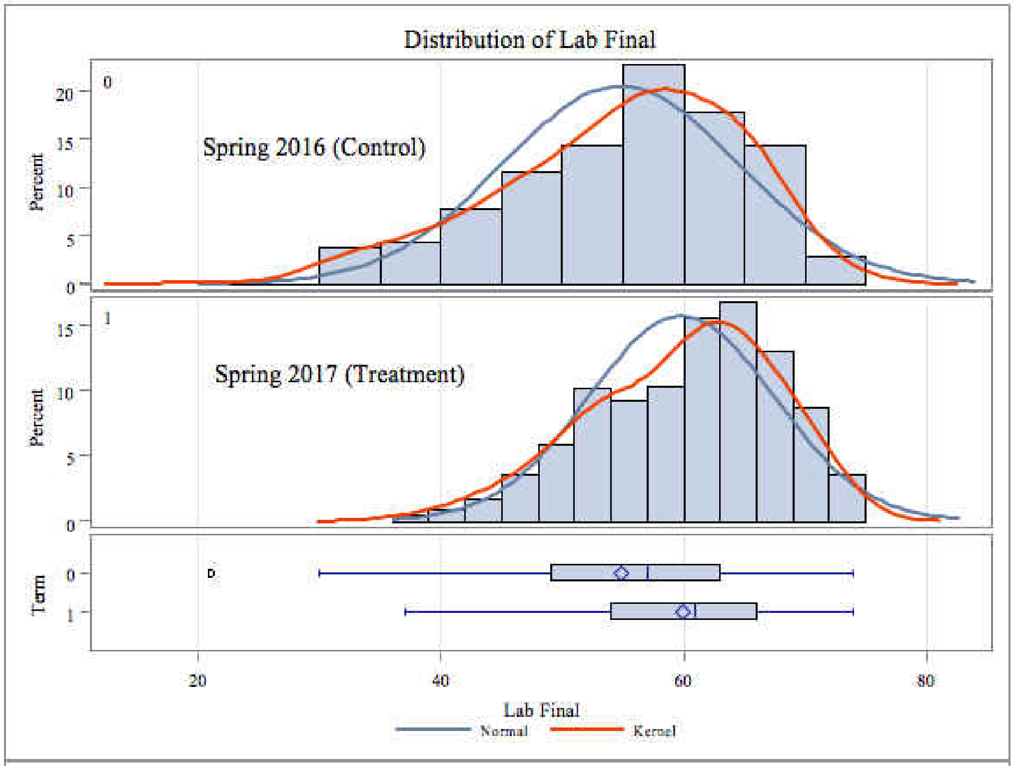


Figure 9: Comparison of the distributions of final lab practical exam scores between Spring 2016 (top) and Spring 2017 (bottom).

Logistic regression analysis was performed to create propensity scores based on the covariates academic level, gender, race, age, and degree program. The covariate "Honors Standing" was not utilized as a covariate in the analysis of Spring scores because no honors sections were offered during these semesters. See Appendix L for analysis of maximum likelihood estimates for each of the covariates included in the model, odds ratios estimates, and the propensity score classification table. The Hosmer-Lemeshow Goodness-of Fit Test was non-significant ($\chi^2 = 11.9890$, $df = 8$, $p = 0.1517$), indicating a good model and assignment of propensity scores to the two groups.

Propensity score matching accurately paired student populations in the historical control group with students in the intervention group, creating equal-sized groups of 342 matched pairs. See Figure 10 for the distribution of scores after the propensity score matching procedure.

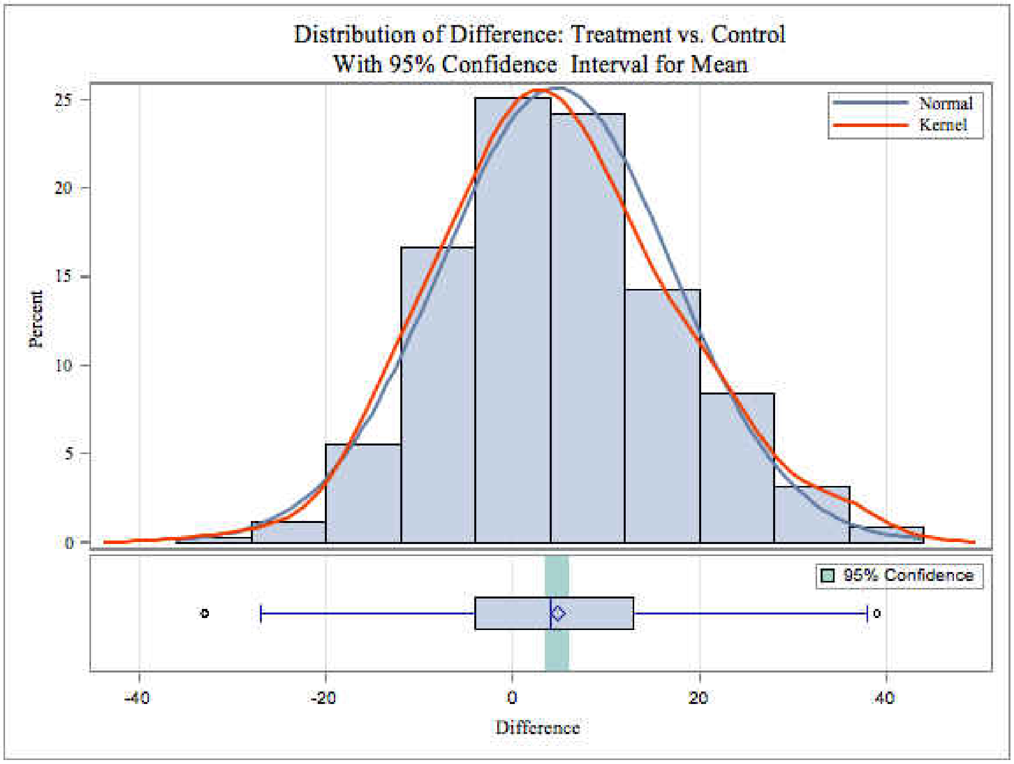


Figure 10: Distribution differences of Spring 2016 and Spring 2017 lab practical exam scores after the propensity score matching procedure.

After scores were matched, an independent t-test was performed to determine if statistically significant differences existed between the Spring 2016 control group and the Spring 2017 intervention group. Results of the independent t-test indicated a statistically significant improvement in mean lab practical final scores in the intervention group (M = 59.76, SD = 7.79) as compared to the historical control group (M = 55.01, SD = 9.66; $t(341) = 7.06$, $p < 0.0001$). Cohen's d was calculated to be 0.539, indicating a medium effect size (Field, 2013). The lab practical final was worth a total of 75 points, therefore the mean increase in scores indicates an increase from an average of 73.35 per cent on the final exam to 79.68 percent, or a more than 6.34 per cent increase in student scores on the lab practical final.

Lab Midterm Exams

Initial analysis of the Spring 2016 lab midterm exam scores to post-intervention Spring 2017 exam scores indicated a significant difference between the mean scores of the two groups. However, there was an unequal distribution of scores between the Spring 2016 control group and the Spring 2017 intervention group of lab practical final exams as well as unseen bias in the non-randomized control and intervention groups. It was unclear if differences between the two groups were due to the implementation of the pre-lab quiz intervention or some other confounding variable. Figure 11 below indicates the differences in these two groups before the propensity score matching procedure was performed.

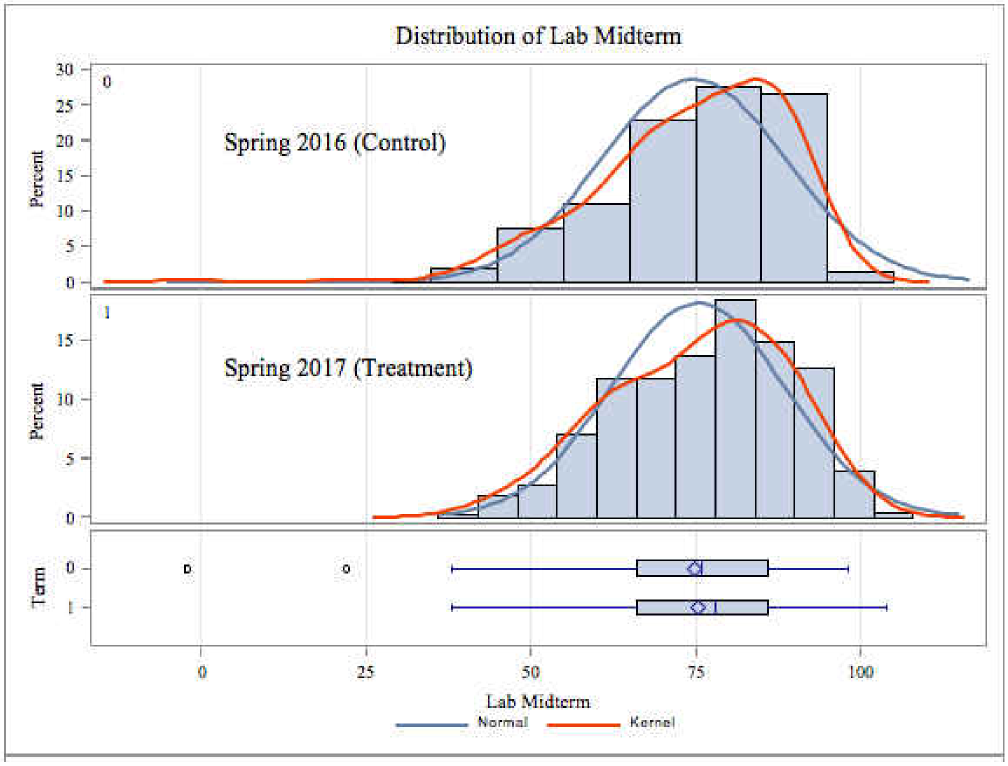


Figure 11: Comparison of the distributions of final lab midterm exam scores between Spring 2016 (top) and Spring 2017 (bottom).

Logistic regression analysis was performed to create propensity scores based on the covariates academic level, gender, race, age, and degree program. "Honors Standing" was not utilized as a covariate in the analysis of Spring scores because no honors sections were offered during these semesters. See Appendix K for analysis of maximum likelihood estimates for each of the covariates included in the model, odds ratios estimates, and the propensity score classification table. The Hosmer-Lemeshow Goodness-of Fit Test was non-significant ($\chi^2 = 11.9890$, $df = 8$, $p = 0.1517$), indicating a good model and assignment of propensity scores to the two groups.

Propensity score matching accurately paired student populations in the historical control group with students in the intervention group, creating equal-sized groups of 342 matched pairs. See Figure 12 for the distribution of scores after the propensity score matching procedure.

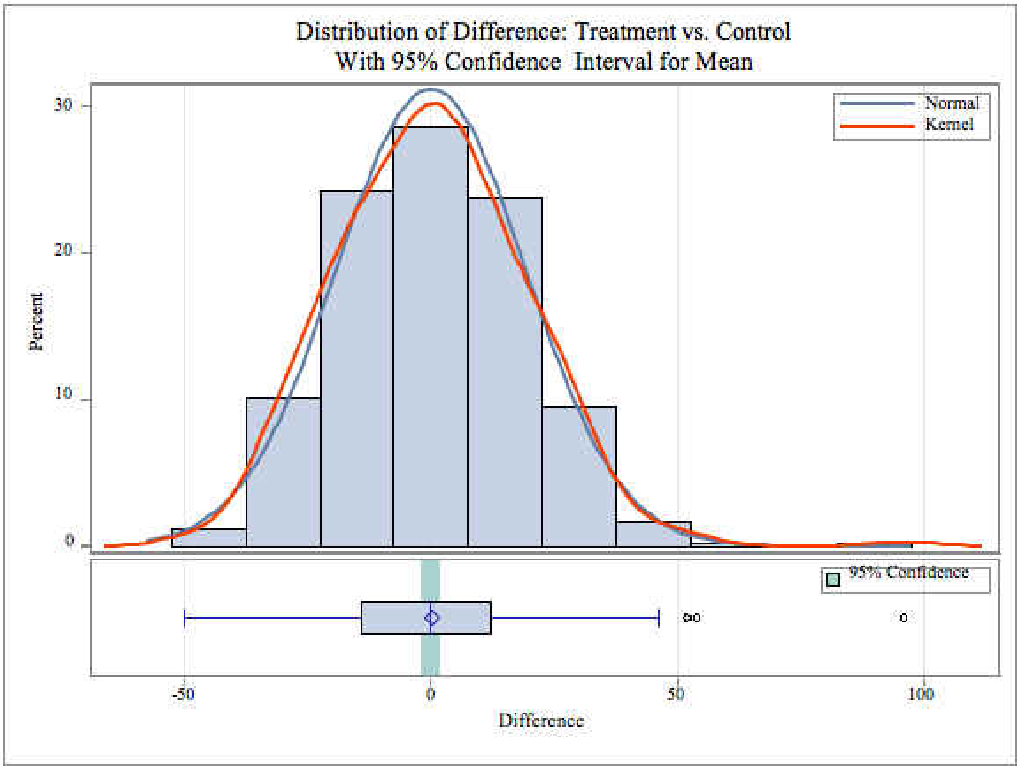


Figure 12: Distribution differences of Spring 2016 and Spring 2017 lab midterm exam scores after the propensity score matching procedure.

After scores were matched, an independent t-test was performed to determine if significant differences existed between the Fall 2015 control group and the Fall 2016 intervention group. Results of the independent t-test indicated a slight increase in mean lab midterm scores in the intervention group (*M* = 74.97, *SD* = 13.23) as compared to the historical control group (*M* = 74.77 SD = 14.07; *t*(510) = -6.88, *p*<0.0001). Cohen's d was calculated to be 0.0151, indicating a very small effect size (Field, 2013). The increase in mean scores indicates 0.2 per cent in lab midterm exam scores in the post-intervention group, which although statistically significant is not practically significant in terms of a meaningful increase to student scores on the midterm lab practical exam during Spring 2017.

Conclusion

Analysis of matched scores between historical control groups and post-intervention groups indicated a statistically significantly positive impact as well as a practically significantly positive impact of pre-lab quizzes on lab practical final exams in the Fall 2016 and Spring 2017 semesters. Post-intervention lab practical exam scores increased by nearly ten per cent in the Fall 2016 semester and over six per cent in the Spring 2017 semesters. Effect sizes for this effect were large and medium for the Fall 2016 and Spring 2017 semesters respectively, which is notable in science education research. Evidence from this component of the study supported the hypothesis that weekly pre-lab formative assessment in a general microbiology laboratory positively affected transfer of learning of microbiology aseptic techniques and knowledge as measured by a significant increase in post-intervention summative final lab practical exam scores compared to historical scores.

Analysis of matched scores between historical control groups and post-intervention groups indicated a very minor positive impact of pre-lab quizzes on lab midterm exam scores in the Spring 2017 semester. Only a 0.2 per cent increase in lab midterm exam scores was noted in the post-intervention group as compared to the historical control group, making the effect of pre-lab formative assessments in the Spring 2017 semester negligible. Evidence from this component of the study did not support the hypothesis that a weekly pre-lab formative assessment in a general microbiology laboratory will positively affect transfer of learning of microbiology aseptic techniques and knowledge as measured by a significant increase in post-intervention summative mid-term lab practical exam scores compared to historical scores. Therefore, we fail to reject the null hypothesis that there was no effect of the pre-lab formative assessments on lab midterm exams.

Analysis of matched scores between historical control groups and post-intervention groups indicated a negative impact of pre-lab quizzes on lab midterm exam scores in the Fall 2016 semester. A 5.6 per cent decrease in lab midterm exam scores in the intervention group as compared to the historical control group suggests a deleterious effect of the pre-lab quiz intervention during the Fall 2016 semester. Evidence from this component of the study did not support the hypothesis that a weekly pre-lab formative assessment in a general microbiology laboratory will positively affect transfer of learning of microbiology aseptic techniques and knowledge as measured by a significant increase in post-intervention summative mid-term lab practical exam scores compared to historical scores.

CHAPTER SIX: DISCUSSION

The research study described in the previous chapters of this dissertation explored the theory of learning transfer as it applied to the general microbiology laboratory and was grounded in the conceptual framework developed by Boud and Walker (1990) that described how students learn from experience. The Boud and Walker conceptual framework incorporates three aspects of learning: preparation, experience, and reflective processes. The first aim of this study described in Chapter Four was to determine if there was any evidence of learning transfer based on students' responses to post-lab reflection questions that queried them about their difficulties in the lab and potential applications to future careers, which addressed the third component of the conceptual framework. The first aim of the study described in Chapter Four also addressed student experiences through the lab activities themselves, which was the second component of the conceptual framework that assisted students in the learning process. The second aim of this research study described in Chapter Five was to demonstrate learning transfer of microbiology knowledge and techniques within the context of general microbiology as measured by statistically significant improvements in summative assessments compared to historical scores after the implementation of formative assessments. The second aim of this study addressed the first component of the conceptual framework, namely preparation of students for learning through pre-lab formative assessments.

In this chapter, I will discuss the implications of this study by discussing the findings of each component of the study and addressing: 1) how these findings corroborate or contradict prior research on learning transfer in undergraduate science courses; 2) how these findings address deficits in the literature related to learning transfer in undergraduate microbiology courses; and 3) how these findings add to the current knowledge base on learning transfer in undergraduate microbiology courses for each research question. Finally, I will discuss the potential contributions of this study, the limitations of this study, and areas for future research.

Discussion and Implications of Qualitative Findings

Findings During the Coding Process

A priori codes for factors affecting student learning were grounded in the literature review on learning transfer and my personal experience teaching microbiology for over a decade as an adjunct instructor. *A priori* and emergent codes are listed in Table 2 in Chapter Four. A number of interesting findings resulted from the coding process itself. For example, there was no evidence of two *a priori* codes: "Food or Drink in Lab" and "PPE or Lab Attire," among the responses coded in this study. The absence of evidence of these codes was surprising given that personal experience and previous observation of MCB 3020 suggested that students had difficulties with not bringing food or drinks into the lab and not coming to lab dressed in appropriate lab attire. I personally witnessed my own students in my teaching career and students in MCB 3020 coming to lab in open-toed shoes or shorts and being sent away to change shoes or clothing. In one instance, a student in MCB 3020 was required to wear bags over their shoes in order to comply with the closed-toe shoe policy. Additionally, I personally witnessed a number of students complaining about not being able to bring food into the lab or needing to eat immediately before or after the lab. Nevertheless, no evidence of these two codes was found during the coding process among selected responses, which was an unexpected finding in the coding process. Considering this somewhat unexpected finding in light of my experience as a microbiology instructor, I realize that issues with food and drinks in the lab and student lab attire are rather disruptive to the lab experience because I have to take somewhat punitive action against students who, for example, come to the lab in sandals despite being instructed not to. I recognize that although significant energy and effort is required from me as an instructor in dealing with what can be considered largely behavioral issues, in the larger sense, food and drinks in the lab and proper lab attire are not truly significant issues in terms of the student experience in the lab. Historically I have placed greater importance on these issues than was truly warranted.

Other codes emerged during the coding process that contributed significantly to an understanding of the student experience in MCB 3020. For example, "identification of bacteria" and "interpretation of media" emerged as issues students struggled with consistently throughout all lab quizzes. While issues relating to identification of bacteria and interpretation of media were not unexpected in a microbiology laboratory, these codes were not considered in the development of *a priori* codes under the parent code, "factors affecting learning." In the development of *a priori* codes, "factors affecting learning" encompassed "identification of bacteria" and "interpretation of media," yet as the coding process continued, consistent and specific comments by students relating to both identification of bacteria and interpretation of media necessitated the addition of these two codes. Student difficulties in identifying bacteria and interpreting media signaled areas that affected student learning in the lab. Although laboratory curricular materials gave students guidelines regarding the identification of particular bacterial colonies on different types of solid media or the reaction patterns of different bacterial species in biochemical test media, these findings indicate that students may need greater support in the identification of bacteria and interpretation of media.

A related code, “streak plate skills” also emerged in the coding process as students expressed difficulties with the three-zone streak plate method. Difficulties with streak plate skills remained relatively constant throughout the semester as students expressed difficulties with effectively isolating bacterial colonies using this method. One of the main expressions of difficulty was that students struggled with not piercing or slashing the agar when inoculating bacteria onto the agar surface. The three-zone streak is a skill that is tested as part of the MCB 3020 lab curriculum, and given these expressions, students may benefit from low-stakes practice with inoculating agar plates early in the semester to prepare them for the skills test later in the semester.

The codes labeled “manual dexterity” and “need practice” also emerged in the coding process. Although students expressing difficulties with manual manipulation of microbiological materials somewhat declined throughout the semester, the high volume of codes relating to manual dexterity in the early quizzes suggests that students may benefit from low-stakes time spent in the early lab activities simply practicing the manipulation of microbial media, test tubes, petri dishes, inoculating loops, and other lab equipment prior to performing more high-stakes experiments. The expressions regarding “needing practice” were for the most part very positive, as students expressed confidence that they would get better with these techniques with practice. If students had the opportunity to practice these techniques early in the semester, they may have greater success with the outcomes of experiments due to reductions in mistakes or contaminations due to imperfect techniques. Perhaps in future semesters, the lab curriculum could be structured to allow for more opportunities for low-stakes practice with some of the microbiological techniques requiring significant manual dexterity to assist students with developing the type of manual dexterity required by these techniques. Additionally, meta-communicative signaling that acknowledges the need for a higher level of manual dexterity both in the lab and in clinical practice may prepare students more effectively in practicing these techniques.

As the coding process continued, an emergent code of “nonsense” was added, as student responses either were nonsensical or seemed simply to be filler in order for the student to earn points on the post-lab quiz for answering the question. The increase in nonsense codes was an important finding because it suggested that students were experiencing what came to be defined as “quiz exhaustion” from being asked the same questions on every post-lab quiz with only minor modifications related to the lab activity encountered in the previous week. While some student responses remained detailed and thoughtful, it was noted that the majority of responses, especially those relating to application of microbiology lab activities to future careers, became increasingly less detailed and thoughtful and increasingly nonsensical. A similar finding was noted in a study involving guided reflection questions administered to undergraduate physics students (Dounas-Frazer & Reinholz, 2015). In this study, undergraduate physics students were given detailed reflection questions to answer at the end of each week’s physics lab activities to encourage deep understanding and develop learning skills. Researchers noted a decrease in the number and variety of reflection responses from the beginning to the end of the semester. The findings from this dissertation study corroborate this research, indicating that asking the same questions repeatedly in reflection activities may lead to what I defined as "quiz exhaustion" in this study and may reduce meaningful reflections of student experiences in the lab.

As noted in Chapter 2, dearth in the literature exists with respect to qualitative analysis of student experiences in undergraduate general microbiology labs. The findings of the coding process alone for the qualitative analysis of this study add significantly to the knowledge base regarding student experiences in undergraduate microbiology labs. Although a number of *a priori* codes were developed prior to the coding process based on the current literature on student experiences in undergraduate science labs in general and microbiology labs in particular, the codes that emerged during the coding process give greater depth and nuance to an understanding of some of the difficulties students experience in the microbiology lab. For example, student complaints about PPE or food and drink in the lab may not be as much of a significant issue to students as previously understood, but given the codes that emerged relating to identification of bacteria, interpretation of media, issues with manual dexterity and streak plate skills suggest that students may need more practice and support with these issues in order to be more successful in general microbiology labs. Reduction of intrinsic cognitive load (ICL) through practice with manipulation of microbiological materials may facilitate learning transfer by improving germane cognitive load (GCL; Baddeley, 1992; Bannert, 2002; Sweller, 1998 Winberg, 2007).

Findings Related to Learning Transfer in Research Question One

The first qualitative research question asked, "Do student responses to open-ended post-lab questions show meaningful evidence of learning transfer over the course of the semester?" The three sub-questions related to the first qualitative research question were, a) "What is the evidence of evolution of transfer of automaticity over the course of the semester?" b) What is the evidence of evolution of transfer of complexity over the course of the semester?" and c) "What is the evidence of evolution transfer of context over the course of the semester?" The following sections will address findings related to the first research question and each of the sub research question.

Overall, there was significant evidence of learning transfer based on student responses to reflection questions given in post-lab quizzes in the Summer 2016 semester of MCB 3020. Indications from student responses indicated primarily an evolution within low-road transfer, some evolution from lateral transfer to theoretical vertical transfer, and significant evolution from near to far transfer. Given the paucity of research on learning transfer among undergraduate students in general microbiology, findings from this component of the study add to the current knowledge base by providing evidence of student experiences in a general microbiology course that indicate instances in which learning transfer does or does not occur. Each of the following sections will address findings for qualitative sub-questions a, b, and c.

Transfer of Automaticity

Evidence from student responses related to transfer of automaticity suggested an evolution within low-road transfer skills from the beginning to the end of the semester. In early quizzes, students expressed that they had difficulties with some of the habits and practices they were learning in the lab. As the semester progressed, students expressed that these habits and practices had become "second nature" to them. The evolution of low-road transfer of automaticity is a significant finding, because it suggests that learning transfer is indeed occurring among students in the population studied. The low-road habits developed through the practice of aseptic technique, two-tube transfer, and the three-zone streak technique are important foundations to the application of these skills in future contexts such as future courses, research contexts, or clinical contexts. However, compared to other codes related to learning transfer, evidence of transfer of automaticity was minor.

Evidence of evolution from low-road to high-road transfer of automaticity was lacking, however. Any evidence suggesting evolution from low-road transfer to high-road transfer was theoretical in nature as students recognized that the practices and habits developed in MCB 3020 would be used again in future career settings. The findings related to a lack of evolution from low-road to high-road transfer of automaticity are unsurprising because students were only observed through one semester of general microbiology and not studied longitudinally as they progressed to other courses or to future careers.

Transfer of automaticity has not been extensively studied in research related to undergraduate science labs in general or undergraduate microbiology labs in particular. The findings related to transfer of automaticity in this study add to the current knowledge base regarding the development of habits and practices among students in general microbiology labs, and may provide greater insights into student experiences regarding transfer of automaticity (Bassok, 1990; Gick & Holyoak, 1983; Perkins & Salomon, 1992; Perkins & Salomon, 1989; Salomon & Perkins, 2015; Singley & Anderson, 1989). Evidence of low-road learning transfer among students in undergraduate microbiology courses suggests that students are developing habits of techniques through the course of the semester, which is a primary learning outcome in most general microbiology courses (AAAS, 2011; ASM Curriculum Recommendations, 2012; Baker et al., 2012). The qualitative methodologies utilized in this study may be helpful to undergraduate microbiology educators who wish to assess low-road transfer of automaticity and the development of practices and habits of their students through analysis of student reflections.

Transfer of Complexity

Evidence from student responses related to transfer of complexity indicated primarily lateral transfer of automaticity at the beginning of the semester to a balance between lateral and vertical transfer at the end of the semester. Evidence of lateral transfer included student comments regarding applying skills and techniques learned in early lab activities in later labs and some evidence of vertical transfer to future contexts. However, any evidence of vertical transfer was theoretical because students were not observed applying skills and techniques they learned in MCB 3020 to more complex situations abstracted from the learning context. Rather, students recognized that skills and techniques learned in MCB 3020 could be used in more complex situations abstracted from the learning context. While this recognition was important, it did not provide evidence that vertical learning transfer had occurred. The findings related to lack of vertical transfer were unsurprising, given that students were not observed as they progressed from the context of MCB 3020 to other environments where the skills learned would be applied to more complex situations. Regardless, the finding that lateral transfer occurred among students in MCB 3020 was significant, because it suggests that transfer of complexity is taking place among students based on their comments regarding the use of techniques and skills learned in lab activities. Evidence of transfer of complexity was moderate compared to the minimal evidence of transfer of automaticity.

Transfer of complexity has not been extensively studied in research related to undergraduate science labs in general or undergraduate microbiology labs in particular. The findings related to transfer of complexity in this study add to the current knowledge base regarding transfer of complexity among students in undergraduate microbiology labs, as students demonstrated evidence of lateral learning transfer of skills and techniques, which is another primary learning outcome for most microbiology courses (AAAS, 2011; ASM Curriculum Recommendations, 2012; Baker et al., 2012). This research study addresses dearth in the literature with respect to lateral learning transfer of microbiology laboratory skills and techniques to contexts related to the learning context as well as theoretical vertical transfer to future applications outside the learning environment (Gagné, 1965, Singley & Anderson, 1989). The qualitative methodologies utilized in this study may be helpful to undergraduate microbiology educators who wish to assess transfer of complexity in their students through analysis of student reflections related to transfer of skills and techniques utilized in undergraduate microbiology courses.

Transfer of Context

The greatest evidence of learning transfer was noted in transfer of context, as students expressed application of knowledge and understanding to contexts related to the learning context of the laboratory as well as contexts outside the laboratory. Specifically, it was noted that there was an evolution of primarily near learning transfer of context in beginning of the semester to primarily far learning transfer at the end of the semester. The tipping point for the shift from evidence of near transfer to far transfer occurred coincident with lab activities that required identification of specific organisms such as *Salmonella, Shigella, Escherichia coli,* and *Proteus* as well as lab activities that involved antibiotics, disinfectants, and antiseptics. The real-world applications of identification of microbes, prescription of antibiotics, and use of disinfectants seemed to become manifest to students, primarily students who identified themselves as going into the healthcare professions.

Anecdotal evidence based on my experience as a volunteer in the MCB 3020 lab as well as informal conversations with the graduate teaching assistants (GTAs) who worked as lab instructors suggests that GTAs instructing the majority of the labs plan on careers in various aspects of healthcare, primarily medicine or physician's assistants. The findings noted with respect to transfer of context seem to indicate that meta-communicative signaling regarding the application of knowledge and understanding gained in MCB 3020 primarily focuses on applications to healthcare professions (Floriani, 1993; Goffman, 1974; Gumperz, 1982; Tapper, 1999). While this type of meta-communicative signaling may be beneficial to students planning on future careers in healthcare, students in other professional fields such as research or education may not perceive the value of MCB 3020 to their future careers, despite the fact that the curriculum taught in MCB 3020 has application in a wide variety of fields. A qualitative study conducted with experienced nurses suggested that there was a lack of meta-communicative signaling in undergraduate microbiology classes based on their perceptions of incoming nursing students. Nurses interviewed in the study indicated that there was a disparity between the theoretical knowledge gained in undergraduate microbiology and clinical practice as they trained students who had recently emerged from their undergraduate pre-nursing training (Cox, 2014). However, beyond this study, there is little evidence in the literature related to meta-communicative signaling regarding microbiological practices relating to clinical applications. Lack of meta-communicative signaling for students planning on careers other than in healthcare fields may actually inhibit learning transfer, as they are unable to perceive the application for the knowledge and understanding gained in MCB 3020 to contexts outside the course. However, analysis of meta-communicative signaling by GTAs in MCB 3020 was beyond the scope of this study.

Transfer of context has not been extensively studied in research related to undergraduate science labs in general or undergraduate microbiology labs in particular. Evidence from this study suggests that both near and far transfer of knowledge and understanding of microbiology curriculum occurs in undergraduate microbiology labs, and addresses a dearth in the literature regarding transfer of context. Transfer of knowledge or understanding from the learning context to other contexts is a major aim of education in general and science education specifically (AAAS, 2011; ASM Curriculum Recommendations, 2012; Baker et al., 2012; Dewey, 1938; Dewey, 1916; Gagné, 1965; Mayer, 1975; Royer, 1979; Singley & Anderson, 1989), yet there is little evidence of learning transfer in undergraduate microbiology courses. The qualitative methodologies utilized in this study may benefit undergraduate science educators and especially undergraduate microbiology educators who wish to evaluate evidence of learning transfer of context in their students. The finding that learning transfer of context primarily occurred among students planning on future careers in healthcare also directly relates to findings regarding future careers discussed in the following section.

Findings Regarding Learning Transfer in Research Question Two

Qualitative research question two asked, "How do microbiology students perceive the role of the lab in helping them to prepare for their future careers in medicine, nursing, pharmacy, allied health, academic research, or industry?" Findings from this component of the study indicated that students made explicit references to their future careers in the early quizzes of the semester, but specific mention of future careers significantly declined as the semester progressed, and responses became more general, citing future careers in "healthcare" or "research" without citation of any career in particular. Evidence of quiz exhaustion was noted coincident with the decline in specific mentions of future careers.

Despite the low numbers of specific references to the application of MCB 3020 in future careers overall, it seems that students in pre-medical fields, specifically pre-medicine and pre-physician's assistant students were able to perceive MCB 3020 as helping them to prepare for their future careers. Significant representation was also seen among students who are intending to pursue higher education and academic careers or other professional careers. This finding was meaningful because it indicated evidence of learning transfer among students planning on pursuing careers in the healthcare field and specifically answered research question two, as students were able to perceive the role of the lab in helping them to prepare for future careers. However, students planning on careers in healthcare were not the only students in the course. In the quantitative component of the study, over 25 degree programs were listed, many of which were not specifically related to health care fields. Therefore, this finding suggests that not all students enrolled in MCB 3020 are able to perceive the direct application of the course to their future careers.

Although they can be considered healthcare fields, very few specific mentions of pre- nursing pre-pharmacy, pre-dental, or pre-veterinary programs were noted across all quizzes. For example, while nursing can be considered to be a component of the healthcare field, there was a paucity of responses specifically mentioning the nursing program. The reason for this may be that many nursing students elect to take "Microbiology for Health Professionals," (MCB 2004C), class that is more focused for pre-nursing students than is MCB 3020. Regardless, pre-veterinary, pre-pharmacy, and pre-dental students were underrepresented in specific comments relating to the application of MCB 3020 to their future careers. The minimal number of responses for these future careers students may indicate that greater effort needs to be expended to assist students in perceiving the relevance of MCB 3020 to career tracks such as dental, nursing, pharmacy, or veterinary fields.

The limited volume and specificity of responses regarding application of MCB 3020 to future careers related to medicine may also have to do with the graduate teaching assistants (GTAs) teaching the lab section. Anecdotal evidence and my volunteer experience with MCB 3020 suggest that the majority of these GTAs who are the primary instructors of the labs are pre-medical students in master's degree programs who are planning on a career in medicine. The meta-communicative signaling given by these GTAs to students regarding applications to future careers may emphasize application of the MCB 3020 lab primarily to the medical field (Floriani, 1993; Goffman, 1974;

Gumperz, 1982; Tapper, 1999). However, this study was primarily focused on the experiences of students in MCB 3020, and analysis of the interrelationship between GTAs was not considered in this study, but is an area for future research.

Student perceptions of the application of undergraduate science labs to future careers have not been extensively studied in research related to undergraduate science labs in general or undergraduate microbiology labs in particular (Feldman, 1969; Goldrick et al., 1990; Gomez & Gomez, 1987; Larson & Lusk, 2006; Kneebone et al., 2002; Maginnis & Cruzon, 2010; Yoder, 1993). The findings in this study related to student perceptions of the application of knowledge and skills learned in the general microbiology lab to future careers add to the current knowledge base regarding the need for effective meta-communication in undergraduate microbiology labs to facilitate this type of learning transfer. While undergraduate students may perceive the microbiology laboratory course as a necessary pre-requisite for future courses within certain degree programs, students may not have a clear understanding of how the knowledge and skills learned in the lab apply specifically to their future careers, especially those not directly related to healthcare or research. Meta-communicative signaling by lab instructors concerning applications to future careers may facilitate learning transfer and assist students in understand the relevance of the course to a wide variety of career applications. Observation of meta-communicative signaling by laboratory instructors was not a part of this study, but is an area for future research.

Findings Regarding Research Question Three

Research question three asked, "What difficulties do students encounter when performing laboratory experiments in general microbiology?" The findings regarding difficulties students encountered in the microbiology lab were not unsurprising to me as a microbiology instructor, but provided some important insights to the student experience in the lab. The main difficulty noted in this study was with procedural skills. Student difficulties in performing techniques such as the two-tube transfer, three-zone streak, the Gram stain, or simply maintaining habits of aseptic technique were consistent in student responses to reflection questions throughout the semester. Coincident with the difficulties with procedures was evidence of students having difficulties with manual dexterity and students expressing that they need more practice in performing procedures. These three issues are interrelated and give insights on a significant issue for microbiology students, which is high intrinsic cognitive load (ICL) in the microbiology lab (Baddeley, 1992; Bannert, 2002; Sweller, 1998 Winberg, 2007). Given the evidence from student responses related to difficulties in the lab, students spend a great deal of time focusing on maintaining asepsis in inoculating media, performing the three-zone streak to isolate bacteria, performing staining techniques, and performing other procedures. Students may perceive these techniques and practices as extraneous to the purposes of the lab; however, aseptic technique, the three-zone streak, staining techniques, and other procedures are fundamentally important components of the microbiology laboratory that prepare students for work in clinical fields that by their nature have high intrinsic cognitive load.

Yet, the focus on these procedures and techniques could detract from students' understanding of the principles of microbiology being taught in the lab. Difficulties experienced by students with ICL in the microbiology lab may be interfering with learning transfer because they are unable to focus on germane cognitive load (GCL). For example, in Table 6 in Chapter Four, the evidence of low-road transfer of skills significantly decreases from lab quiz one to lab quiz ten. Student expressions relating to certain procedures becoming "natural" or "habit" to them are in the minority. In fact, although some evidence of evolution within low-road transfer was found, very few students expressed that skills such as the two-tube transfer, three-zone streak, aseptic technique, and others had become habitual for them in the later quizzes. Additionally, student responses relating to lateral transfer of learning are noted in Chapter Four, Table 7. Evidence of lateral transfer of complexity was low given the overall number of responses coded in this study. Despite evidence of some evolution of transfer of complexity from lateral to theoretical vertical transfer, the volume of responses coded for lateral transfer was low compared to other codes. These findings suggest that high ICL exists throughout the semester in MCB 3020, which may inhibit GCL and transfer of learning in many respects.

In MCB 3020, students are required to pass a skills test in which they demonstrate proficiency with performing the two-tube transfer, the three-zone streak, and the Gram stain prior to the end of the semester. Students practice these skills by performing them throughout the semester in various lab activities and then are subject to skills tests at various intervals throughout the semester, with several opportunities to pass the skills test without a point deduction. However, during observation of the lab as a volunteer, I noted that skills tests were conducted at the end of certain lab activities that already had high ICL, students experienced a great deal of stress when performing the skills tests, and many of them failed on the first attempt. If students had the opportunity for low-stakes practice of skills such as the two-tube transfer, the Gram stain, and three-zone streak as well as other procedures such as aseptic technique and practice with microscopes early in the semester, this may reduce ICL and allow students to focus on GCL, which could more effectively facilitate learning transfer. For example, students are required to demonstrate an effective three-zone streak as part of their skills test in MCB 3020 by turning in a streaked plate to the lab coordinator for analysis. Quite often, these submissions have serious issues, are rejected and given a zero grade, and students have to re-submit a streaked plate for credit. If students were allowed to turn in a non-graded streaked plate for analysis and feedback prior to the final graded streaked plate, they may experience a reduction in ICL. Similarly, lab instructors could offer non-graded opportunities for students to demonstrate the two-tube transfer and Gram stain, giving feedback on any errors and offering suggestions for improvement prior to the graded event. Low-stakes practice opportunities such as these would require some restructuring of the laboratory schedule and may require extra effort by lab instructors in observing skills test practice and giving feedback. Additionally, multiple opportunities for practice with the three-zone streak would require increased demand for petri dishes and cause increased biohazard waste in the lab. However, not unlike low-stakes formative assessments in the classroom, these low-stakes lab technique practice opportunities could significantly reduce ICL among students, improve student outcomes in the lab, and lead to greater learning transfer of microbiological skills and techniques in future contexts.

Student experiences in undergraduate science labs, particularly difficulties students encounter in these labs has not been extensively studied. Particularly, there is paucity in the literature with respect to the experiences and difficulties encountered by students in undergraduate microbiology labs. However, the findings of this study regarding high ICL among students in MCB 3020 corroborate previous studies on cognitive load theory in undergraduate science laboratory courses (Gregory & Trapani, 2012; Scharfenberg & Boger, 2013; Srisawasdi & Panjaburee, 2015; Weinberg & Berg, 2007). The findings in this study related to student perceptions of difficulties with procedures encountered in the general microbiology lab add to the current knowledge base regarding the need for reduction of high ICL. Reduction of high ICL could potentially occur through low-stakes practice of microbiology laboratory techniques and skills in the early days and weeks of undergraduate microbiology labs and thus increase GCL to more effectively facilitate learning transfer.

The second main difficulty that students encountered in MCB 3020 was interpretation of lab results. Students expressed difficulties with interpreting results of bacterial reactions to selective and differential media as well as results of biochemical tests. Evidence of student difficulties in interpreting results began with quiz five and remained constant through the end of the semester. In the semesters prior to Fall 2016, lab materials in MCB 3020 were comprised of a brief lab packet, PowerPoint presentations in lab that were also available in the UCF learning management system for MCB 3020, and explanations from lab instructors (Rediske, 2015; unpublished manuscript). PowerPoint presentations included outlines of procedures as well as pictures of the different reactions of bacteria as they grew in different media types as well as exemplary reactions to various biochemical tests. The explanations of potential results were presented as part of the introduction to lab activities, and students were expected to review them if they had questions after class. The lack of robust curricular materials may have contributed to some of the difficulties students encountered with interpretation of lab results. After the Summer 2016 semester, an interactive lab manual with complete descriptions of media, results, and with pictures of the different types of media was developed by myself, the course instructor, and the laboratory coordinator for MCB 3020 to provide more comprehensive curricular materials that could assist students having difficulties with interpretation of lab results (Ambivero et al., 2017). The interactive lab manual was suggested for student use in the Fall 2016 and Spring 2017 semesters, but was not required by the course instructor (Camilla Ambivero, personal communication). However, difficulties with interpretation of results could also be attributed to high ICL as students struggled with laboratory techniques and skills while simultaneously expected to interpret and understand results of bacterial reactions to media and biochemical tests.

The study of student perceptions regarding the difficulties of students with interpretation of results in undergraduate science labs has not been extensively studied in research related to undergraduate science labs in general or undergraduate microbiology labs in particular. The findings in this study related to student perceptions of difficulties with interpretation of lab results encountered in the general microbiology lab also add to the current knowledge base regarding the reduction of ICL, the promotion of GCL, which could facilitate learning transfer.

Discussion and Implications of Quantitative Findings

The quantitative research question for this mixed methods study asked, "What is the effect of weekly pre-lab formative assessments on students' transfer of learning of microbiology laboratory techniques and knowledge?" The hypothesis for this research question was, "A weekly pre-lab formative assessment in a general microbiology laboratory will positively affect transfer of learning of microbiology aseptic techniques and knowledge as measured by a significant increase in post-intervention summative mid-term lab exam and final lab practical exam scores compared to historical scores." Because there were somewhat disparate results between the Fall and Spring semesters, the discussion and implications of the quantitative findings for the lab practical final exam and lab midterm exam will be considered separately.

Quantitative Findings from Comparison of Lab Practical Final Exams

Comparison of mean lab practical final exam scores from the Fall 2015 control group with the Fall 2016 intervention group indicated a statistically significant and practically significant increase in student scores. Mean lab practical final scores increased from 53.6 points (71.4 per cent) to 60.9 points (81.3 per cent), an increase of nearly 10 per cent, or nearly a full letter grade improvement in the post-intervention group. Additionally, the effect size for this analysis was large (0.797), which is notable in science education research. The increase in post-intervention scores suggests that this finding supports the hypothesis that a significant increase in post-intervention lab practical exam scores compared to historical scores is due to the intervention of a pre-lab formative assessment, as well as supports previous research that indicated that formative assessments improve student outcomes on summative assessments in undergraduate science courses (Basey, et al., 2014; Cann, 2016, Chabalengula et al., 2009; Smith, 2007). Additionally, this finding adds to the current knowledge base by suggesting that formative assessments in undergraduate microbiology labs have a positive effect on student outcomes on summative assessments.

Comparison of mean lab practical final exam scores from the Spring 2016 control group with the Spring 2017 intervention group indicated a statistically significant and practically significant increase in student scores. Mean lab practical final scores increased from 55.01 points (73.4 per cent) to 59.8 points (79.7 per cent), an increase of 6.3 per cent in the intervention group. Additionally, the effect size for this analysis was moderate (0.430), which is notable in science education research. The increase in post-intervention scores suggests that this finding supports the hypothesis that a significant increase in post-intervention lab practical exam scores compared to historical scores is due to the intervention of a pre-lab formative assessment. This finding supports previous research that indicated that formative assessments improve student outcomes in undergraduate science courses (Basey et al., 2014; Cann, 2016, Chabalengula et al., 2009; Smith, 2007). Additionally, this finding adds to the current knowledge base by suggesting that formative assessments have a positive effect on student outcomes on summative assessments in undergraduate microbiology labs.

Quantitative Findings from Comparison of Lab Midterm Exams

Comparison of mean lab midterm exams scores from the Fall 2015 control group with the Fall 2016 intervention group indicated a statistically significant *decrease* in midterm lab exam scores. Mean midterm lab exam scores decreased from 81.3 points (81.3 per cent) to 75.7 points (75.7 per cent), a decrease of 5.6 percent, or half of one letter grade in the post intervention group. This finding contradicts previous research that indicates that formative assessments improve student outcomes in undergraduate science courses (Basey et al., 2014; Cann, 2016, Chabalengula et al., 2009; Smith, 2007), and contradicts the hypothesis that a significant increase in post-intervention lab practical exam scores compared to historical scores is due to the intervention of a pre-lab formative assessment.

Comparison of mean lab midterm exams scores from the Spring 2016 control group with the Spring 2017 intervention group indicated a statistically significant yet practically insignificant increase in scores. Mean scores on the midterm lab exam increased from 74.77 points (74.77 per cent) to 74.97 points (74.97 per cent), or an increase of 0.2 per cent. While this finding corroborates previous research that formative assessments have a positive impact on summative assessments, the practical significance of this finding is nearly meaningless in terms of improvements in student outcomes (Basey et al., 2014; Cann, 2016, Chabalengula et al, 2009; Smith, 2007).

Differences in Quantitative Findings Between Midterm and Final Exams

Significant differences were noted in post-intervention student performance between the lab midterm and the lab practical final exam that warrant further discussion. First, analysis of the content of midterm exams indicated that there was no significant difference in the post-intervention groups as compared to the historical control groups. Moreover, no extrinsic factors were identified that would suggest a reason for the decrease post-intervention midterm exam scores when there was an increase in lab practical final exam scores that would explain the disparity between the post-intervention scores.

Next, there is a significant difference in the administration of the midterm lab exam and the final lab practical exam that may explain the significant difference in student performance on the exams post-intervention. The lab midterm exam is given as a 50-question multiple-choice exam administered during the lecture section of MCB 3020, with each question worth two points for a total of 100 points. The lab midterm exam assesses students on content knowledge directly related to lab activities and outcomes up to the midpoint of the semester, but provides no visual cues and is not administered in the laboratory itself. Students utilize a bubble sheet to answer questions and exams are scored electronically. In contrast, the lab practical final exam is given as a 75-point exam with questions administered as stations set up around the laboratory space that require students to observe and interpret various biochemical tests, images under the microscope, or growth of microbes on a petri dish as well as other questions directly related to lab activities. Students move from station to station around the room, with one minute to interpret the lab materials at each station to answer the questions. Lab practical exam questions are also multiple-choice questions and bubble sheets are utilized in this context as well. The significant disparity in student performance between the midterm lab exam and the final lab practical could be attributed to differences in administration of the exam and the lack of intercontextual cues in the midterm lab exam (Engle, 2006; Greeno, 2006). Further, the combination of the pre-lab quiz intervention combined with the context cues from the laboratory itself could explain the increase in lab practical final scores over the historical control group. In contrast, the lack of contextual cues could have overcome any benefit to students from the pre-lab formative assessments. Additionally, any beneficial effect of pre-lab formative assessments may be cumulative over the course of the semester, and positive effects may not be noted until the culmination of the course at the lab practical exam.

Finally, per personal communication with the course instructor and the laboratory coordinator, indicated that the intent of the midterm lab exam was *not* to prepare for the lab practical final exam. Rather this exam is given as a mid-semester assessment of student progress in the MCB 3020 lab. The lab practical exam is the culminating assessment in the course, and draws on lab curricula from the entire semester. In-depth psychometric analysis and comparison of the pre-lab quizzes, midterm lab exam, and lab practical final may provide further insights between the disparities seen between the post-intervention lab exams.

Potential Contributions of the Study

Personal experience and pilot studies suggest that assisting students in making connections between the microbiology lecture, laboratory, and future careers gives more practical meaning to the lab experience leading to transfer of learning and that instructor attitudes toward these connections impact the degree to which connections are made (Rediske, McAfee, Eisenreich, Sivo, & Butler, unpublished manuscript). The study described in this dissertation has demonstrated improvements student outcomes in MCB 3020 at UCF within the population studied as the result of the implementation of pre-lab formative assessments and post-lab reflections. Improvements in outcomes among these students may assist in facilitating transfer of learning of microbiology knowledge and understanding, aseptic and other microbiological techniques, and infection control practices from the microbiology laboratory to the clinical setting or other future careers. Furthermore, improved student outcomes in MCB 3020 could have the potential to increase retention of students in BSBS degree programs at UCF, facilitate better preparation for upper division courses, and improve the overall status of UCF graduates from BSBS programs. In addition, a recent study (Brazeal & Couch, 2017) indicated that students with high buy-in to formative assessments in general biology courses have higher scores on summative assessments. The finding of this study that formative assessments in MCB 3020 at UCF have a positive impact on lab practical final summative assessments is supported by this recent research.

The research described in this study also has the potential to contribute to future curriculum design in introductory or general microbiology courses. The observation of high intrinsic cognitive load (ICL) among students in the early lab activities of microbiology courses suggests that curricular adjustments to allow for more practice of microbiological techniques early in the semester may reduce ICL. Additionally, this study has the potential to impact future curricular design of microbiology courses to employ pre-lab formative assessments as well as post-lab reflective activities to improve student outcomes on summative assessments in the course. Curricular adjustments that allow for more practice of microbiological skills and techniques to reduce ICL and the implementation of pre-lab formative assessments and post-lab reflections could positively impact student outcomes at large research universities, as well as smaller liberal arts or community colleges.

Ultimately, improved learning transfer of microbiological skills and techniques among students in planning on careers in healthcare may benefit their future patients. Students who have developed habits and practices related to scrupulous attention to aseptic technique, maintenance of sterile fields, meaningful understanding of microbes and the infections they cause, as well as a meaningful understanding of the use of antibiotics, disinfectants, and antiseptics may reduce HAIs in clinical practice. Although students involved in this study have not been observed longitudinally, the foundations of aseptic technique and infection control have been laid in MCB 3020 at UCF. Evidence of meaningful learning transfer observed in this study may have a long-term effect not only on the lives of students preparing for careers in healthcare, but for patients under their care.

Limitations of the Study

The intervention of this study was based on a curricular change to the General Microbiology (MCB 3020) curriculum in the Burnett School of Biomedical Sciences (BSBS) at UCF. The implementation of pre-lab formative assessment and post-lab reflective questions occurred throughout all laboratory sections of MCB 3020 during Fall 2016 and Spring 2017 semesters, which did not allow for randomized selection of students into control groups and intervention groups. Historical control groups from the Fall 2015 and Spring 2016 semesters were required to compare differences between matched groups in the intervention semesters. Although propensity score matching was utilized to reduce bias from non-randomized sampling of control and intervention groups, hidden bias not accounted for by the covariates used in propensity score matching may have caused differences between the two groups.

Additionally, this study suffered from the following threats to internal validity: history, maturation, and statistical regression (Edmonds & Kennedy, 2013; p. 34; Gall, Gall, & Borg, 2007). Historical threats to internal validity were ameliorated due to the time span between data collection periods and the same instructor teaching each section being studied. Maturation rates and statistical regression between both the historical control groups and the intervention groups were approximately equal from lab practical midterm to the lab practical final. Although the primary threats to internal validity were addressed in the research design, these threats may have had an unforeseen impact on the study.

Anecdotal evidence based on personal communication with microbiology instructors at a variety of institution types suggests that pre-lab formative assessments and post-lab reflection questions are currently implemented in some microbiology courses, thus limiting the generalization of this study. The efficacy of implementation of a pre-lab assessment may be moot to other institutions that already employ pre-lab formative assessments. Post-lab open-ended reflection questions only demonstrate the experiences of UCF students in MCB 3020 during the Summer 2016 semester and are not necessarily generalizable to other populations.

Another limitation of this study was quiz exhaustion in the qualitative component of the study. Students were asked the same questions with only minor variations week to week based on the lab exercises performed. A significant reduction in the quality and specificity of student responses to the open-ended reflection questions, as many students resorted to nonsense responses. Quiz exhaustion may have had a significant impact on the overall qualitative assessment of student experience in MCB 3020 in the Summer 2016 semester.

Further, due to the high volume of responses to open-ended reflection questions, only quizzes 1, 3, 5, 7, 9, and 10 were qualitatively coded and analyzed. Significant issues impacting the student experience in MCB 3020 during the Summer 2016 may have been overlooked because quizzes 2, 4, 6, and 8 were not analyzed. For example, there was a low number of codes related to difficulties with using the microscope based on the quizzes sampled. In the lab activities covered by lab quiz two, students practiced several differential microbial staining procedures that were subsequently observed under the microscope. Personal experience and anecdotal evidence from my time spent volunteering in the lab suggest that students encountered many difficulties with these staining procedures and observation under the microscope, yet these difficulties were not noted in the qualitative analysis of student responses to open-ended quiz questions.

Additionally, only two coders were involved in the analysis of the qualitative data in this study. As one of the coders, my research experience includes a balance of some microbiology research and mainly science education research. The second coder was Morgan McAfee, a Methodology, Measurement, and Analysis doctoral student at UCF, who has extensive experience in educational research. Because the two coders involved in this study were primarily concerned with education research, our perspectives on student responses to reflection questions may have been more focused on primarily educational outcomes than on microbiological knowledge and skills and the culture that existed in the BSBS department and the MCB 3020 lab during the period studied.

Another limitation to the quantitative component of the study was that only two semesters of pre- and post-intervention student outcomes were analyzed, and differences in student outcomes were noted between the Fall and Spring semesters. It is unclear why students in the post-intervention Fall semester had a ten per cent increase in lab practical final exam scores while there was only a five per cent increase in lab practical final exam scores in the post-intervention Spring semester. It is unclear whether similar improvements in student outcomes would be seen in the post-intervention Summer semester or other future semesters in which pre-lab formative assessments are implemented.

Finally, a major limitation of this study was that students were not observed longitudinally as they progressed into high-level microbiology courses at UCF or into their future careers. Any observation of high-road or vertical transfer was entirely theoretical as students recognized how habits, practices, and techniques learned in the microbiology lab could potentially be applied to future contexts or careers. However, there was no actual observation of students using these habits, practices, and techniques in contexts outside the MCB 3020 lab. Although some aspects of learning transfer of automaticity, complexity, and context were observed in both the qualitative and quantitative component of this study, without long-term observation of student behaviors and applications, there is no concrete evidence of high-road or vertical transfer among the student population studied.

Areas for Future Research

The research described in this dissertation may serve as the impetus for future studies related to the facilitation of learning transfer among students in undergraduate microbiology courses. Several areas for future research have been noted in both the qualitative and quantitative components of this study, and will be detailed in the next sections.

Future Research Based on the Qualitative Component of this Study

First and foremost, the remaining post-lab reflection questions should be analyzed to determine if the themes that emerged in lab quizzes 1, 3, 5, 7, 9, and 10 are consistent in lab quizzes 2, 4, 6, and 8 or if other themes emerged. Qualitative analysis of the remaining quizzes may identify other difficulties experienced by students in MCB 3020 as well as identify areas of learning transfer not observed in the quiz analysis conducted in this study. To address the issue of two coders with limited perspective on the culture and environment of the BSBS department and the MCB 3020 lab, future qualitative studies could benefit from a third coder within the BSBS department at UCF whose primary focus is microbiology research, who is microbiology professor, or an individual directly involved with the MCB 3020 lab who could offer a different perspective on student reflective responses.

Future research on student reflections in the microbiology lab should also address the leading reflection questions utilized in this research. Students were specifically asked about the difficulties they had in MCB 3020 and how the lab exercises applied to their future careers. Not only were these leading questions, but because they were also repeated for each lab quiz, students demonstrated quiz exhaustion, and their responses became incrementally less specific and meaningful as the semester progressed. Future research on the student experience in undergraduate microbiology could first prompt students to reflect on their experience in a more general way, with a reflective prompt such as, “Describe your experience in the microbiology lab this week” or “Describe how what you learned in the microbiology lab this week could be beneficial in other contexts.” If greater specificity regarding applications to future careers is desired, questions such as, “What are your future career plans? How does the lab activity in MCB 3020 today apply to your future career?” may elicit more specific and meaningful reflections. Additionally, reflective prompts could be regularly altered to address the same general queries regarding difficulties experienced by students in the lab and applications to future careers, but to provide enough variance in the wording of reflection questions to reduce quiz exhaustion.

Another area for future research could be to observe the meta-communication and intercontextual cues given by Graduate Teaching Assistants (GTAs) during the course of the lab. GTAs could be surveyed for their future career plans, and the types of meta-communicative signals or intercontextual cues could be studied and compared to student responses regarding applications of the microbiology lab to their future careers. Future research could also focus on assisting lab instructors to illustrate applications of MCB 3020 to a wider variety of future careers to engage students intending to pursue careers not fully represented by this study.

An important area for future research could be in reducing intrinsic cognitive load (ICL) among students, particularly in the early laboratory activities in the semester. Students could be given more low-stakes practice with techniques such as the two-tube transfer, the three-zone streak, and the Gram stain in the introductory labs in the semester that may assist in reducing high ICL and ameliorate some of the difficulties students expressed with manual dexterity and needing to practice microbiological techniques in this study. In addition, student interviews or surveys regarding their ICL in the lab could provide greater insights into the student experience and offer perspectives on curricular adjustments to reduce ICL.

An interactive lab manual was developed after the Summer 2016 semester that provided more complete explanations of lab procedures, provided copious pictures of the outcomes of the biochemical tests performed in the MCB 3020 lab, provided context for the applications to future careers, and prompted students to reflect on their lab experiences. Although this interactive lab manual was published and available to students, the course instructors did not require it, and very few students took advantage of this resource in the Fall 2016 and Spring 2017 semesters. Future work could examine the impact of the interactive lab manual on student outcomes in the course using a quasi-experimental design similar to the design utilized in this study. Additionally, future research could determine the effect of the interactive lab manual on reducing ICL among students in MCB 3020.

Finally, with regard to the qualitative component of this study, longitudinal analysis of students in MCB 3020 could be conducted to determine the degree of high-road transfer, vertical transfer, and far transfer as they progress into more advanced courses and potentially to their future careers. Although this study noted an evolution from near to far transfer of knowledge and understanding of microbiology from the beginning to the end of the semester, any evidence of vertical transfer or high-road transfer were theoretical at best. Longitudinal analysis of students in future contexts could provide insight into high-road and vertical transfer after completion of MCB 3020.

Such a study could track students as they progress to other, more advanced courses in the BSBS department and as they enter their careers. Student outcomes in courses in could be analyzed to determine if their experiences in MCB 3020 have an effect on their performance in more advanced labs. Additionally, students could be observed and interviewed in laboratory settings to determine if the skills and practices they learned in MCB 3020 assist them in being more successful in more advanced lab techniques. Finally, a cohort of students could be tracked, observed, and interviewed as they graduate from UCF and enter clinical careers to determine if the knowledge, skills, and techniques learned in MCB 3020 lead to effective application in their professional practices.

Future Research Based on the Quantitative Component of this Study

The research conducted in this study indicated a statistically and practically significant increase in student scores on the lab practical final exam after the implementation of pre-lab formative assessments in MCB 3020 in both Fall 2016 and Spring 2017. However, there was a statistically significant decrease in midterm lab exam scores in Fall 2016 and a statistically significant yet practically insignificant increase in midterm lab exam scores in Spring 2017. One reason why such a disparity may exist is due to the markedly distinct difference between the administration of the midterm lab exam and the lab practical final exam. As noted previously, the MCB 3020 midterm lab exam is given as a multiple-choice exam in the context of the classroom rather than the lab, while the lab practical final exam is given as an in-lab exam. Several areas of future research may shed light on the differences in post-intervention outcomes. First, an in-depth psychometric analysis of the pre-lab quizzes, midterm lab exam, and the lab practical final exam may reveal why there was such a significant disparity in lab midterm exams between Fall 2015 and Fall 2016. Item analysis, reliability, and validity assessments of pre-lab quizzes and exams may offer insights into student outcomes on exams and may suggest areas in which the quizzes and exams could be modified to provide more effective assessment of student knowledge and understanding (Crocker & Angina, 1986). Further, exploratory factor analysis and confirmatory factor analysis of lab midterm exam and lab practical exam items may shed light on the disparities in student outcomes between the two exams (Gall et al., 2007). Additionally, sensitivity analysis of the propensity score matching procedure may reveal if any hidden bias exists that was not explained by the covariates defined for this analysis. Hidden bias may account for the disparities in student outcomes between the midterm exam and lab practical final exam as well. Moreover, differences in student outcomes may be related to the lab section in which they were enrolled. Multilevel modeling of the effect of lab section on student scores pre- and post-intervention may indicate the effect of the lab section on student outcomes. Another area for future research could be the implementation of a lab practical midterm exam that is administered in a similar fashion to the lab practical final exam to determine if there is a significant effect of lab exam administration on student outcomes. Finally, the quantitative component of this study only encompassed two semesters of pre- and post-intervention student outcomes. Quasi-experimental analysis of the impact of the implementation of pre-lab formative assessments that includes a larger cohort of students may provide richer insights into the effect of formative assessments on summative assessments on student outcomes in MCB 3020.

Future Research on the Impact of Formative Assessment in Undergraduate Microbiology

The research described in this study primarily focused on two key strategies of formative assessment: 1) Providing feedback that moves learners forward; and 2) Activating students as owners of their own learning (Black & Wiliam, 2009). Future studies could address the three other strategies of formative assessment suggested by Black and Wiliam to facilitate learning transfer in the general microbiology lab. Such studies could include utilizing formative assessments that make learning outcomes or achievement benchmarks for each lab activity explicit to students. Additionally, future studies could utilize formative assessments that incorporate in-lab dialog between lab instructors or lab groups that provide evidence of student understanding of lab concepts or procedures to reduce high ICL and facilitate learning transfer. Finally, formative assessments that utilize small group discussions or that are taken as a group could assist students in acting as instructional resources for each other during lab activities (Black & Wiliam, 2009, p. 8).

Conclusion

The undergraduate microbiology lab is an essential learning environment that serves to lay the foundation for conscientious aseptic technique, infection control, and application of microbial diseases for students preparing for careers in healthcare. Effective preparation of future healthcare providers with respect to microbiological habits, techniques, and knowledge has the potential to reduce healthcare-associated infections (HAIs) and ultimately improve patient outcomes. Additionally, the habits, techniques, and knowledge developed in undergraduate microbiology courses are necessary for students planning on other careers such as research, education, or other professional fields. Evidence of learning transfer in undergraduate microbiology labs may indicate that the initial groundwork in aseptic technique, infection control, and microbiological knowledge has been laid, and may lead to the reduction of HAIs among students pursuing careers in healthcare, as well as greater proficiency among students pursuing careers in research, education or other professional fields.

The Boud and Walker (1990) conceptual framework on experiential learning suggests that meaningful learning occurs through three major steps: preparation, experience, and reflection. In this study, learning transfer was facilitated in the preparatory stage of the model through the implementation of pre-lab formative assessments. The lab activities themselves assisted with learning transfer through the experience component of the model. Post-lab reflection questions facilitated learning transfer in the reflection phase of the model.

The research described in this dissertation provides evidence of learning transfer among students in a general microbiology lab at a large research institution in the Southeastern US. Qualitative analysis of student responses to post-lab reflection questions suggests evidence of primarily low-road, lateral, and near transfer, with evidence of theoretical high-road and vertical transfer, and specific evidence of far transfer as well. Theoretical evidence of high-road and vertical transfer is defined in chapter four as recognition by students of habits or skills learned in MCB 3020 applied in future contexts. Students either recognized these applications through shadowing medical professionals or noted that they would be using these skills and habits in their future careers. Implementation of pre-lab formative assessments also indicates evidence of learning transfer through statistically significant increases in lab practical final exam scores. Further research is necessary to determine the lack of statistically significant improvement on midterm exam scores.

The research described in this dissertation adds to the body of knowledge regarding learning transfer as it demonstrates evidence of learning transfer among the population of students studied. Learning transfer has historically been difficult to measure, and the research described in this study adds to the dearth in the literature regarding learning transfer among undergraduate microbiology students. Additionally, the research described in this study provides evidence of high extraneous cognitive load (ECL) among undergraduate microbiology students that may assist instructors in making curricular adjustments to reduce high ECL and thus improve student outcomes in these courses.

My personal experiences as a microbiology instructor and the mother of a disabled child led me to the design of this study. I recognize the importance of the microbiology lab in laying the foundations of best practices in aseptic technique and infection control for students who intend to pursue careers in healthcare. Good or bad habits learned in the microbiology lab may transfer to clinical settings and impact the lives of patients. The findings of this study may assist other microbiology instructors, lab coordinators, and curriculum designers in the use of formative assessments and reflective practices that may not only improve student outcomes in general microbiology courses, but could have a positive future impact on patient outcomes in the clinical setting.

Epilogue

Ethan has been admitted again to the pediatric critical care unit of Florida Hospital. This time it was a "straight admit" from the gastroenterologist's office after routine blood work indicated a dangerously low hematocrit. Ethan was bleeding internally, and we didn't know why. I had just signed the consent forms for a blood transfusion, and sat next to his bed, watching a stranger's blood flowing into the arm of my child, remembering all of the lessons I taught on blood typing in my microbiology classes. It was during this moment of contemplation that the nurse came into my son's room and blithely announced, "Ok! We need to put you on contact precautions because he has tested positive for C-diff." Once again, my professional and personal worlds collided. All that I could think of was *Clostridium difficile, gram-positive endospore-forming bacillus, pseudomembranous colitis, hemorrhagic colitis, explosive diarrhea…* Forefront in my mind were the endospores that were undoubtedly colonizing the surface of his bedroom, our washing machine, and other surfaces in our home, not only threatening Ethan, but me, my other two children, my husband, our nurses, and all of the therapists, teachers, and guests who entered our home. I also came to the realization that my disabled, medically fragile child had likely contracted this infection at the hands of the healthcare workers that cared for him in the hospital. At that moment, the necessity of effective learning transfer of hand washing, aseptic technique, and infection control measures taught in the microbiology lab became intensely personal. No longer was *Clostridium difficile* some abstract organism discussed as part of the gastrointestinal infections chapter in my lecture section or in the endospore stain in the lab, it was currently the organism irritating his already compromised gut, causing massive blood loss in my son, and threatening his life.

Although this particular incident did not end his life, it was the tipping point to a gradual decline in Ethan's overall health. Ethan passed away a little more than three years ago, yet his life continues to impact my perspectives on teaching microbiology. Experiences such as these help me illustrate clearly and personally the importance of aseptic technique in the microbiology lab, future courses, and in my students' future careers. Most of my students have not yet worked in a clinical setting, and may not have the perspective on the vital importance of scrupulous attention to asepsis with a patient like Ethan as I do. As their microbiology instructor, I play an important role in helping them transfer the beginning foundations of aseptic technique to their other pre-medical, pre-nursing, pre-pharmacy, pre-veterinary, pre-physician's assistant, pre-pharmacy, or pre-allied health courses and to a career that could potentially impact a child like Ethan.

APPENDIX A: INSTITUTIONAL REVIEW BOARD OUTCOME LETTER

University of Central Florida

University of Central Florida Institutional Review Board
Office of Research & Commercialization
12201 Research Parkway, Suite 501
Orlando, Florida 32826-3246
Telephone: 407-823-2901, 407-882-2012 or 407-882-2276
www.research.ucf.edu/compliance/irb.html

NOT HUMAN RESEARCH DETERMINATION

From : **UCF Institutional Review Board #1**
FWA00000351, IRB00001138

To : **Andrea Rediske and Co-PIs: David Boote, Jacquelyn Chini, Malcolm. Butler, Morgan McAfee, and Stephen Sivo,**

Date : **February 15, 2017**

Dear Researcher:

On 02/15/2017 the IRB determined that the following proposed activity is not human research as defined by DHHS regulations at 45 CFR 46 or FDA regulations at 21 CFR 50/56:

Type of Review:	Not Human Research Determination
Project Title:	Analysis of the Effects of Formative Assessment in Promoting Transfer of Learning in an Undergraduate General Microbiology Course
Investigator:	Andrea Rediske
IRB ID:	SBE-16-12796

University of Central Florida IRB review and approval is not required. This determination applies only to the activities described in the IRB submission and does not apply should any changes be made. If changes are to be made and there are questions about whether these activities are research involving human subjects, please contact the IRB office to discuss the proposed changes.

On behalf of Sophia Dziegielewski, Ph.D., L.C.S.W., UCF IRB Chair, this letter is signed by:

Signature applied by Patria Davis on 02/15/2017 01:13:29 PM EST

IRB Manager

APPENDIX B:
POST-LAB QUIZZES WITH REFLECTION QUESTIONS

Week 1 – Exercises 1 and 2

1. PPE is required for work in a BSL-1 lab?
   a. Lab coat
   b. Gloves
   c. Goggles
   d. All of the above
   e. B and C only

2. Calculate the total magnification of a sample if you are using 5x oculars and the 50x objective lens.
   a. 55x
   b. 2500x
   c. 250x
   d. 1000x

3. When preparing a negative stain you use a(n) _________ dye which will be ________ by the bacterial cells.
   a. anionic, repelled
   b. cationic, repelled
   c. cationic, attracted
   d. anionic, attracted

4. What aspect(s) of lab exercises 1 and 2 was most challenging for you? Explain your answer in the space below:

5 What aspect(s) of lab exercises 1 and 2 was most important for you in preparing for your future career? Explain your answer in the space below.

Week 2 – Exercises 3 and 4

1. Choose the correct order of steps for the Gram stain.
   a. Start with smear, iodine, crystal violet, safranin, ethanol, blot dry
   b. Start with smear, crystal violet, ethanol, iodine, safranin, blot dry
   c. Start with smear, safranin, iodine, ethanol, crystal violet, blot dry
   d. Start with smear, crystal violet, iodine, ethanol, safranin, blot dry

2. If you forgot the decolorizing step of the acid-fast stain, acid-fast negative cells would appear ________.
   a. Colorless
   b. Reddish pink
   c. Blue
   d. Green

3. The Gram stain and acid-fast stain are examples of:
   a. Structural stains
   b. Simple stains
   c. Differential stains
   d. Complicated stains

4. What aspect(s) of lab exercises 3 and 4 was most challenging for you? Explain your answer in the space below:

5 What aspect(s) of lab exercises 3 and 4 was most important for you in preparing for your future career? Explain your answer in the space below.

Week 3 – Exercise 5

1. A natural medium is one that usually has raw materials and is considered undefined.
   a. True
   b. False

2. When performing a 3-zone streak plate for isolation you should always
   a. retrieve sample from the culture for every zone
   b. flame your loop between each zone
   c. raise the angle of the loop as you streak zone 3b
   d. A and B
   e. B and C

3. The pour plate technique is a quantitative method for isolating bacterial colonies.
   a. True
   b. False

4. What aspect(s) of lab exercise 5 was most challenging for you? Explain your answer in the space below:

5 What aspect(s) of lab exercise 5 was most important for you in preparing for your future career? Explain your answer in the space below.

Week 4 – Exercises 6 and 7

1. A complete clearing around colonies on a 5% sheep's blood agar plate is indicative of which type of hemolysis?
   a. Gamma
   b. Alpha
   c. Beta
   d. Theta

2. Transferring 1 mL of a sample into a 9 mL dilution blank results in a ______ dilution.
   a. 1/1000
   b. 1/99
   c. 1/10
   d. 1/100

3. To determine if an organism ferments lactose the following selective/differential media could be used.
   a. MacConkey agar
   b. Phenylethyl alcohol agar
   c. Eosin methylene blue agar
   d. A and C
   e. B and C

4. What aspect(s) of lab exercises 6 and 7 was most challenging for you? Explain your answer in the space below:

5 What aspect(s) of lab exercises 6 and 7 was most important for you in preparing for your future career? Explain your answer in the space below.

Week 5 – Exercise 8

1. Lipase, starch, and milk agar plates are all used to test for the presence of __________.
   a. alphaenzymes
   b. exoenzymes
   c. hexokinases
   d. endoenzymes

2. Which of the following reactions can you detect using litmus milk?
   a. acid curd
   b. alkaline
   c. reduction
   d. peptonization
   e. all of the above

3. Kligler's Iron agar and phenol red broth can both be used to detect which of the following?
   a. sugar fermentation
   b. gas production
   c. H_2S production
   d. A and B only
   e. B and C only

4. What aspect(s) of lab exercise 8 was most challenging for you? Explain your answer in the space below:

5 What aspect(s) of lab exercise 8 was most important for you in preparing for your future career? Explain your answer in the space below.

Week 6 – Exercises 9 and 10 pt. 1

1. After adding zinc to a nitrate reduction test it turns red. What result does this indicate?
   a. positive for nitrate reductase
   b. positive for nitrite reductase
   c. negative for zinc reductase
   d. negative for nitrate reductase

2. The Voges-Proskauer test is used to identify 2,3-butanediol fermenters.
   a. True
   b. False

3. SM110 media is _______ for the pathogen *Staphylococcus aureus* via the ____________ component.
   a. differential, 7.5% salt
   b. selective, mannitol
   c. selective, 7.5% salt
   d. differential, manitol

4. What aspect(s) of lab exercises 9 and 10 part 1 was most challenging for you? Explain your answer in the space below:

5 What aspect(s) of lab exercises 9 and 10 part 1 was most important for you in preparing for your future career? Explain your answer in the space below.

Week 7 – Exercises 10 pt. 2 and 11 pt. 1

1. Which of the following media were used for isolation of *Streptococcus* species on **day 1** of the Gram positive pyogenic cocci study?
   a. SM110 broth
   b. Blood agar
   c. BHI
   d. MSA

2. Bacteria in the family *Enterobacteriaceae* are characterized as:
   a. Gram-negative
   b. rods
   c. oxidase negative
   d. All of the above

3. A Mannitol Salt Agar plate is inoculated with an unknown sample. After incubation there is growth on the plate but no color change. What might you be able to learn about the organism from this result?
   a. the organism can tolerate 7.5% salt
   b. the organism is not able to ferment mannitol
   c. the organism is not *Staphylococcus aureus*
   d. All of the above

4. What aspect(s) of lab exercise 10 part 2 and exercise 11 part 1 was most challenging for you? Explain your answer in the space below:

5 What aspect(s) of lab exercise 10 part 2 and exercise 11 part 1 was most important for you in preparing for your future career? Explain your answer in the space below.

Week 8 – Exercises 10 pt. 3 and 11 pt. 2

1. In DNAse agar, a zone of clearing around your inoculation line is indicative of a positive result?
   a. False
   b. True

2. Bismuth sulfite agar is useful for determining which of the following about an organism?
   a. Glucose fermentation
   b. H_2S production
   c. Lactose fermentation
   d. A and B

3. *Streptococcus* and *Staphylococcus* species can be easily differentiated using which of the following tests?
   a. Glucose fermentation
   b. SIM deep agar
   c. Catalase
   d. Citrate

4. What aspect(s) of lab exercise 10 part 3 and exercise 11 part 3 was most challenging for you? Explain your answer in the space below:

5 What aspect(s) of lab exercise 10 part 3 and exercise 11 part 2 was most important for you in preparing for your future career? Explain your answer in the space below.

Week 9 – Exercises 11 pt. 3 and 15 day 1

1. Which of the following test is most helpful in differentiating *Salmonella* and *Proteus*?
   a. KIA
   b. Urea
   c. Catalase
   d. All of the above

2. What result would you expect Salmonella to give when inoculated on KIA?
   a. Gluc +, Lac +, H_2S +
   b. Gluc +, Lac -, H_2S -
   c. Gluc +, Lac +, H_2S -
   d. Gluc +, Lac -, H_2S +

3. In the MPN test, lactose broth is used at both single and double strength.
   a. True
   b. False

4. What aspect(s) of lab exercise 11 part 3 and exercise 15 day 1 was most challenging for you? Explain your answer in the space below:

5 What aspect(s) of lab exercise 11 part 3 and exercise 15 day 1 was most important for you in preparing for your future career? Explain your answer in the space below.

Week 10 – Exercises 13 pt. 1 and 15 day 2

1. In the sanitary analysis of water study, we are looking for _____, which is a _________.
   a. *Citrobacter*, fecal coliform
   b. *Enterobacter*, coliform
   c. *E. coli*, fecal coliform
   d. *Shigella*, fecal coliform

2. Bacteriostatic agents completely kill bacteria.
   a. True
   b. False

3. Which of the following antimicrobial agents were used in the disk diffusion assay?
   a. Iodine
   b. Phenol
   c. Formaldehyde
   d. All of the above

4. What aspect(s) of lab exercise 13 part 1 and exercise 15 day 2 was most challenging for you? Explain your answer in the space below:

5 What aspect(s) of lab exercise 13 part 1 and exercise 15 day 2 was most important for you in preparing for your future career? Explain your answer in the space below.

Week 11– Exercises 12 pt. 2 and 13

1. What medium was used for the mycology studies?
   a. BHI
   b. TSA
   c. PDA
   d. NA

2. The mold _____ was used to demonstrate sexual reproduction and the formation of ______.
   a. *Rhizopus*, zygospores
   b. *Aspergillus*, ascospores
   c. *Mucor*, zygospores
   d. *Penicillium*, sporangiospores

3. Which of the following would be considered a disinfectant?
   a. Iodine
   b. Lysol
   c. Formaldehyde
   d. A and B
   e. B and C

4. What aspect(s) of lab exercise 12 part 2 and exercise 13 was most challenging for you? Explain your answer in the space below:

5 What aspect(s) of lab exercise 12 part 2 and exercise 13 was most important for you in preparing for your future career? Explain your answer in the space below.

APPENDIX C: EXEMPLARY STUDENT QUOTES FOR TRANSFER OF AUTOMATICITY

Table 11: Evidence of Transfer of Automaticity for Lab Quiz One

	Representative Student Quotes
Low-Road	We had just learned those techniques so they were not yet habit for me. Practicing sterilization techniques, cleaning the desktops before and after each lab, and of course the dress code of the lab. The repetition in aseptic technique and preparing stains will help improve my efficiency in the future.
High-Road	For example, yesterday I saw an injection in the back, and the doctor carefully made sure not to contaminate the needle. He kept it in the sterile wrapper until the last minute, when he needed to use it, and also made sure to wipe everything down with an alcohol wipe before and after use.

Table 12: Evidence of Transfer of Automaticity for Lab Quiz Three

	Representative Student Quotes
Low-Road	This exercise was important for preparing myself for the future as it is an essential step in microbiology dealing with bacteria. There are some basic steps that will be used over and over again. Also, a 3 zone streak method is a test we have to master in order to pass the class so it is very important that I learn how to do it correctly. I think being able to keep an aseptic, sterile field is very important for my future career choice. Each lab, we practice the aseptic technique more and more and it shows why its so important.
High-Road	The precision that comes with gently using your sterilized loop against the agar was most important for my future career. This is because in a surgery you need to have a steady hand, and for the 3-zone streak you also need a steady hand, so this was good practice for the future.

Table 13: Evidence of Transfer of Automaticity for Lab Quiz Five

	Representative Student Quotes
Low-Road	Remembering the sterilize [sic] my environment before and after lab is a very important practice for my pursuit of a future medical career. I think the two tube transfers in this lab allowed me to practice and perfect that technique which will most definitely be used in a lab environment if I am to work in research in the future.

	Representative Student Quotes
	The same thing that challenged me as I begin to work in the field I am going to be expected to complete many tasks in short periods of time. So practicing efficiency is very important for my future because being able to work quickly without sacrificing quality will set me apart from others.
	I finally felt that using the microscope to find our samples was easier and faster. this demonstrates that with practice I can improve in using new tools and equipment.
High-Road	The aspects of lab exercise 8 that was most important for me in preparing for my future career as a physician assistant (PA) are being able to take initiative and of course, having patience. Since my lab partner was absent, I had to take initiative and perform the majority of the inoculations on my own before I was able to get someone to assist me. (Many PAs practice medicine autonomously and only consult their supervising physician when they need to.) Furthermore, patience was definitely imperative for this particular lab due to the repetitiveness of procedures and sharing the incinerator and bacteria.

Table 14: Evidence of Transfer of Automaticity for Lab Quiz Seven

	Representative Student Quotes
Low-Road	We have performed the isolation techniques multiple times before, therefore I did not find that challenging.
	I think that repetition of making the three-zone streak plates was important for preparing me for my future career. Doing this over and over again made it seem like second nature by the time I left the lab, and I no longer needed the template when drawing out the three sections on my petri dish.
	Further practicing good lab aseptic procedures, given that this lab seemed to be quite prone to contamination and error; the lab overall was a good chance to further practice the small things that will prevent big problems when it comes down to reading results.
	By practicing Gram staining until I perfect it, I will teach myself to get good at something essential in my future medical career. Determination and hard-work is what this lab has taught me, that and much more.
High-Road	In this class we are able to perfect a craft that we will be using our entire life.

Table 15: Evidence of Transfer of Automaticity for Lab Quiz Nine

	Representative Student Quotes
Low-Road	The most important aspect was mastering what I found most challenging (aseptic technique using the pipette). I'm comfortable using the loop because of its size and the ease of inoculation but getting better at pipetting might prove to be key in tests I have to do as a medical professional. Techniques are getting easier because of previous exposure. Other than that this lab was pretty simple skill wise, because we have done so many inoculations in the past.

Table 16: Evidence of Transfer of Automaticity for Lab Quiz Ten

	Representative Student Quotes
Low-Road	This lab was relatively simple, since most of the techniques used have been used in prior exercises. Actual performance of everything was almost second nature at this point in lab. I do not think anything in this lab was too challenging, because it was all things that we have had a good amount of practice with. The most important aspect of this lab was definitely proper sterilization techniques that I feel I will find myself using more often than not in my future labs.
High-Road	The most important part of the lab exercises in terms of preparing for my future career was learning proper sterilization techniques for the forceps used to prepare the antibiotic solutions. When I become a surgeon I'm going to have to make sure all my tools are properly sterilized before having it come in contact with the patients I will be working with.

APPENDIX D: EXEMPLARY STUDENT QUOTES FOR TRANSFER OF COMPLEXITY

Table 17: Evidence of Transfer of Complexity for Lab Quiz One

	Representative Student Quotes
Lateral Transfer	The simple stain is the most important in at least identifying what kind of disease shape I'm at least dealing with, when performing a gram stain I imagine it will be even more important.
	Practicing the two test tube transfer since this is a skill necessary to know in order to pass this course.
	Although it was the most challenging, I do believe that being Having only worked with much bigger objects before, being able to correctly magnify cells to a near perfect resolution will be a skill that will probably follow with me the rest of my life.
Vertical Transfer	Even though most places have people who prepare slides for the doctors to read it is still important to know how it is done so I can be aware of what I'm looking at based on how the slide was prepared. Such as the dye used will determine the ionic properties of the cell membrane which could help diagnostics.

Table 18: Evidence of Transfer of Complexity for Lab Quiz Three

	Representative Student Quotes
Lateral Transfer	The most important thing I learned in this lab is how to isolate bacteria. We learned two methods to do this. The pour plate method and 3 zone streak. Its important to be able to isolate bacteria because this can help determine if a pathogen is causing a disease.
	The three zone streak plate was the most interesting part to me, and it is extremely important because it can be applied to Koch's postulates. It is necessary to know how to isolate a pure culture in the medical field so the causes of certain diseases can be definitively determined.
	Knowing how to start a petri dish and place the bacteria on the agar correctly is the start of many experiments dealing with unknown bacteria or even known bacteria.
Vertical Transfer	The fact that everything requires such care and precision to do will help me out in a future of surgery, considering everything has to be calculated and near perfect to not harm anyone. The patience and care it took not to scratch the agar in the three zone streak plate reminded me of the care a physician has to have when doing anything in the medical field.

Table 19: Evidence of Transfer of Complexity for Lab Quiz Five

	Representative Student Quotes
Lateral Transfer	There were many different test tubes with media and agar that involved different steps. It was easy to get confused and mess up because there were so many inoculations that needed to be done. I am glad that my TA advised me to label each test tube so I didn't mix up any of the media. I did each bacteria one by one, slowly and carefully so I did the experiment correctly. Also, a 2 tube test transfer is very important because I do not want to contaminate the bacteria and get al.l of my results wrong. The aspect I can take away from lab 8 was trying to work well with my partner. Sometimes the person you work with isn't as good or at the same skill level, so you have to rewind, and slow it down for them. You can say this lab has taught me to try to work well with others. In my future career, I'm certain I'll have to work well with others, and I'm glad this lab exposed me to it. I think the most useful aspect of this week's lab was the lesson on how to calculate dilution. Having done the experiment first and then seeing the process in person really helped as well. While a bit confusing at first sign, it became really easy after reviewing my notes at home.
Vertical Transfer	This will be important in vet school because one method might give you the same answer over and over again, but the different methods can tell to what degree and solidify the results with more evidence. It was also an excellent way of figuring out unknown cultures.

Table 20: Evidence of Transfer of Complexity for Lab Quiz Seven

	Representative Student Quotes
Lateral Transfer	It is very important to sterilize the loop properly and making sure it is flamed all the way before putting the loop into different plates and test tubes. If I did not sterilize properly, my results could be contaminated. It is important that we are able to gather bacteria, observe the production on different media and decipher the meaning of the results. It is also important to isolate a single bacteria from a group of bacteria to make a pure culture and further test the pure culture for more answers The following directions aspect is something I'll probably be able to take away from this lab. In my future I definitely will have to follow directions and make sure I don't miss a step cause it could be fatal. Also its important not to waste resources like having to go grab a new media cause I messed up won't fly in the real world.

	Representative Student Quotes
Vertical Transfer	This lab exercise will help me in my future career because it has educated me in the dangers and signs of Salmonella [sic]. By noticing the signs of abdominal cramping, fever, and diarrhea after the initial infection I would be able to diagnose and treat my patient to immediately get rid of the colonies of Salmonella [sic] in their body. If I were to suspect that my patient was infected with Salmonella [sic], I would be able to use Hektoen Enteric (HE) agar as a means of isolating and differentiating salmonella [sic]from other enterics infecting the gastrointestinal tract.
	This lab was irrelevant to my future career in forensic science as at no point will I be required to work with microorganisms. However, as before, aseptic technique may be useful for proper precautions when handling unknown biological samples.

Table 21: Evidence of Transfer of Complexity for Lab Quiz Nine

	Representative Student Quotes
Lateral Transfer	It is really important to measure out the precise amount of water to put it into the tube. When doing the three zone streaks, one must also remember to do it gently because the agar was more difficult to work with this time in lab. One could easily slash the agar.
	The aspect of lab exercise 11 part 3 that was most important for me in preparing for my future was to learn how to use other biochemical tests (KIA, SIM and urea broth) to differentiate Salmonella spp. from other lactose-negative and H2S positive Enterobacteriaceae.
	Sterilization and being able to use the pipet in exercise 15 day 1, I would say was the most important. Knowing how to hold it properly, and reading the pipet.
Vertical Transfer	I aspire to be an environmental biologist as a future career path, and considering that, being able to test water samples for the concentrations of bacteria that exist within them is extremely imperative in my field of choice. From drinking water, to ocean water, lake water, etc. Having the knowledge of these tests and being able to correctly run and analyze the results could lead to breakthrough knowledge in a certain environmental research study.
	The water testing is most important. If a dog comes into the office with an odd infection, I would ask the owners if he's recently been to a dark

	Representative Student Quotes
	park and if that dog park had a lake. If so, I might ask for a water sample to see if the lake was a reservoir for the patient's symptoms.

Table 22: Evidence of Transfer of Complexity for Lab Quiz Ten

	Representative Student Quotes
Lateral Transfer	The most important part for me was understanding the methods behind the experiments
	The most important aspect of this lab was definitely proper sterilization techniques that I feel I will find myself using more often than not in my future labs.
	The most important part of the lab for my future career was the Kirby-bauer test. This test in particular is important because it is that standard for testing the effectiveness of antibiotics.
Vertical Transfer	The most important part of the lab exercises in terms of preparing for my future career was learning proper sterilization techniques for the forceps used to prepare the antibiotic solutions. When I become a surgeon I'm going to have to make sure all my tools are properly sterilized before having it come in contact with the patients I will be working with.
	The most important aspect that helps prepare me for my future career was the Kirby-Bauer test using the Mueller-Hinton plates. With this test, health care professionals can decide which antibiotic works best for a person infected with an unknown bacteria. The results are really clear and it is not difficult to determine which antibiotic works and which one does not.
	Becoming a teacher for high school, I don't think I would ever use this type of lab in my classroom. For high school biology it wouldn't really have a place. But I could always use the knowledge I gained from it just in case any of my students have a question about something pertaining to it.

APPENDIX E: EXEMPLARY STUDENT QUOTES FOR TRANSFER OF CONTEXT

Table 23: Evidence of Transfer of Context in Lab Quiz One

	Representative Student Quotes
Near Transfer	Sterilizing my tools helps me in the future because in the future, the environment I will be working in needs to be sterile.
	Aseptic technique is definitely the most important concept I learned this week because if I ever wish to work for a laboratory it is imperative that I maintain a sterile environment because no experiment of mine will be considered valid if it has been conducted without the use of aseptic technique.
	I feel as though both labs have given me a better understanding of how important it is to prevent cross-contamination in a medical setting.
Far Transfer	As a future physician. I probably will not be presented with many times when I would personally have to look at a culture but when I send the samples to the labs (Urine, a swab, etc.) it is important to know exactly what they do in the labs and this teaches me that.

Table 24: Evidence of Transfer of Context in Lab Quiz Three

	Representative Student Quotes
Near Transfer	Understanding methods that can quantify and isolate bacterial samples is useful to determine lab techniques that will help to identify infections.
	I believe the most important preparation in this lab was the information on how to properly use agar. Since it is a solidifying agent it was needed to know how much time experimenters had to put agar and the bacteria together
	The most important aspect of exercise 5 was to understand that a sample collected is not pure, but instead there can be a mix of bacteria in it. Knowing how to properly isolate bacteria is essential in the health for identification, cure and treatment.
Far Transfer	I would say that the most important aspect would be to correctly complete the three-zone streak method. My goal is to become a veterinarian and I have seen many clinics that do their own microbiology testing. This will serve me well in the future. Plus it's awesome!
	I am not going into the medical or science field but I'd like to be a school teacher. During the pour method we had to work with our partner because the tubes were very big. My partner was very confused so I was able to guide him a little bit by helping him through the steps. Being a

	Representative Student Quotes
	teacher I will also have to help kids understand what it is they are doing and why it is important. By the time it came it making my pour plate he even caught me on forgetting a step.

Table 25: Evidence of Transfer of Context in Lab Quiz Five

	Representative Student Quotes
Near Transfer	Learning the process of what certain media looks like or even smells like can be beneficial in the future. When I may not be aware of the media I am dealing with but recognize the reaction or even scent of it I might be able to make an educated guess on what it is and how it may react. Learning these traits can be basic learning for future research I intend to do.
	Reading the results from all the test tubes was the most important part of lab exercise for me. It was a cool way to see what bacteria use as energy as well as being able to differentiate bacteria based on enzymes used. I feel this will help me pay attention to the physiology of bacteria as well as understand culture environments.
	I think the most important aspect of this lab would be to understand what each medium produces, what its reaction are, its purpose, etc. especially for the lab midterm and practical. To understand this all is essential to pass the class and therefore continue on with the rest of my academic plan because if I don't pass this lab, I don't pass the course and therefore I'm set back, it would be a waste of time and money, neither of which I have so it's important to know.
	The aspect I can take away from lab 8 was trying to work well with my partner. Sometimes the person you work with isn't as good or at the same skill level, so you have to rewind, and slow it down for them. You can say this lab has taught me to try to work well with others. In my future career, I'm certain I'll have to work well with others, and I'm glad this lab exposed me to it.
Far Transfer	While I was at the hospital this weekend shadowing, they had to run some lactose tests and the physician was asking the nurse about the patients blood work and she responded they sent the work back to be tested. Then the physician asked her if the cultures came back positive or negative. This weekend I experienced how microbiology lab impacted my future career.

	Representative Student Quotes
	The ability to look at the sample and identify what the results mean was most important in preparing for my future career as a PA. I'm going to have to be able to read results and accurately come up with a diagnosis.

Table 26: Evidence of Transfer of Context in Lab Quiz Seven

	Representative Student Quotes
Near Transfer	I think finding a beta hemolytic colony is really important and will help on the lab final, being able to recognize one. And from lab 11, I was interested in learning about salmonella, because it is something we can catch easily dealing with meat. Seeing how much bacteria was growing on my fomite (which was my own personal cell phone) was a reminder about how easily bacteria can transfer and grow on personal belongings. The most important part of these labs, since they were pretty straight forward was trying to identify Staph and understanding the material, the lecture portion of the lab since in one way or other we'll be tested on this material, it's important to understand it and know what you're doing so that you pass the course and you're able to move on with the rest of your undergraduate courses and graduate.
Far Transfer	The most important aspect of these lab exercises that I feel will be important for my future career is being able to swab evidence, or a person, and isolate and perform further tests to see what it has come in contact with. The most important aspect of these exercises were [sic] being able to isolate the specific bacteria colonies. This is important because when gathering a sample from a patient, the sample will contain a mix of bacteria and you must be able to isolate a specific type to see which bacteria is causing harm in the body. Exercise 11 part 1 helped me how to distinguish between Salmonella and Shigella by using a Hektoen Enteric agar plate. This can help me as a physician in the future when a patient comes in sick with foreign bacteria in their GI tract.

Table 27: Evidence of Transfer of Context in Lab Quiz Nine

	Representative Student Quotes
Near Transfer	It was important for my career to learn, one how to read a dichotomous key and how to differentiate between Salmonella and proteus, since

	Representative Student Quotes
	their morphology is similar. Also, it is very helpful to know that Urease is the key to determining the difference. Working on unknowns has been extremely beneficial for me. This is allowing me to have full control of the tests I do in order to determine my organisms, which is the first applicable thing I feel like we've done so far.
Far Transfer	Studying and differentiating between Proteus and Salmonella bears clinical significance since they can be pathogens. As an aspiring physician, it is likely that I will have to be able to identify different kinds of disease-causing microorganisms to help diagnose and treat a patient, and knowing the biochemical tests and varying results will prove useful. The ability to test water for microbial content is an important factor in many industries for waste management and water treatment, among other applications. In many engineering fields, water quality is an important consideration in process development and management. I want to be a doctor one day and understanding how to run all of these tests and interpret the results are very valuable skills to have as a doctor. I honestly feel that this lab is one of the most important labs at UCF in preparation for medical school. I've learned so much more in this lab compared to any other lab at UCF.

Table 28: Evidence of Transfer of Context in Lab Quiz Ten

	Representative Student Quotes
Near Transfer	It will be beneficial for my future career to learn about the importance of disinfectant and antiseptic compounds in a lab setting. This lab showed how microbiology is easily applied to our everyday lives. It shows how important it is for things that we don't even think about on a regular basis like if our water is contaminated.
Far Transfer	The most important part of the lab exercises in terms of preparing for my future career was learning proper sterilization techniques for the forceps used to prepare the antibiotic solutions. When I become a surgeon I'm going to have to make sure all my tools are properly sterilized before having it come in contact with the patients I will be working with.

	Representative Student Quotes
	I think the most important aspect of lab exercise 13 part 1 that could help me prepare for my future career is knowing the action of each antibiotic used as well as the side effects any of the antibiotics used in this lab could have. By knowing the action of the antibiotics, I will be able to determine the effect the antibiotic could have on a patient and obviously the side effects caused by the prescribed antibiotic. For example, I won't prescribe an antibiotic to a patient if he or she has some sort of allergy or reaction to the components of that antibiotic. Or another example could be that maybe the antibiotic has side effects that include damage to kidneys or damage to auditory nerves, so knowing these certain facts about any antibiotic being used is extremely critical because it prevents any further damage or infection since some antibiotics are known for affecting human cells. I may one day work at a water treatment plant and if I do ensuring we have clean water will be just another regular day at work. Plus who knows one day I may chose to live in Montana by myself and if I do I'm going to want to make sure my local water supply is clean for drinking and bathing purposes.

APPENDIX F: EVIDENCE OF TRANSFER OF LEARNING TO FUTURE CAREERS

Table 29: Evidence of Transfer of Learning to Future Careers in Quiz One

Field	Representative Student Quotes
Higher Education and Research	I think the most important aspect of both of the lab exercises was learning the proper procedure to perform the fundamental activities that are going to be required in the future. I hope to perform research in a lab at some point in my career, so it is imperative that I learn, memorize, and become comfortable with the exact steps that these procedures require, especially with regard to keeping the materials sterile.
Other Professional Field	I'm going into crop science, so no doubt doing stains of plant microbes and fungal parasites will be incredibly important. I wish to work in a crime laboratory once I graduate, and aseptic techniques will be very important in those analysis [sic].
Pre-Dental	In my case it is important, because I wasn't to become a dentist and the foundation of maintaining a successful practice is making sure that the environment is a hygienic and sterile as possible.
Pre-Medical	Aseptic technique, staining bacteria, and observing through a microscope are all important for my future career in medicine as a doctor. A doctor needs to know how to make sterile cultures to diagnose bacterial infections a patient may have by staining the bacteria properly.
Pre-Nursing	I hope to become a nurse and it will be important for me to know how different bacteria look in a microscope and which type of stain I should use to see the bacteria. I can cut down the time the lab needs if I can tell them what type of bacteria I think it is.
Pre-Pharmacy	It is most important to know all proper way to working with this organism such field in micro laboratory or pharmaceutical field in future as well.
Pre-Physician's Assistant	The most important aspect for me was preparing smear preparations. Mainly because this was something I've never done before and had to learn solely in lab. I plan on becoming a PA and possibly specializing in dermatology so this kind of collection/analysis process could prove vital in my career (biopsy, skin prick test, etc.).
Pre-Veterinary	My future career goals are to earn my Doctorate of Veterinary Medicine. The most important aspects of lab for my career would be

Field	Representative Student Quotes
	learning to follow aseptic technique, recognizing various organisms under the microscope, learning how to properly use, handle, and clean the microscope, practicing stain techniques, and so much more.

Table 30: Evidence of Transfer of Learning to Future Careers in Quiz Three

Field	Representative Student Quotes
Higher Education and Research	Both of the skills learned in lab exercise 5 were important in preparing for my future because they are useful techniques that can be applied in clinical and research settings. When a sample of bacteria is given it is rare that they are in a pure culture. So the isolation techniques learned: the pour plate method and the three zone streak, can be used to isolate bacteria from a mixed culture so that I can work with a single species of microorganism.
Other Professional Field	The transferring of the culture from tube to tube, The mixing and pouring into the plate; are all lab procedures that will be important in preparing me for my future career as a forensic scientist. I will be working in the lab on a daily basis conducting test and taking samples from tubes.
Pre-Dental	*There was no evidence of learning transfer to the dental field in this quiz among the responses coded.*
Pre-Medical	The fact that everything requires such care and precision to do will help me out in a future of surgery, considering everything has to be calculated and near perfect to not harm anyone. The patience and care it took not to scratch the agar in the three zone streak plate reminded me of the care a physician has to have when doing anything in the medical field.
Pre-Nursing	*There was no evidence of learning transfer to the nursing field in this quiz among the responses coded.*
Pre-Pharmacy	*There was no evidence of learning transfer to the pharmaceutical field in this quiz among the responses coded.*
Pre-Physician's Assistant	The most important aspect of lab exercise 5 that prepares me for my future career as a PA is the delicate and careful technique that must be acquired through the 3 zone streak method. If I were to specialize in surgery as a PA, I would have to have a steady, careful, and precise hand and eye coordination.
Pre-Veterinary	Again, everything I am doing is in hopes of having some sort of career in the veterinary medicine field. Learning how to isolate the bacteria of

Field	Representative Student Quotes
	a sick animal is going to be a useful technique when trying to figure out why animals are getting sick, and moving on to trying to make them better. Is it a single microbe, multiple microbes?

Table 31: Evidence of Transfer of Learning to Future Careers in Quiz Five

Field	Representative Student Quotes
Higher Education and Research	Definitely in knowing what type of media is used is important to determine what is the outcome from an organism. Learning and understand the bacteria's physiology is an important key in working as a microbiologist. When one understand the bacteria physiology, he/she can determine methods to treat the patient or design drugs to kill the bacteria if they are pathogenic.
Other Professional Field	As a chemist, understanding and being able to characterize a bacteria based on it's physiological characteristics will allow for the design of effective drugs that may interfere with certain metabolic pathways that the bacteria possess.
Pre-Dental	Determining the unknown Bacteria. I am hoping to go into the dental field, and the mouth is a major area for bacteria entry. Learning about this bacteria now may help in the future.
Pre-Medical	I think that understanding how certain organisms metabolize different nutrients and being able to discern that from the results will definitely be helpful for my future career as a doctor.
Pre-Nursing	*There was no evidence of learning transfer to the nursing field in this quiz among the responses coded.*
Pre-Pharmacy	In the pharmacy field it may be important to understand is microbes will ferment the sugars or not, knowing how to test for this may pose as viable information for my future.
Pre-Physician's Assistant	The ability to look at the sample and identify what the results mean was most important in preparing for my future career as a PA. I'm going to have to be able to read results and accurately come up with a diagnosis.
Pre-Veterinary	This will be important in vet school because one method might give you the same answer over and over again, but the different methods can tell to what degree and solidify the results with more evidence. It was also an excellent way of figuring out unknown cultures.

Table 32: Evidence of Transfer of Learning to Future Careers in Quiz Seven

Field	Representative Student Quotes
Higher Education and Research	The skills used in these labs such as the 3-zone streak plate, 2-tube transfer, and gram stain will aide in any possible lab-based internships or research I may do in the future
Other Professional Field	This lab was irrelevant to my future career in forensic science as at no point will I be required to work with microorganisms. However, as before, aseptic technique may be useful for proper precautions when handling unknown biological samples.
Pre-Dental	The aspects used in this lab are good to be able to observe how bacteria form, in dentistry, biofilms are one of the most common grouping of bacteria. It is interesting to see how these processes occur and how they can apply to real life situations.
Pre-Medical	The most important thing in this lab was to identify possible fomites that are present in the hospital lab setting. Since I want to become a doctor, I must be aware of possible things that might contaminate the patient. Simple things such as machines and stethoscopes could contain fomites. With that in mind, I need to be cleaning all my supplies often and be more cautious of other potential safety hazards. This lab exercise will help me in my future career because it has educated me in the dangers and signs of Salmonella. By noticing the signs of abdominal cramping, fever, and diarrhea after the initial infection I would be able to diagnose and treat my patient to immediately get rid of the colonies of Salmonella in their body. If I were to suspect that my patient was infected with Salmonella, I would be able to use Hektoen Enteric (HE) agar as a means of isolating and differentiating salmonella from other enterics infecting the gastrointestinal tract.
Pre-Nursing	*There was no evidence of learning transfer to the nursing field in this quiz among the responses coded.*
Pre-Pharmacy	*There was no evidence of learning transfer to the pharmaceutical field in this quiz among the responses coded.*
Pre-Physician's Assistant	As a PA, I will probably be testing patients for things like staph and strep.
Pre-Veterinary	*There was no evidence of learning transfer to the veterinary field in this quiz among the responses coded.*

Table 33: Evidence of Transfer of Learning to Future Careers in Quiz Nine

Field	Representative Student Quotes
Higher Education and Research	Many Microbiologists jobs are to research about and ensure we can prevent the spread of pathogenic microbes that harm the population. Salmonella and other pathogenic bacteria are important to study and are extremely relevant to a large sector of possible jobs I may have researching pathogens. Seeing how we can isolate them from healthy bacteria is important if we encounter infection.
Other Professional Field	As I'd like to go into public health, an important part of my job might be to test water samples for E-Coli because this can be dangerous and can make people very sick if it isn't treated properly.
Pre-Dental	The bacterial examination of water is very essential to my future career because I will be working as a dentist and if the drinking water is not clean then bacteria may make complications in teeth and possible create cavities.
Pre-Medical	Studying and differentiating between Proteus and Salmonella bears clinical significance since they can be pathogens. As an aspiring physician, it is likely that I will have to be able to identify different kinds of disease-causing microorganisms to help diagnose and treat a patient, and knowing the biochemical tests and varying results will prove useful.
	The aspect of lab exercise 11 part 3 that was most important for me in preparing for my future career as a physician assistant is the clinical connection regarding Salmonella. As the exercise pamphlet mentioned, Salmonella has been in the news causing food-borne outbreaks in the US and around the world. It is important to inform my patients of the signs and symptoms that Salmonellosis can present so that they know when to seek treatment. As for lab exercise 15 day 1, the aspect that was most important for me in preparing for my future career was definitely a steady hand. I know this skill will come in handy during my surgery rotations and it is best that I get practice now!
Pre-Nursing	I think understanding how intestinal bacteria reacts to each test will help me identify it as a nurse. Gastrointestinal issues are very common and it can even be an over growth of the patients normal bacteria that causes them to need to come into a hospital. Salmonella and E. coli are probably the ones we hear about most, however the others are just as important and understanding what the test results mean for my patient can help me save them and get them out of the hospital faster.

Field	Representative Student Quotes
Pre-Pharmacy	*There was no evidence of learning transfer to the pharmaceutical field in this quiz among the responses coded.*
Pre-Physician's Assistant	Being able to differentiate proteus from salmonella actually applies to the PA profession. Proteus is a bacteria that is often the cause of UTIs, so it will be important to be familiar with its traits and chemical characteristics.
Pre-Veterinary	The water testing is most important. If a dog comes into the office with an odd infection, I would ask the owners if he's recently been to a dark park and if that dog park had a lake. If so, I might ask for a water sample to see if the lake was a reservoir for the patient's symptoms.

Table 34: Evidence of Transfer of Learning to Future Careers in Quiz Ten

Field	Representative Student Quotes
Higher Education and Research	I feel like this lab really helped me understand the clinical aspect to microbiology, which in a way gives me a small idea of what that could be like if I were to get involved in microbial research for clinical purposes
Other Professional Field	The most important aspect for me was learning how to preform disinfectant/antiseptic disk and the kirby bauer method. I think this lab was very helpful for me in my future career as a lab technician because now I can integrate the results which is an important skill for a lab technicians.
Pre-Dental	This entire lab exercise was important for my future career. As a prospective dentist, I found it incredibly important to know about the antimicrobial agents and antibiotics. As well as, knowing which to use depending on their cell wall.
Pre-Medical	The most important part of the lab exercises in terms of preparing for my future career was learning proper sterilization techniques for the forceps used to prepare the antibiotic solutions. When I become a surgeon I'm going to have to make sure all my tools are properly sterilized before having it come in contact with the patients I will be working with.
Pre-Nursing	*There was no evidence of learning transfer to the nursing field in this quiz among the responses coded.*

Field	Representative Student Quotes
Pre-Pharmacy	This has probably been the most relevant lab to my future, as we actually used chemicals that helped to fight and prevent bacterial infections and saw their effect on living and growing microorganisms. It will be important for me to understand and know the differences between different medicines and what they do to microorganisms as a pharmacist.
Pre-Physician's Assistant	The aspects of both lab exercise 13 part 1 and lab exercise 15 day 2 that were most important for me in preparing for my future career as a physician assistant include having a steady hand when handling instruments like forceps and Q-tips.
Pre-Veterinary	I found all of the exercises to be relevant, primarily the antibiotics study as antibiotic resistance is becoming more and more prevalent and can cause many issues in the veterinary field with compliance issues as well.

APPENDIX G: DIFFICULTIES ENCOUNTERED BY STUDENTS IN MCB 3020

Procedural Issues

Table 35: Students Expressing Issues with Procedural Skills in Lab Quiz One

Representative Student Quotes
Aspects that were challenging for me were making sure I had enough of the microbe on my slide, and also making sure it stuck and didn't wash off. Initially using a Bunsen burner and using 3 passes was a fairly simple procedure for a heat fix, but I'm rather unconfident when I'm underdoing or overdoing my heat fix with the new micro incinerator. For lab 2, I found the gram stain to be a tad tricky mainly due to how many steps were involved as well as the quality of the steps. For example, not thoroughly rinsing off the dye, or pouring too much of the dye on the culture. I would say if I had to pick the most challenging aspect of lab, I would choose the negative stain. Since I'm a veterinary nurse, I have previously prepared blood smears for the doctors to view under the microscope. Since the viscosity of blood and the nigrosin mixture are slightly different, my stain did not come out as evenly as I was expecting. I was still able to view the bacteria under the microscope. This was the first time I viewed a negative stain, and it was so fun to see!

Table 36: Students Expressing Issues with Procedural Skills in Lab Quiz Three

	Representative Student Quotes
General Procedural Skills	In this lab I kept forgetting to let the sterilizing loop cool down so I kept seeing steam come out whenever I had to transfer a bacteria. I realized this happened because I kept stressing out about the agar cooling down, but I know I still have to follow instruction in order to get correct results. Remembering the steps for the lab was very challenging. It was a slow process but it had to be done correctly. There was a lot of steps that go into this process that need to be taken carefully. Remembering to keep everything organized was a challenge but it did keep everything organized and out together so it was worth the hassle. The most challenging aspect of this lab was doing the pour plate isolation technique in a quick manner before the liquid agar started to solidify. Sometimes, I need time to collect my thoughts and realize what I am doing. By the time I grabbed the liquid agar from the incubator, I did not realize that I had to work fast immediately before the agar would start to solidify so I had to quickly act.

	Representative Student Quotes
Streak Plate Skills	The most challenging aspect for me was the final part of the three zone streak plate. It was difficult on the first attempt to increase the angle of the sterilizing loop against the agar without creating a gash in it. I think my second attempt and third attempts turned out much better than the first.

Table 37: Students Expressing Issues with Procedural Skills in Lab Quiz Five

	Representative Student Quotes
General Procedural Skills	The shear [sic] volume of tests and the details associated with them provide a challenge to keep them straight.
	The most challenging aspect of this lab was making sure that I transferred the correct organism to the correct tubes. There were so many tubes and bacteria tubes that I had to double check I was grabbing the correct tubes.
	The most challenging part of lab 8 was putting the right amount of bacteria on the gram stain and also doing it correctly. Mine had too much bacteria and I picked from different cultures which contaminated my results.
	The aspect of lab exercise 8 that I figured to be the most challenging was the inoculation in the KIA tubes. I thought I wasn't going to get much inoculation since I was not used to the stabbing/streaking method. However, the results did come out as they were supposed to so the process didn't go as bad as I had thought
	These labs required some of the most work so far so remaining accurate and also efficient was a challenge. For example instead only doing 4 or 5 inoculations we did almost 20 so maintaining the same level quality even though there are much more to do
Streak Plate Skills	The most challenging part of the lab session this past week was the three zone streaking on the agar plates. I'm not using the whole plate in the 3b zone, so I need to improve on this skill by using all the room given to me on the plate.

Table 38: Students Expressing Issues with Procedural Skills in Lab Quiz Seven

	Representative Student Quotes
Streak Plate Skills	My hands are very unsteady, so all the streak plates were incredibly challenging to pull off sans agar slashing and so on.

	Representative Student Quotes
	The most challenging part of this lab was the amount of inoculations and streaking that needed to be done. It is also challenging to remember which media selects and/or differentiates for which organism The most challenging part of the lab exercises this week were performing the three zone streak plates with patience and precision. There were a lot of streak plates done in this week's lab procedures, and it's easy to rush to get through them quickly, but taking my time and performing this task with precise streaking will allow me to obtain the results I am looking for. There were times when I rushed the streak plates and noticed that those plates lacked growth in some areas, so this is something I could work on.
Isolation of Bacteria	The most challenging aspects of lab excise 10 part 2 was trying to isolate the colonies onto the blood agar plates. Also, achieving complete isolation of four colonies was difficult and very tedious because there could be contamination if my isolations were done incorrectly. The most challenging part of this lab was isolating staph and strep from the original blood agar plates because I was not sure how to tell them apart. Also, it was hard to remember where the species come from (staph on the fomite but strep in the throat). it was confusing. Getting obvious staphylococci and streptococci colonies on my streak plates, whether they looked like strep. or neither. Even when I asked the TA's they were not able to find much, especially for my fomite. Lab exercise 10 part 2 was most challenging for me when I had to locate and isolate a beta hemolytic colony for streptococcus from the first blood agar plate. It was challenging because I wanted to make sure I selected the right colony and it was hard to locate on some of the plates.

Table 39: Students Expressing Issues with Procedural Skills in Lab Quiz Nine

	Representative Student Quotes
Streak Plate Skills	I think the hardest part for me this week was not slashing the agar, since they were so delicate. Unfortunately I still slashed it, so for future reference I should note that not to put any pressure on the loop at all when conducting the three zone streak. The potato agar seemed to be softer and more prone to slashing than other agars we have used in the lab. Streak plates were a little more difficult to perform because of this.

Table 40: Students Expressing Issues with Procedural Skills in Lab Quiz Ten

	Representative Student Quotes
General Procedural Skills	It was most difficult in understanding what was going on with the chemical aspects of the lab. It was also challenging to remember what inhibitors were being used and what activities they were doing
	I think the most challenging part of the lab was, learning about how to determine if fecal matter were in the test tubes, and also the amount of bubbles it created in the test tube also threw me of cause my result came out to be 2-3-2 on the chart they showed us in lab. which is not on the chart.
	The most challenging aspect of these labs was the ability to distinguish between the antiseptics and disinfectants. The concept is still one that confuses me, and I have a hard time differentiating between the two based on concept. Identifying the solutions that we submerged the cotton discs into as either disinfectant or antiseptic was of some difficulty for me.
	Using a ruler to precisely measure the diameter of the zones of resistance was the most difficult part for me due to the inability to create an accurate answer. Although this was not enforced to do within the lab period, I did it anyways to further my knowledge of this lab.
Streak Plate Skills	The most challenging part of these lab exercises was keeping everything in order. My lab partner and I almost forgot to inoculate out organism on out plate with the lawn mechanism before placing the disks on it. However, we remembered that step before it was too late and performed the inoculation before putting the disks on the plate.
	The most challenging for me in this lab was doing the mueller hinton agar plate because I would have to try to reach all of the surface of the agar but since it is hard to see, I did not know if I reached all of it or not. Also, I had to turn it 90 degrees and swab the entire so I also did not know if I touched every single area.

Issues with Interpretation of Data

Table 41: Issues Related to Interpretation of Results in Lab Quiz Three

	Representative Student Quotes
Interpretation of Media	The most challenging aspect of lab was the unknown. It was difficult for me to not know if the cultures are going to turn out as they should. I know that I did all of the procedures as explained, but there is always a possibility for error. With this possibility, the waiting game is the hardest part.

Table 42: Issues Related to Interpretation of Results in Lab Quiz Five

	Representative Student Quotes
Identification of Bacteria	The aspect of lab exercise 8 that was the most challenging for me was learning about how to differentiate bacteria based on their characteristics, such as the production of exoenzymes and the ability to ferment sugar. Associating which bacteria caused which reaction and why was also challenging. It was a copious amount of information to process at once The most challenging part in exercise 8 was trying to describe the plates. Besides the color and regularity/ irregularity, it was hard to decipher exactly what shape or elevation or margin the colony was.
Interpretation of Media	The most challenging part of lab 8 was understanding the reasons for using the different types of media and being able to interpret the results. It was interesting learning how to easily organize all of the different tests without having to repeatedly label all of the tubes. The most challenging part of exercise 8 was differentiating between the reactions. It took me a long time to understand what each test did and what indicators I should look for. However, I made a chart that distinctly differentiates them and now it is easier for me to understand. Also, I confused the blue ridge cap with the smooth ridge cap which messed up some of my data. I need to be more observant and careful next lab. One of the hardest things was ensuring that the results that were being red were accurate in instances where the colors were a bit ambiguous. Also, the characteristics of the nutrient agar plates with all of the different bacterial growths. It would have been helpful if as a class we did one of the plates together in order to have some sort of consensus on what each looks like on the plate, rather than the pictures on the slides. Finally, something that I found challenging was the size of the

	litmus milk test tube, because it was a little smaller it was hard to pick up and put down on the test tube rack because the only place to initially lift it was the cap which could have led to breaking the tube if not careful, it would have been helpful to have that be in a taller test tube for ease of handling, as well as for reading the results so that its less likely that the milk was disturbed.

Table 43: Issues Related to Interpretation of Results in Lab Quiz Seven

	Representative Student Quotes
Identification of Bacteria	The most challenging part of these lab exercises was determining if the right strain of Staphyloccocus was isolated on the plates. The colonies appear the same; however, the Staphyloccocus that was to be taken for further testing was golden in color instead of white. I had to pay close attention to which colony to take.
	The most challenging part about lab this week is to be able to identify the small Streptococcus colonies on blood agar. We were suppose to make three zone streak plates from samples off of our throat and then try and find independent colonies of Streptococcus. The samples from my throat provided a lot of different bacteria type which caused a lot of different colonies to grow so it was hard to try and identify Streptococcus colonies. It was even harder to try and pick them off from the plate with my loop. Hopefully, we will run test Wednesday will indicate I have successfully isolated the small gray colonies.
Interpretation of Media	The most challenging part for this lab would have had to been recognizing what was on my media. This lab had different results because we were testing on ourselves and a different object. Not everyone had the same results like we mostly always do. It was challenging to know if you do it correct or not and what actually happened to your agar depending on what your circumstance was.
	We were supposed to choose a few different colonies that had beta hemolysis and on my plate it was hard for me to find beta hemolysis or even distinguish which colonies were beta, which were alpha, and which were gamma. Most of the colonies on my plate looking extremely similar! I will definitely have to work on differentiating hemolysis!
	It is difficult to keep track of what to inoculate and how considering there was so many tubes and medias as well as keeping track of what media is differential or selective and what it is an indicator for.

Table 44: Issues Related to Interpretation of Results in Lab Quiz Nine

	Representative Student Quotes
Identification of Bacteria	The most challenging part was identifying Salmonella. Also, knowing how to differentiate between Salmonella and Proteus since the results for both are very similar.
Interpretation of Media	The most challenging part of the exercises was being able to distinguish salmonella from proteus using the various selective/differential media (EMB, KIA, etc.) and identify enterobacteriaceae.
	The most challenging part is still understanding the indicators of each test. The procedures and inoculations are easy but understanding what the indicators are and their significance can be a little challenging at first.
	Trying to use prior knowledge from what I have learned in previous labs and apply it to the lab we did today. Especially the media used and how it would react with the different effects that these bacteria have on them.

Table 45: Issues Related to Interpretation of Results in Lab Quiz Ten

	Representative Student Quotes
General Interpretation of Results	It was most difficult in understanding what was going on with the chemical aspects of the lab. It was also challenging to remember what inhibitors were being used and what activities they were doing.
	The hardest part of this lab for me was making sure that I read the MPN chart correctly. Furthermore, I will need to make sure I understand which antibiotics kill gram negative bacteria and which kill gram positive bacteria.
	The most challenging part of these lab exercises was understanding how the fungi reproduced. I think it will be easy to understand once studied more.
	The most challenging part about this week lab was understanding how to read the Kirby-Bauer Antimicrobial susceptibility chart. It's strange that there are different standards for the individual antibiotic. Once I understood how to read the chart it was very easy to understand how to use it.
Interpretation of Media	I found it difficult to read some of the results from the potato plates because they were very hazy.

The most challenging part was trying to read and understand the EMB and Endo agars were difficult as well because I forgot what a positive and negative look like and what the results meant. I kept getting the Endo agar results confused with MSA because they both have a pink tone agar. I also had trouble trying to interpret the MPN chart. I did not understand the confidence limits.

Issues with Manual Dexterity

Table 46: Issues Related to Manual Dexterity in Lab Quiz One

Representative Student Quotes
Given that my hands are a bit shaky and that I'm not the most coordinated person, the two-tube transfer's a bit awkward to perform.
The aspects that was most challenging to me was the 2 tube transfer because, I have to get use the hold and the way that the GTA wants me to handle the tube. Also, I don't understand how I am suppose to hold the loop with the 2 tube transfer skill.
The most challenging aspects of the first two labs for me was the two tube transfer because it felt as though my pinkies would drop the tube tops any second. I suppose I will just have to get used to that.

Table 47: Issues Related to Manual Dexterity in Lab Quiz Three

Representative Student Quotes
The most challenging aspect was when I had to change the loop angle from zone 3A to 3B. It's hard to streak the entire distance of 3A to 3B without stopping while changing the loop angle.
For Lab 5 I didn't have a partner so it was challenging to do the pour plate method alone without the extra hands to help hold/pour while the next tube was being inoculated. I was using the water bath, but I was afraid that I would kill the bacteria in the tubes while I was pouring. For the 3-zone streak, I was having some issues with the loop, it felt too hot at times even when I had waited more than 15 seconds, so the procedure probably took me more time than necessary.
The most challenging part of this lab was trying to correctly hold all the tubes at the same time. Sometimes I was worried that I would drop one on accident for having the proper grip.

Representative Student Quotes
The most challenging part was making sure to stab or scape the agar with the loop. I don't have the steadiest of hands. And it was so easy to stab through the agar.

Table 48: Issues Related to Manual Dexterity in Lab Quiz Five

Representative Student Quotes
I had some difficulty with two tube transfer during this lab. I have an issue gripping the caps, but as I got to the last transfers I was more comfortable. It was very interesting to see the results, but a lot of info to take in.
The fishtailing and stab for the KIA media was most difficult for me, I think I got too much bacteria on my loop, but I'm not sure, so that was confusing.

Table 49: Issues Related to Manual Dexterity in Lab Quiz Seven

Representative Student Quotes
My hands are very unsteady, so all the streak plates were incredibly challenging to pull off sans agar slashing and so on.
I had the most difficulty keeping my fingers from burning on the loop handle after so many sterilizations.
Agility of doing the procedures is very important in my future career. It is essential to have manual dexterity and faster responses in order to treat patients fast and effectively.
The most challenging part for me was selecting a streptococcus colony for the 3-zone streak as well as being gentle with the agar plates to not slash it.

Table 50: Issues Related to Manual Dexterity in Lab Quiz Nine

Representative Student Quotes
The most challenging for me in this lab was getting the pipette to work and measure exactly 1.0 mL and 0.1mL and put them into the tubes. The water would always go past my desire point so I kept having to redo it.
Using the pipettes for the water, there was not a perfect seal between the tip and the device and water would keep draining out of the end. I'm very used to using the automatic ones and found this actually to be surprisingly difficult and frustrating.
Using the pipets again really hard for me because I have an unsteady hand. Also there might be a slight difference in liquid measurements for me because there would be

Representative Student Quotes
times were I would go a little past the lines so I know that I have to work on my pipetting work.

Table 51: Issues Related to Manual Dexterity in Lab Quiz Ten

Representative Student Quotes
Strangely enough, gripping the antiseptic disks with the tweezers was actually a little more difficult than anticipated because the tweezers were stiffer than I am used to. On one occasion I accidentally dropped the disk into the iodine, but was able to grab it immediately before any problems arose.
The most challenging part of this lab was lighting the Bunsen burner. It always gives me a hard time. But it was pretty neat to see the tweezers catch on fire while it was being sterilized.
What was most challenging for me was delivering the most accurate amount of liquid from the water sample into the test tubes using the pipette.

Students Expressing that They "Need Practice"

Table 52: Students Expressing that They "Need Practice" in Lab Quiz One

Representative Student Quotes
The more I use the microscope, the better I will get at it.
I had a little trouble holding the test tubes and caps right in my hands. But nothing I couldn't do with more practice.
However, in the lab 2 exercise, finding the stained bacterial cells with the microscope was challenging until I got more practice and can find them with ease now.
The two tube transfer was challenging in the beginning because I was not able to multitask holding the tube caps while transferring the media, but after few times of practice, I was able to get it right. Practice makes good.
The aseptic smear preparation was most challenging for me but I strongly believe I will become significantly better at it as the semester goes on.

Table 53: Students Expressing that They "Need Practice" in Lab Quiz Three

Representative Student Quotes
The most challenging part of lab five for me was streaking zone 3b on the streak plate. I found this challenging because I kept cutting into the agar with the loop. I think with more practice this motion will get easier and I will become better at it.
The most challenging aspect of lab exercise 5 for me was keeping the zone 3b streak only in zone 3b for the three-zone streak procedure. I will certainly work on this because I understand its critical for isolating individual bacterial cells! Another aspect that was hard for me during the pour plate method was minimizing the time the plate was exposed to the air. I will work on both aspects to perfect my techniques.

Table 54: Students Expressing that They "Need Practice" in Lab Quiz Five

Representative Student Quotes
The most challenging part of lab exercise 8 was, surprisingly, doing the 3 zone streaks. I need to practice a little more with those again.
Detecting the Unknown. I believe with a little more practice and exposure it will become much easier to determine unknown microorganisms
Keeping up with what medium did what. If this is on the practical, I have some studying to do because all I really did was follow the instructions. I really didn't 'get it' how I really would have liked to since I might have to perform these tests on my own at a later date. I'm going to watch some YouTube videos to hopefully clear the confusion before then.

Table 55: Students Expressing that They "Need Practice" in Lab Quiz Seven

Representative Student Quotes
I had to be extra careful to isolate the correct bacteria and in addition some of my plates didn't isolate many colonies. practice of a 3 zone streak plate is definitely needed.
I had a hard time learning how to interpret al.l the different results from the lab exercises; however, I do believe these skills will get better with more practice.
The most challenging about lab exercise 10 part 2 and exercise was not inoculating properly. I was afraid of outside contaminants as I was just getting over a cold. Coughing was a common symptom that I had, in which I had to keep coughing into my arm. With proper practice and protocol, however, everything turned out well.

Table 56: Students Expressing that They "Need Practice" in Lab Quiz Nine

Representative Student Quotes
After further review of the material as well as being exposed to the material more, I believe I will be able to better understand which tests to use.
Also, in exercise 15 the hardest part of that was trying to get the perfect measurement of water form the pipet. Learning proper pipetting technique is something that I need to work on
When I was attempting to confirm the results of SIM, I was confused as to whether or not the result was motile or was H2S positive. After a while of figuring out what each result looked like an meant, I began to get a grasp of what was going on.

Table 57: Students Expressing that They "Need Practice" in Lab Quiz Ten

Representative Student Quotes
The dexterity demanded of the translation of the "disk" into alcohol solution and into the appropriate petri dishes presented quite a personal challenge. However, with more practice, I am sure the technique would not be beyond my grasp of mastery.
The aspects in exercise 13 that were most difficult for me technique wise were pipetting the exact amount of water into the lactose broth tubes and making sure that no more of no less came out of the pipettes. Pipetting was only a technique that we did about once before in lab and sometimes the holders would not always work. But for me a few extra drips of water kept sneaking out!
I think if I took my time in the future, and performed the dilutions with patience and execution, my diluted samples would have turned out a little better.

Issues with Microscopy Skills

Analysis of Lab Quiz One

Table 58: Issues Related to Use of the Microscope in Lab Quiz One

Representative Student Quotes
Adjusting the microscope to the proper setting to see the culture. I have not used a microscope in quite a while, which made it more difficult using the microscope at first.

Representative Student Quotes
I think that the hardest part for me out of the two labs was figuring out how to properly use a microscope when it came to looking at the bacteria on the slides. If you can't get it completely focused, it's hard to distinguish what shape the cells are.
However, I have not used microscopes often, and had a very difficult time with visualizing the negative stain. It took me almost the entire time to visualize the yeast, and I was unable to visualize anything for the other two samples. I will pay close attention to the techniques described next time and hopefully I will improve.

Analysis of Lab Quiz Five

Table 59: Issues Related to the Use of the Microscope in Lab Quiz Five

Representative Student Quotes
I still have trouble either finding my species under the microscope or executing the gram stain correctly.
The most challenging aspect of the lab was manipulating the microscope to find my organisms.

Analysis of Lab Quiz Ten

Table 60: Issues Related to the Use of the Microscope in Lab Quiz Ten

Representative Student Quotes
The most challenging part of this lab was seeing understanding the difference between sexual and asexual reproduction in fungi and being able to see the difference using the microscope.

Time Constraints

Table 61: Students Expressing Issues with Time Constraints in Lab Quiz One

Representative Student Quotes
The most challenging aspect of labs 1 and 2 was making sure that there was a proper amount of the sample on each slide during the 1 tube transfer without applying so much that the class would be held up waiting for the slides to dry.

Representative Student Quotes
…the most challenging aspect was trying to find the bacteria under the microscope. it took so long.

Table 62: Students Expressing Issues with Time Constraints in Lab Quiz Three

Representative Student Quotes
The most challenging part of the lab was the pour plate method because everything needed to be done quickly before the molten agar solidified.

Table 63: Students Expressing Issues with Time Constraints in Lab Quiz Five

Representative Student Quotes
This lab was a complex lab and I had to make sure I got it done correctly within the time allowed, which was somewhat stressful.
The most challenging part of lab 8 was working with so many species and agar in a certain time. The separation of duties between partners helped, but the limited space was an issue.

Table 64: Students Expressing Issues with Time Constraints in Lab Quiz Seven

Representative Student Quotes
Completing all tasks in the time given was a challenge. Other than time restraints. The techniques were simple.
The directions for the second lab seemed rushed and a few of my classmates and I felt like we needed further direction to get started.

Table 65: Students Expressing Issues with Time Constraints in Lab Quiz Nine

Representative Student Quotes
And also the hard part for me was when we had to inoculate multiple things, and we had very little time, since we started doing skills test. So I had to make sure I do my work very fast. Since time was an issue.
Working fast was challenging because it requires hand skills which I am still developing.
It was also pretty challenging this week because I feel like we had so much to do in very little time. I felt like I was almost being rushed a bit.

Table 66: Students Expressing Issues with Time Constraints in Lab Quiz Ten

Representative Student Quotes
The other hard part was trying to concentrate on that lab while knowing I still had to work on my unknowns.
Not only was it a great chance to isolate two bacteria and grow them, it was also a great lesson for time management.
The unknowns were the most challenging part for me simply for the fact that my time management skills were tested. Leaving me with no time left for confirmation tests

APPENDIX H: PRE-LAB QUIZZES FALL 2016

Quiz 1

1. If you arrive to lab after quizzes have been completed you will still be allowed to take the quiz for that day.
   a. True
   b. False

2. Which of the following PPE is NOT required when working in MCB3020 labs?
   a. Lab coat
   b. Gloves
   c. Face shield
   d. Goggles

3. At the beginning of lab ________ is used to clean the bench top.
   a. Bleach wipes
   b. Lysol
   c. Amphyll
   d. 70% EtOH

4. Which of the following tubes is an example of an agar slant preparation?
   a. Tube A
   b. Tube B

B A

5. What is **primarily** used for sterilizing loops in MCB3020?
   a. Microincinerator
   b. Bunsen burner
   c. Gas sterilization
   d. Ethanol

Quiz 2

1. In the event of a spill you should:
   a. Clean it up yourself as quickly as possible
   b. Let the people around you know
   c. Let a TA know
   d. B and C

2. Petri dishes should be:
   a. stored upside down with the media upwards
   b. labeled on the lid
   c. stored in cold temperatures
   d. inoculated without sterilizing your loop

3. Before uncapping tubes in a two tube transfer you should sterilize and cool your loop.
   a. True
   b. False

4. Which of the following can be identified about a sample using a simple stain?
   a. Morphology
   b. Size
   c. Arrangement
   d. All of the above

5. Calculate the total magnification when viewing a sample through the 40X objective (assume oculars are 10X).
   a. 4,000X
   b. 400X
   c. 40,000X
   d. 4X

Quiz 3

1. Negative stains use ______ dyes which are ________ by the charge of the bacterial cell.
   a. Cationic, attracted
   b. Anionic, attracted
   c. Cationic, repelled
   d. Anionic, repelled

2. What extra step is required when preparing a smear from a solid culture?
   a. Add ethanol to the slide
   b. Add a loopful of DI water to the slide
   c. Heat fix twice
   d. Resuspend the sample

3. The resolution of the microscopes used in MCB3020 is:
   a. 2 µm
   b. 2 mm
   c. 0.2 µm
   d. 2 cm

4. The Gram stain is one of the most widely used ________ stains.
   a. Differential
   b. Structural
   c. Simple
   d. Negative

5. What is the primary (first) dye used during the Gram stain?
   a. Safranin
   b. Methylene blue
   c. Crystal violet
   d. Nigrosin

Quiz 4

1. The Gram stain differentiates bacteria based on the ________ content in the cell wall.
   a. Cholesterol
   b. Mycolic acid
   c. Lipid A
   d. Peptidoglycan

2. What color would you expect Gram negative cells to be?
   a. Purple
   b. Pink
   c. Blue
   d. Green

3. The decolorizer used in the Gram stain is:
   a. 95% ethanol
   b. Water
   c. Acid alcohol
   d. There is no decolorizer used in the Gram stain

4. Steam is used in both the acid-fast and endospore stains.
   a. True
   b. False

5. What color would you expect vegetative cells to be in the endospore stain?
   a. Green
   b. Pink
   c. Purple
   d. Brown

Quiz 5

1. When performing the endospore stain, the presence of free spores is a positive result.
   a. True
   b. False

2. Which of the following genera is an endospore producer?
   a. Staphylococcus
   b. Mycobacterium
   c. Nocardia
   d. Clostridium

3. The presence of _________ in the cell wall is used to differentiate cells in the **acid-fast** stain.
   a. Mycolic acid
   b. Peptidoglycan
   c. Spores
   d. The acid-fast stain is not a differential stain.

4. A pure culture contains ________ .
   a. An assortment of bacterial species
   b. A single bacterial genus
   c. A single bacterial species
   d. No bacterial growth at all

5. Which of the following pure culture techniques will you be using today?
   a. Pour plate
   b. Serial dilution
   c. Three zone streak
   d. A and C

Quiz 6

1. When identifying colonies isolated using the pour plate method, you may see __________.
   a. Surface colonies
   b. Bottom colonies
   c. Embedded colonies
   d. All of the above

2. The pour plate technique is a quantitative method for isolating colonies.
   a. True
   b. False

3. In which zone should isolation be seen using the three zone streak plate method?
   a. Zone 1
   b. Zone 2
   c. Zone 3A
   d. Zone 3B

4. Brain Heart Infusion (BHI) agar is an example of a _________ medium.
   a. Defined
   b. Selective
   c. Complex
   d. Combination

5. Which of the following media is ONLY selective?
   a. Phenyl ethyl alcohol (PEA) agar
   b. MacConkey agar
   c. Blood agar
   d. Eosin methylene blue (EMB) agar

Quiz 7

1. EMB is **selective** for:
   a. Lactose fermenters
   b. Gram negative bacteria
   c. Gram positive bacteria
   d. Non-lactose fermenters

2. The indicator in MacConkey agar is:
   a. Phenol red
   b. Litmus
   c. Neutral red
   d. Eosin Y

3. Following incubation colonies on a blood agar plate have clear halo around them. This is:
   a. Beta hemolysis
   b. Alpha hemolysis
   c. Lambda hemolysis
   d. Gamma hemolysis

4. What organism will be used for today's experiment?
   a. Mycobacterium leprae
   b. Bacillus anthracis
   c. Proteus vulgaris
   d. Escherichia coli

5. In today's lab we will be using the pour plate method to perform a viable plate count.
   a. True
   b. False

Quiz 8

1. If 0.1 mL is transferred from a culture into a 9.9 mL dilution blank, what is the dilution factor?
   a. 1:1
   b. 1:10
   c. 1:100
   d. 1:1000

2. 1 mL is plated from a tube at a **1:10,000** dilution. What is the final dilution on the plate?
   a. 1:1
   b. 1:100
   c. 1:10,000
   d. 1:100,000

3. The countable range for the viable plate count method is between ____ and ____ colonies.
   a. 3, 300
   b. 10, 30
   c. 30, 200
   d. 30, 300

4. Which of the following is **NOT** tested for with litmus milk media?
   a. Fermentation of lactose
   b. Litmus reduction
   c. Sulfur reduction
   d. Protein metabolism

5. Biochemical tests can aid in the differentiation and identification of bacteria based on _______:
   a. Exoenzymes
   b. Sugar fermentation
   c. Other metabolic processes
   d. All of the above

Quiz 9

1. In exercise 8, sugar fermentation tubes supplemented with which of the following sugars were used?
    a. Glucose
    b. Lactose
    c. Mannitol
    d. All of the above

2. Milk agar, starch agar, and lipase agar all test for the presence of __________.
    a. endoenzymes
    b. exoenzymes
    c. endogenous enzymes
    d. Homogenous enzymes

3. Some bacteria are capable of breaking down the protein ________ in litmus milk media.
    a. starch
    b. litmus
    c. casein
    d. albumin

4. Before reading starch agar, ethanol must be added to the plate.
    a. True
    b. False

5. A tube of KIA is inoculated and read 18 hours later. The tube shows a completely red slant and a yellow butt. Which sugar(s) was fermented?
    a. Glucose
    b. Mannitol
    c. Lactose
    d. A and B

Quiz 10

1. After the addition of iodine to starch agar, a clearing around the bacterial colony is a positive result for the enzyme:
   a. Glucoase
   b. Amylase
   c. Starchase
   d. It is not a positive result

2. Glucose is included in KIA at what percent?
   a. 0.1%
   b. 1%
   c. 1.1%
   d. 10%

3. The indicator used in the broth sugar fermentation tubes is:
   a. Crystal violet
   b. Phenol red
   c. Neutral red
   d. Bromothymol blue

4. Urea broth detects the enzyme **urease**.
   a. True
   b. False

5. Before reading the results of tryptone broth _______ must be added.
   a. VP I and II
   b. Methyl red
   c. Kovac's reagent
   d. Iodine

Quiz 11

1. The enzyme catalase breaks hydrogen peroxide down into:
   a. Water
   b. Oxygen
   c. CO_2
   d. A and B

2. The Voges-Proskauer test is used to identify _________.
   a. Protein metabolism
   b. Tryptophanase
   c. 2,3-butanediol fermenters
   d. Urease

3. When running the **IMViC** battery of tests you would use the following media: Tryptone broth, Motility, Voges-Proskauer and Simmons citrate.
   a. True
   b. False

4. SIM medium tests for which of the following?
   a. Indole
   b. Motility
   c. Sulfur reduction
   d. All of the above

5. ________ medium must be placed in an ice bath prior to reading the result.
   a. Gelatinase
   b. Nitrate
   c. Methyl red
   d. Phenylalanine

Quiz 12

1. A positive result for the urease test is a color change to _________ due to a(n) __________ in pH.
   a. Cerise, increase
   b. Yellow, decrease
   c. Cerise, decrease
   d. Yellow, increase

2. Following incubation, a nitrate tube turns red after the addition of nitrate I and II. This is a positive result for nitrate reductase.
   a. True
   b. False

3. The indicator in citrate medium is:
   a. Bromothymol blue
   b. Malachite green
   c. Crystal violet
   d. Phenol red

4. In today's experiment you will be looking for which of the following organisms?
   a. E. coli
   b. Streptococcus
   c. Staphylococcus
   d. B and C

5. Samples will be collected from which of the following locations in today's lab?
   a. Fomite
   b. Nose
   c. Throat
   d. All of the above

Quiz 13

1. Which of the following media were used last lab to isolate the pyogenic cocci?
   a. Blood agar
   b. Potato dextrose agar
   c. Staph 110
   d. A and C

2. MSA is useful in the isolation of *Streptococcus*.
   a. True
   b. False

3. Today you are trying to identify beta hemolytic *Streptococcus*. Beta hemolysis __________.
   a. is complete lysis of red blood cells
   b. is partial lysis of red blood cells
   c. does not result in any lysis of red blood cells
   d. blood has nothing to do with hemolysis

4. In the Minimum Inhibitory Concentration (MIC) experiment which of the following media was used?
   a. Tryptone broth
   b. MH broth
   c. SIM
   d. Nutrient agar

5. Which of the following antimicrobial agents was used for the MIC experiment?
   a. Ampicillin
   b. Formaldehyde
   c. Phenol
   d. All of the above

Quiz 14

1. You will receive reference strains of *Streptococcus pyogenes* and *Staphylococcus aureus* as positive controls for the Gram positive pyogenic cocci study.
   a. True
   b. False

2. SM110 media contain __________ making them useful in selecting for *Staphylococcus.*
   a. Neutral red
   b. Bile salts
   c. 7.5% NaCl
   d. None of the above

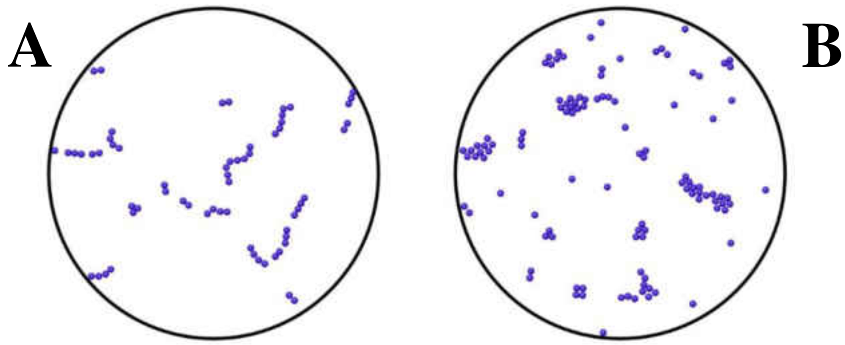
3. Which of the following media will test if an organism is able to promote the clotting of plasma?
   a. DNase
   b. Coagulase
   c. BHI
   d. Nitrate

4. Which of the following media used in the Gram negative intestinal pathogens studies is/are differential for lactose fermentation?
   a. Eosin Methylene Blue agar
   b. Bismuth Sulfite agar
   c. Salmonella-Shigella agar
   d. A and C

5. Salmonella is considered a primary pathogen since it will cause disease in anyone.
   a. True
   b. False

Quiz 15

1. Which of the following images is most likely *Staphylococcus*?
   a. Image A
   b. Image B



2. The indicator used in DNase media is:
   a. Methyl green
   b. Neutral red
   c. Bromothymol blue
   d. Malachite green

3. *Streptococcus* is typically positive for catalase.
   a. True
   b. False

4. Which of the following media used in the Gram negative intestinal pathogens studies selects for Gram negative bacteria?
   a. Eosin Methylene Blue agar
   b. Hektoen Enteric agar
   c. Salmonella-Shigella agar
   d. All of the above

5. Members of Enterobacteriaceae are all positive for which of the following?
   a. Glucose fermentation
   b. Lactose fermentation
   c. Motility
   d. All of the above

Quiz 16

1. Which of the following media would be MOST useful in differentiating *Proteus vulgaris* and *Salmonella*?
    a. KIA
    b. Urea
    c. SIM
    d. Phenol red lactose

2. What result would you expect *Salmonella* to have in a KIA tube?
    a. Glucose fermentation
    b. Glucose and lactose fermentation
    c. Sulfur reduction
    d. All of the above

3. *Salmonella* and *Proteus* will have the same result in SIM media.
    a. True
    b. False

4. You will be testing bacterial samples in which of the following conditions in today's lab?
    a. Temperature
    b. pH
    c. UV-radiation
    d. All of the above

5. _________ is the indicator present in fluid thioglycollate broth that detects the presence of oxygen.
    a. Tetrazolium chloride
    b. Phenol red
    c. Resazurin
    d. None of the above

Quiz 17

1. An organism that is a (n) _________ will most likely grow **only** at the top of the thioglycollate broth tube.
   a. Obligate aerobe
   b. Microaerophile
   c. Strict anaerobe
   d. Facultative anaerobe

2. Which of the following media was used for inoculations in the Mycology study?
   a. MSA
   b. PDA
   c. EMB
   d. NA

3. Fungal hyphae can be classified as:
   a. Septate
   b. Aseptate
   c. Broken
   d. A and B

4. In Exercise 15 (Bacterial Examination of Water) we are testing for the presence of ________ in water samples.
   a. Nitrates
   b. Sulfites
   c. Fungi
   d. Coliforms

5. Day 1 of the Bacterial Examination of Water study is known as the ___________ test.
   a. Assumptive
   b. Presumptive
   c. Confirmed
   d. Completed

Quiz 18

1. Which of the following organisms is the **primary indicator** of fecal contamination in water samples?
   a. Enterobacter aerogenes
   b. Escherichia coli
   c. Staphylococcus aureus
   d. Alcaligenes faecalis

2. What media is used in the Most Probable Number (MPN) method when testing water samples?
   a. Single strength lactose broth
   b. Double strength lactose broth
   c. A and B
   d. None of the above

3. A positive tube in the MPN test will have a bubble present in the Durham tube.
   a. True
   b. False

4. What medium is used for inoculations in Exercise 13 (Control of Microorganisms)?
   a. Mueller-HInton
   b. Brain Heart Infusion
   c. Nutrient Agar
   d. Potato Dextrose Agar

5. Which of the following antimicrobial agents is used on inanimate objects and surfaces?
   a. Antibiotic
   b. Antiseptic
   c. Disinfectant
   d. All of the above

Quiz 19

1. In the membrane filter technique, the filter used has what size pores?
   a. 4.5 mm
   b. 0.37 µm
   c. 0.45 µm
   d. 4.5 µm

2. What media is used in the Most Probable Number (MPN) method when testing water samples?
   a. Single strength lactose broth
   b. Double strength lactose broth
   c. A and B
   d. None of the above

3. In the Kirby-Bauer assay, as antibiotic diffuses into the medium a concentration gradient is created with higher concentrations of antibiotic farther away from the antibiotic disk.
   a. True
   b. False

4. What inoculation method was used to prepare the plates for the disk diffusion assay?
   a. Pour plate
   b. Solid lawn
   c. 3-Zone streak
   d. Spread plate

5. Which of the following would be considered an antiseptic?
   a. Phenol
   b. Iodine
   c. Lysol
   d. Water

APPENDIX I: PRE-LAB QUIZZES SPRING 2017

Quiz 1

1. If you arrive to lab after quizzes have been completed you will still be allowed to take the quiz for that day.
   a. True
   b. False

2. Which of the following PPE is NOT required when working in MCB3020 labs?
   a. Lab coat
   b. Gloves
   c. Face shield
   d. Goggles

3. At the beginning of lab ________ is used to clean the bench top.
   a. Bleach wipes
   b. Lysol
   c. Amphyll
   d. 70% EtOH

4. Which of the following tubes is an example of an agar slant preparation?
   a. Tube A
   b. Tube B

A B

5. What is **<u>primarily</u>** used for sterilizing loops in MCB3020?
   a. Microincinerator
   b. Bunsen burner
   c. Gas sterilization
   d. Ethanol

Quiz 2

1. In the event of a spill you should:
   a. Clean it up yourself as quickly as possible
   b. Let the people around you know
   c. Let a TA know
   d. B and C

2. Petri dishes should be:
   a. stored upside down with the media upwards
   b. labeled on the lid
   c. stored in cold temperatures
   d. inoculated without sterilizing your loop

3. Before uncapping tubes in a two tube transfer you should sterilize and cool your loop.
   a. True
   b. False

4. Which of the following can be identified about a sample using a simple stain?
   a. Morphology
   b. Size
   c. Arrangement
   d. All of the above

5. Calculate the total magnification when viewing a sample through the 40X objective (assume oculars are 10X).
   a. 4,000X
   b. 400X
   c. 40,000X
   d. 4X

Quiz 3

1. Negative stains use ______ dyes which are ________ by the charge of the bacterial cell.
   a. Cationic, attracted
   b. Anionic, attracted
   c. Cationic, repelled
   d. Anionic, repelled

2. What extra step is required when preparing a smear from a solid culture?
   a. Add ethanol to the slide
   b. Add a loopful of DI water to the slide
   c. Heat fix twice
   d. Resuspend the sample

3. The resolution of the microscopes used in MCB3020 is:
   a. 2 µm
   b. 2 mm
   c. 0.2 µm
   d. 2 cm

4. The Gram stain is one of the most widely used ________ stains.
   a. Differential
   b. Structural
   c. Simple
   d. Negative

5. What is the primary (first) dye used during the Gram stain?
   a. Safranin
   b. Methylene blue
   c. Crystal violet
   d. Nigrosin

Quiz 4

1. The Gram stain differentiates bacteria based on the ________ content in the cell wall.
   a. Cholesterol
   b. Mycolic acid
   c. Lipid A
   d. Peptidoglycan

2. What color would you expect Gram negative cells to be?
   a. Purple
   b. Pink
   c. Blue
   d. Green

3. The decolorizer used in the Gram stain is:
   a. 95% ethanol
   b. Water
   c. Acid alcohol
   d. There is no decolorizer used in the Gram stain

4. Steam is used in both the acid-fast and endospore stains.
   a. True
   b. False

5. What color would you expect vegetative cells to be in the endospore stain?
   a. Green
   b. Pink
   c. Purple
   d. Brown

Quiz 5

1. When performing the endospore stain, the presence of free spores is a positive result.
   a. True
   b. False

2. Which of the following genera is an endospore producer?
   a. Staphylococcus
   b. Mycobacterium
   c. Nocardia
   d. Clostridium

3. The presence of _________ in the cell wall is used to differentiate cells in the **acid-fast** stain.
   a. Mycolic acid
   b. Peptidoglycan
   c. Spores
   d. The acid-fast stain is not a differential stain.

4. A pure culture contains ________ .
   a. An assortment of bacterial species
   b. A single bacterial genus
   c. A single bacterial species
   d. No bacterial growth at all

5. Which of the following techniques could you use to get a pure culture?
   a. Pour plate
   b. Lawn inoculation
   c. Three zone streak
   d. A and C

Quiz 6

1. When identifying colonies isolated using the pour plate method, you may see __________.
    a. Surface colonies
    b. Bottom colonies
    c. Embedded colonies
    d. All of the above

2. The pour plate and spread plate techniques are methods that can be used for isolating colonies.
    a. True
    b. False

3. In which zone should isolation be seen using the three zone streak plate method?
    a. Zone 1
    b. Zone 2
    c. Zone 3A
    d. Zone 3B

4. Brain Heart Infusion (BHI) agar is an example of a _________ medium.
    a. Defined
    b. Selective
    c. Complex
    d. Combination

5. Which of the following media is ONLY selective?
    a. Phenyl ethyl alcohol (PEA) agar
    b. MacConkey agar
    c. Blood agar
    d. Eosin methylene blue (EMB) agar

Quiz 7

1. EMB is selective for:
   a. Lactose fermenters
   b. Gram negative bacteria
   c. Gram positive bacteria
   d. Non-lactose fermenters

2. The indicator in MacConkey agar is:
   a. Phenol red
   b. Litmus
   c. Neutral red
   d. Eosin Y

3. Following incubation colonies on a blood agar plate have a complete clearing around them. This is:
   a. Beta hemolysis
   b. Alpha hemolysis
   c. Lambda hemolysis
   d. Gamma hemolysis

4. What organism will be used for today's experiment?
   a. *Mycobacterium leprae*
   b. *Bacillus anthracis*
   c. *Proteus vulgaris*
   d. *Escherichia coli*

5. In today's lab we will be performing the viable plate count procedure.
   a. True
   b. False

Quiz 8

1. If 0.1 mL is transferred from a culture into a 9.9 mL dilution blank, what is the dilution factor?
   a. 1:1
   b. 1:10
   c. 1:100
   d. 1:1000

2. 1 mL is plated from a tube at a 1:10,000 dilution. What is the final dilution on the plate?
   a. 1:1
   b. 1:100
   c. 1:10,000
   d. 1:100,000

3. The countable range for the viable plate count method is between ____ and ____ colonies.
   a. 3, 300
   b. 10, 30
   c. 30, 200
   d. 30, 300

4. Which of the following is NOT tested for with litmus milk media?
   a. Fermentation of lactose
   b. Litmus reduction
   c. Sulfur reduction
   d. Protein metabolism

5. Biochemical tests can aid in the differentiation and identification of bacteria based on _______:
   a. Exoenzymes
   b. Sugar fermentation
   c. Other metabolic processes
   d. All of the above

Quiz 9

1. In exercise 8, sugar fermentation tubes supplemented with which of the following sugars were used?
   a. Glucose
   b. Lactose
   c. Mannitol
   d. All of the above

2. Milk agar, starch agar, and lipase agar all test for the presence of __________.
   a. endoenzymes
   b. exoenzymes
   c. endogenous enzymes
   d. Homogenous enzymes

3. Some bacteria are capable of breaking down the protein ________ in litmus milk media.
   a. starch
   b. litmus
   c. casein
   d. albumin

4. Before reading starch agar, ethanol must be added to the plate.
   a. True
   b. False

5. A tube of KIA is inoculated and read 18 hours later. The tube shows a completely red slant and a yellow butt. Which sugar(s) was fermented?
   a. Glucose
   b. Mannitol
   c. Lactose
   d. A and B

Quiz 10

1. After the addition of iodine to starch agar, a clearing around the bacterial colony is a positive result for the enzyme:
   a. Glucoase
   b. Amylase
   c. Starchase
   d. It is not a positive result

2. Glucose is included in KIA at what percent?
   a. 0.1%
   b. 1%
   c. 1.1%
   d. 10%

3. The indicator used in the broth sugar fermentation tubes is:
   a. Crystal violet
   b. Phenol red
   c. Neutral red
   d. Bromothymol blue

4. Urea broth detects the enzyme urease.
   a. True
   b. False

5. Before reading the results of tryptone broth _______ must be added.
   a. VP I and II
   b. Methyl red
   c. Kovac's reagent
   d. Iodine

Quiz 11

1. The enzyme catalase breaks hydrogen peroxide down into:
   a. Water
   b. Oxygen
   c. CO_2
   d. A and B

2. The Voges-Proskauer test is used to identify _________.
   a. Protein metabolism
   b. Tryptophanase
   c. 2,3-butanediol fermenters
   d. Urease

3. When running the IMViC battery of tests you would use the following media: Tryptone broth, Motility, Voges-Proskauer and Simmons citrate.
   a. True
   b. False

4. SIM medium tests for which of the following?
   a. Indole
   b. Motility
   c. Sulfur reduction
   d. All of the above

5. ________ medium must be placed in an ice bath prior to reading the result.
   a. Gelatinase
   b. Nitrate
   c. Methyl red
   d. Phenylalanine

Quiz 12

1. A positive result for the urease test is a color change to _________ due to a(n) __________ in pH.
   a. Cerise, increase
   b. Yellow, decrease
   c. Cerise, decrease
   d. Yellow, increase

2. Following incubation, a nitrate tube turns red after the addition of nitrate I and II. This is a positive result for nitrate reductase.
   a. True
   b. False

3. The indicator in citrate medium is:
   a. Bromothymol blue
   b. Malachite green
   c. Crystal violet
   d. Phenol red

4. In today's experiment you will be looking for which of the following organisms?
   a. *E. coli*
   b. *Streptococcus*
   c. *Staphylococcus*
   d. B and C

5. Which of the following Gram positive organisms is a common cause of pharyngitis?
   a. *Staphylococcus epidermidis*
   b. *Escherichia coli*
   c. *Streptococcus pyogenes*
   d. *Moraxella catarrhalis*

Quiz 13

1. Which of the following media/tests could be used to differentiate *Staphylococcus* and *Streptococcus*?
   a. Nitrate
   b. EMB
   c. Catalase
   d. A and C

2. MSA is useful in the isolation of Streptococcus.
   a. True
   b. False

3. Today you are trying to identify beta hemolytic Streptococcus. Beta hemolysis __________.
   a. is complete lysis of red blood cells
   b. is partial lysis of red blood cells
   c. does not result in any lysis of red blood cells
   d. blood has nothing to do with hemolysis

4. In the Minimum Inhibitory Concentration (MIC) experiment which of the following media was used?
   a. Tryptone broth
   b. MH broth
   c. SIM
   d. Nutrient agar

5. Which of the following antimicrobial agents was used for the MIC experiment?
   a. Ampicillin
   b. Formaldehyde
   c. Phenol
   d. All of the above

Quiz 14

1. You will receive reference strains of *Streptococcus pyogenes* and *Staphylococcus aureus* as positive controls for the Gram positive pyogenic cocci study.
   a. True
   b. False

2. MSA contains __________ making it useful in selecting for Staphylococcus.
   a. Neutral red
   b. Bile salts
   c. 7.5% NaCl
   d. None of the above

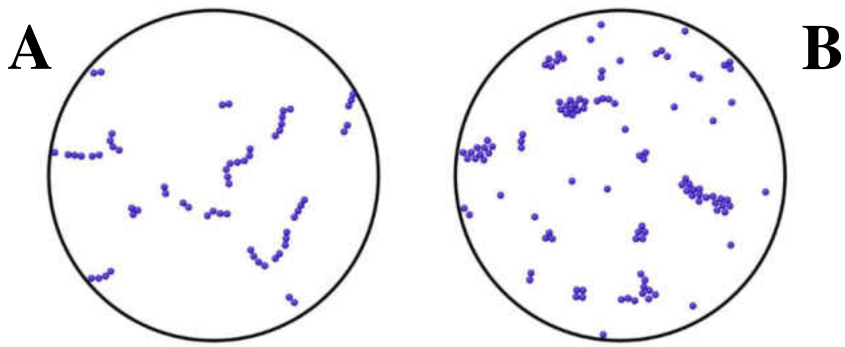
3. Which of the following media will test if an organism is able to promote the clotting of plasma?
   a. DNase
   b. Coagulase
   c. BHI
   d. Nitrate

4. Which of the following media used in the Gram negative intestinal pathogens studies is/are differential for lactose fermentation?
   a. Eosin Methylene Blue agar
   b. Bismuth Sulfite agar
   c. Salmonella-Shigella agar
   d. A and C

5. Salmonella is considered a primary pathogen since it will cause disease in anyone.
   a. True
   b. False

Quiz 15

1. Which of the following images is most likely Staphylococcus?
   a. Image A
   b. Image B



2. The indicator used in DNase media is:
   a. Methyl green
   b. Neutral red
   c. Bromothymol blue
   d. Malachite green

3. Streptococcus is typically positive for catalase.
   a. True
   b. False

4. Which of the following media used in the Gram negative intestinal pathogens studies selects for Gram negative bacteria?
   a. Eosin Methylene Blue agar
   b. Hektoen Enteric agar
   c. Salmonella-Shigella agar
   d. All of the above

5. Members of Enterobacteriaceae are all positive for which of the following?
   a. Glucose fermentation
   b. Lactose fermentation
   c. Motility
   d. All of the above

Quiz 16

1. Which of the following media would be MOST useful in differentiating Proteus vulgaris and Salmonella?
   a. KIA
   b. Urea
   c. SIM
   d. Phenol red lactose

2. What result would you expect Salmonella to have in a KIA tube?
   a. Glucose fermentation
   b. Glucose and lactose fermentation
   c. Sulfur reduction
   d. A and C

3. Salmonella and Proteus will have the same result in SIM media.
   a. True
   b. False

4. You will be testing bacterial samples in which of the following conditions in today's lab?
   a. Temperature
   b. pH
   c. UV-radiation
   d. All of the above

5. _________ is the indicator present in fluid thioglycollate broth that detects the presence of oxygen.
   a. Tetrazolium chloride
   b. Phenol red
   c. Resazurin
   d. None of the above

Quiz 17

1. An organism that is a (n) _________ will most likely grow only at the top of the thioglycollate broth tube.
   a. Obligate aerobe
   b. Microaerophile
   c. Strict anaerobe
   d. Facultative anaerobe

2. Which of the following media was used for inoculations in the Mycology study?
   a. MSA
   b. PDA
   c. EMB
   d. NA

3. Fungal hyphae can be classified as:
   a. Septate
   b. Aseptate
   c. Broken
   d. A and B

4. In Exercise 15 (Bacterial Examination of Water) we are testing for the presence of ________ in water samples.
   a. Nitrates
   b. Sulfites
   c. Fungi
   d. Coliforms

5. Day 1 of the Bacterial Examination of Water study is known as the ___________ test.
   a. Assumptive
   b. Presumptive
   c. Confirmed
   d. Completed

Quiz 18

1. Which of the following organisms is the primary indicator of fecal contamination in water samples?
   a. *Enterobacter aerogenes*
   b. *Escherichia coli*
   c. *Staphylococcus aureus*
   d. *Alcaligenes faecalis*

2. What media is used in the Most Probable Number (MPN) method when testing water samples?
   a. Single strength lactose broth
   b. Double strength lactose broth
   c. A and B
   d. None of the above

3. A positive tube in the MPN test will have a bubble present in the Durham tube.
   a. True
   b. False

4. What medium is used for inoculations in Exercise 13 (Control of Microorganisms)?
   a. Mueller-Hinton
   b. Brain Heart Infusion
   c. Nutrient Agar
   d. Potato Dextrose Agar

5. Which of the following antimicrobial agents is used on inanimate objects and surfaces?
   a. Antibiotic
   b. Antiseptic
   c. Disinfectant
   d. All of the above

Quiz 19

1. In the membrane filter technique, the filter used has what size pores?
   a. 4.5 mm
   b. 0.37 µm
   c. 0.45 µm
   d. 4.5 µm

2. What media were used to identify E. coli in the water study?
   a. EMB
   b. Hektoen Enteric
   c. Endo agar
   d. A and C

3. In the Kirby-Bauer assay, as antibiotic diffuses into the medium a concentration gradient is created with higher concentrations of antibiotic farther away from the antibiotic disk.
   a. True
   b. False

4. What inoculation method was used to prepare the plates for the disk diffusion assay?
   a. Pour plate
   b. Solid lawn
   c. 3-Zone streak
   d. Spread plate

5. Which of the following would be considered an antiseptic?
   a. Phenol
   b. Iodine
   c. Lysol
   d. Water

Quiz 20 and Quiz 21

1. Practicing proper aseptic technique is important for preventing contamination of:
   a. your sample
   b. yourself
   c. the environment
   d. All of the above

2. The simple stain method:
   a. Utilizes a cationic dye
   b. Uses two dyes to stain all cells present
   c. Is a differential stain
   d. A and B

3. The Gram stain and the acid-fast stain are examples of ________ stains. The acid-fast stain compares differences in _______ content in the cell wall.
   a. Simple; peptidoglycan
   b. Differential; mycolic acid
   c. Differential; peptidoglycan
   d. Negative; LPS

4. Which of the following techniques could be used to obtain isolated colonies of a mixed culture?
   a. Pour plate
   b. Solid lawn
   c. 3-Zone streak
   d. A and C

5. Which of the following tests would be most helpful in differentiating Staphylococcus and Streptococcus?
   a. Catalase
   b. KIA
   c. A and B
   d. None of the above

6. This medium used in the Gram negative study is selective for Gram negatives and is differential for H2S production ONLY.
   a. Bismuth Sulfite
   b. Eosin Methylene Blue
   c. Phenylethyl alcohol
   d. Hektoen Enteric

7. A serial dilution was performed using a bacterial culture. 0.1 mL is plated from a tube with a dilution of 10^{-5}. What is the final dilution after plating?
   a. 104
   b. 10-^{5}
   c. 10^{-6}
   d. 10^{5}

8. An unknown sample is used to inoculate a coagulase test and MSA. After incubation, the coagulase tube is solid and the colonies growing on MSA are yellow. This sample was most likely:
   a. *Staphylococcus epidermidis*
   b. *Escherichia coli*
   c. *Staphylococcus aureus*
   d. *Streptococcus pyogenes*

9. Which of the following media is often used then testing for water quality?
   a. mEndo agar
   b. Nutrient agar
   c. MacConkey agar
   d. Phenylethyl alcohol agar

10. Sporangiospores are the _______ spores of _________.
   a. Asexual, ascomycetes
   b. Sexual, zygomycetes
   c. Asexual, zygomycetes
   d. Sexual, ascomycetes

APPENDIX J: PROPENSITY SCORE ANALYSIS RESULTS FOR FALL LAB PRACTICAL EXAM SCORES

Table 67: Fall Lab Practical Exam Propensity Score Model Fit Statistics

Criterion	Intercept Only	Intercept and Covariates
AIC	1524.423	1560.605
SC	1529.425	1755.689
-2 Log L	1522.423	1482.605

Table 68: Fall Lab Practical Exam R^2 Values

R-Square	0.0356	Max-rescaled R-Square	0.0475

Table 69: Fall Lab Practical Exam Propensity Score Testing Global Null Hypothesis

Test	Chi-Square	DF	Pr > ChiSq
Likelihood Ratio	39.8174	38	0.3892
Score	35.1829	38	0.6004
Wald	23.7324	38	0.9659

Table 70: Fall Lab Practical Exam Propensity Score Type 3 Analysis of Effects

Effect	DF	Wald Chi-Square	Pr > ChiSq
AcadLvl	4	5.2791	0.2598
Hon_Stand	1	0.3352	0.5626
Gender	1	1.6225	0.2027
Race	7	4.2445	0.7512
Age	1	3.8599	0.0495
Degree	24	8.1319	0.9990

Table 71: Fall Lab Practical Exam Propensity Score Analysis of Maximum Likelihood Estimates

Parameter		Term	DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq	Standardized Estimate	Exp(Est)
Intercept		1	1	1.1299	0.5043	5.0195	0.0251		3.095
AcadLvl	2	1	1	-0.00219	0.1845	0.0001	0.9905	-0.00059	0.998
AcadLvl	3	1	1	0.2772	0.2131	1.6927	0.1933	0.0751	1.319
AcadLvl	4	1	1	-0.4504	0.5822	0.5983	0.4392	-0.0288	0.637
AcadLvl	5	1	1	-0.2636	0.4841	0.2966	0.5860	-0.0225	0.768

Analysis of Maximum Likelihood Estimates (cont'd)

Parameter		Term	DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq	Standardized Estimate	Exp(Est)
Hon_Stand		1	1	0.1488	0.2569	0.3352	0.5626	0.0203	1.160
Gender		1	1	-0.1660	0.1303	1.6225	0.2027	-0.0450	0.847
Race	1	1	1	-0.1479	0.1825	0.6562	0.4179	-0.0303	0.863
Race	2	1	1	-0.0352	0.2202	0.0256	0.8728	-0.00579	0.965
Race	3	1	1	-0.0283	0.1591	0.0315	0.8591	-0.00673	0.972
Race	4	1	1	0.2076	0.2994	0.4809	0.4880	0.0250	1.231
Race	5	1	1	-0.3962	0.9290	0.1819	0.6697	-0.0147	0.673
Race	6	1	1	0.2924	0.3762	0.6042	0.4370	0.0275	1.340
Race	7	1	1	1.5188	1.1052	1.8884	0.1694	0.0617	4.567
Age		1	1	-0.0456	0.0232	3.8599	0.0495	-0.0820	0.955
Degree	1	1	1	14.2352	1214.7	0.0001	0.9906	0.2367	1521434
Degree	2	1	1	0.0508	1.4274	0.0013	0.9716	0.00119	1.052
Degree	3	1	1	0.0529	0.1962	0.0727	0.7875	0.0100	1.054
Degree	5	1	1	0.1800	0.3883	0.2148	0.6430	0.0159	1.197
Degree	6	1	1	1.0648	0.6056	3.0916	0.0787	0.0681	2.900
Degree	7	1	1	-14.3218	1214.7	0.0001	0.9906	-0.2382	0.000
Degree	8	1	1	14.1148	1214.7	0.0001	0.9907	0.2347	1348930
Degree	9	1	1	-0.3772	0.7745	0.2372	0.6262	-0.0166	0.686
Degree	10	1	0	0	.	.	.	.	.
Degree	11	1	1	0.1087	0.1770	0.3772	0.5391	0.0241	1.115
Degree	12	1	1	-14.2604	857.9	0.0003	0.9867	-0.3352	0.000
Degree	13	1	1	-0.2653	0.5330	0.2477	0.6187	-0.0170	0.767
Degree	14	1	1	-0.8140	1.2441	0.4281	0.5129	-0.0234	0.443
Degree	15	1	1	0.7686	1.2343	0.3878	0.5335	0.0221	2.157
Degree	16	1	1	0.6549	0.7787	0.7073	0.4003	0.0307	1.925
Degree	17	1	1	-14.1531	1214.7	0.0001	0.9907	-0.2354	0.000
Degree	18	1	1	-0.5798	1.2449	0.2169	0.6414	-0.0167	0.560
Degree	19	1	1	14.9019	1214.7	0.0002	0.9902	0.2478	2963486
Degree	20	1	1	-14.4939	1214.7	0.0001	0.9905	-0.2410	0.000
Degree	21	1	1	-0.6400	0.6075	1.1100	0.2921	-0.0367	0.527
Degree	22	1	1	-0.4625	0.6057	0.5831	0.4451	-0.0265	0.630
Degree	23	1	1	-0.5291	1.2476	0.1799	0.6715	-0.0152	0.589

Analysis of Maximum Likelihood Estimates (cont'd)

Parameter		Term	DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq	Standardized Estimate	Exp(Est)
Degree	24	1	1	14.1612	1214.7	0.0001	0.9907	0.2355	1412924
Degree	25	1	1	-0.0778	1.4227	0.0030	0.9564	-0.00183	0.925
Degree	27	1	1	14.2733	1214.7	0.0001	0.9906	0.2374	1580561

Table 72: Fall Lab Practical Exam Propensity Score Odds Ratio Estimates

Effect	Term	Point Estimate	95% Wald Confidence Limits	
AcadLvl 2 vs 1	1	0.998	0.695	1.432
AcadLvl 3 vs 1	1	1.319	0.869	2.003
AcadLvl 4 vs 1	1	0.637	0.204	1.995
AcadLvl 5 vs 1	1	0.768	0.297	1.984
Hon_Stand	1	1.160	0.701	1.920
Gender	1	0.847	0.656	1.094
Race 1 vs 8	1	0.863	0.603	1.234
Race 2 vs 8	1	0.965	0.627	1.486
Race 3 vs 8	1	0.972	0.712	1.328
Race 4 vs 8	1	1.231	0.684	2.213
Race 5 vs 8	1	0.673	0.109	4.156
Race 6 vs 8	1	1.340	0.641	2.800
Race 7 vs 8	1	4.567	0.523	39.845
Age	1	0.955	0.913	1.000
Degree 1 vs 4	1	>999.999	<0.001	>999.999
Degree 2 vs 4	1	1.052	0.064	17.262
Degree 3 vs 4	1	1.054	0.718	1.549
Degree 5 vs 4	1	1.197	0.559	2.563
Degree 6 vs 4	1	2.900	0.885	9.504
Degree 7 vs 4	1	<0.001	<0.001	>999.999
Degree 8 vs 4	1	>999.999	<0.001	>999.999
Degree 9 vs 4	1	0.686	0.150	3.129
Degree 11 vs 4	1	1.115	0.788	1.577
Degree 12 vs 4	1	<0.001	<0.001	>999.999

Effect		Term	Point Estimate	95% Wald Confidence	Limits
Degree	13 vs 4	1	0.767	0.270	2.180
Degree	14 vs 4	1	0.443	0.039	5.075
Degree	15 vs 4	1	2.157	0.192	24.234
Degree	16 vs 4	1	1.925	0.418	8.856
Degree	17 vs 4	1	<0.001	<0.001	>999.999
Degree	18 vs 4	1	0.560	0.049	6.425
Degree	19 vs 4	1	>999.999	<0.001	>999.999
Degree	20 vs 4	1	<0.001	<0.001	>999.999
Degree	21 vs 4	1	0.527	0.160	1.734
Degree	22 vs 4	1	0.630	0.192	2.064
Degree	23 vs 4	1	0.589	0.051	6.795
Degree	24 vs 4	1	>999.999	<0.001	>999.999
Degree	25 vs 4	1	0.925	0.057	15.037
Degree	27 vs 4	1	>999.999	<0.001	>999.999

Table 73: Fall Lab Practical Exam Propensity Score Association of Predicted Probabilities and Observed Responses

Percent Concordant	59.1	Somers' D	0.187
Percent Discordant	40.5	Gamma	0.187
Percent Tied	0.4	Tau-a	0.093
Pairs	301644	c	0.593

Table 74: Fall Lab Practical Exam Propensity Score Partitioning for the Hosmer Lemeshow Goodness of Fit Test

		Term = 1		Term = 0	
Group	Total	Observed	Expected	Observed	Expected
1	110	38	38.92	72	71.08
2	111	55	50.19	56	60.81
3	110	51	52.57	59	57.43
4	110	49	54.64	61	55.36
5	118	58	60.58	60	57.42
6	111	61	58.11	50	52.89
7	111	63	59.93	48	51.07
8	112	63	63.08	49	48.92
9	122	72	71.54	50	50.46
10	84	57	57.44	27	26.56

Table 75: Fall Lab Practical Exam Propensity Score Hosmer and Lemeshow Goodness of Fit Test

Chi-Square	DF	Pr > ChiSq
3.0090	8	0.9338

Table 76: Fall Lab Practical Exam Propensity Score Classification Table

	Correct		Incorrect		Percentages				
Prob Level	Event	Non-Event	Event	Non-Event	Correct	Sensi-tivity	Speci-ficity	False POS	False NEG
0.000	567	0	532	0	51.6	100.0	0.0	48.4	.
0.020	567	5	527	0	52.0	100.0	0.9	48.2	0.0
0.040	567	5	527	0	52.0	100.0	0.9	48.2	0.0
0.060	566	5	527	1	52.0	99.8	0.9	48.2	16.7
0.080	566	5	527	1	52.0	99.8	0.9	48.2	16.7
0.100	564	5	527	3	51.8	99.5	0.9	48.3	37.5
0.120	564	5	527	3	51.8	99.5	0.9	48.3	37.5
0.140	563	5	527	4	51.7	99.3	0.9	48.3	44.4
0.160	562	5	527	5	51.6	99.1	0.9	48.4	50.0
0.180	562	5	527	5	51.6	99.1	0.9	48.4	50.0
0.200	562	5	527	5	51.6	99.1	0.9	48.4	50.0
0.220	560	5	527	7	51.4	98.8	0.9	48.5	58.3
0.240	560	6	526	7	51.5	98.8	1.1	48.4	53.8
0.260	559	8	524	8	51.6	98.6	1.5	48.4	50.0

	Correct		Incorrect			Percentages			
Prob Level	Event	Non-Event	Event	Non-Event	Correct	Sensi-tivity	Speci-ficity	False POS	False NEG
0.280	558	9	523	9	51.6	98.4	1.7	48.4	50.0
0.300	556	9	523	11	51.4	98.1	1.7	48.5	55.0
0.320	552	11	521	15	51.2	97.4	2.1	48.6	57.7
0.340	548	14	518	19	51.1	96.6	2.6	48.6	57.6
0.360	540	20	512	27	51.0	95.2	3.8	48.7	57.4
0.380	536	23	509	31	50.9	94.5	4.3	48.7	57.4
0.400	529	32	500	38	51.0	93.3	6.0	48.6	54.3
0.420	523	46	486	44	51.8	92.2	8.6	48.2	48.9
0.440	505	62	470	62	51.6	89.1	11.7	48.2	50.0
0.460	464	89	443	103	50.3	81.8	16.7	48.8	53.6
0.480	413	138	394	154	50.1	72.8	25.9	48.8	52.7
0.500	371	202	330	196	52.1	65.4	38.0	47.1	49.2
0.520	282	266	266	285	49.9	49.7	50.0	48.5	51.7
0.540	204	357	175	363	51.0	36.0	67.1	46.2	50.4
0.560	144	396	136	423	49.1	25.4	74.4	48.6	51.6
0.580	87	446	86	480	48.5	15.3	83.8	49.7	51.8
0.600	41	482	50	526	47.6	7.2	90.6	54.9	52.2
0.620	31	509	23	536	49.1	5.5	95.7	42.6	51.3
0.640	21	518	14	546	49.0	3.7	97.4	40.0	51.3
0.660	20	521	11	547	49.2	3.5	97.9	35.5	51.2
0.680	17	522	10	550	49.0	3.0	98.1	37.0	51.3
0.700	17	522	10	550	49.0	3.0	98.1	37.0	51.3
0.720	17	522	10	550	49.0	3.0	98.1	37.0	51.3
0.740	14	522	10	553	48.8	2.5	98.1	41.7	51.4
0.760	12	523	9	555	48.7	2.1	98.3	42.9	51.5
0.780	11	524	8	556	48.7	1.9	98.5	42.1	51.5
0.800	9	524	8	558	48.5	1.6	98.5	47.1	51.6
0.820	7	526	6	560	48.5	1.2	98.9	46.2	51.6
0.840	5	526	6	562	48.3	0.9	98.9	54.5	51.7
0.860	5	527	5	562	48.4	0.9	99.1	50.0	51.6
0.880	5	530	2	562	48.7	0.9	99.6	28.6	51.5
0.900	5	530	2	562	48.7	0.9	99.6	28.6	51.5

	Correct		Incorrect		Percentages				
Prob Level	Event	Non-Event	Event	Non-Event	Correct	Sensi-tivity	Speci-ficity	False POS	False NEG
0.920	5	531	1	562	48.8	0.9	99.8	16.7	51.4
0.940	5	532	0	562	48.9	0.9	100.0	0.0	51.4
0.960	5	532	0	562	48.9	0.9	100.0	0.0	51.4
0.980	5	532	0	562	48.9	0.9	100.0	0.0	51.4
1.000	0	532	0	567	48.4	0.0	100.0	.	51.6

APPENDIX K: PROPENSITY SCORE ANALYSIS RESULTS FOR FALL MIDTERM EXAM SCORES

Table 77: Fall Lab Midterm Exam Propensity Score Model Fit Statistics

Criterion	Intercept Only	Intercept and Covariates
AIC	1524.423	1560.605
SC	1529.425	1755.689
-2 Log L	1522.423	1482.605

Table 78: Fall Lab Midterm Exam Propensity Score R^2 Statistics

R-Square	0.0356	Max-rescaled R-Square	0.0475

Table 79: Fall Lab Midterm Exam Propensity Score Testing Global Null Hypothesis

Test	Chi-Square	DF	Pr > ChiSq
Likelihood Ratio	39.8174	38	0.3892
Score	35.1829	38	0.6004
Wald	23.7324	38	0.9659

Table 80: Fall Lab Midterm Exam Propensity Score Type 3 Analysis of Effects

Effect	DF	Wald Chi-Square	Pr > ChiSq
AcadLvl	4	5.2791	0.2598
Hon_Stand	1	0.3352	0.5626
Gender	1	1.6225	0.2027
Race	7	4.2445	0.7512
Age	1	3.8599	0.0495
Degree	24	8.1319	0.9990

Table 81: Fall Lab Midterm Exam Propensity Score Analysis of Maximum Likelihood Estimates

Parameter		Term	DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq	Standardized Estimate	Exp(Est)
Intercept		1	1	1.1299	0.5043	5.0195	0.0251		3.095
AcadLvl	2	1	1	-0.00219	0.1845	0.0001	0.9905	-0.00059	0.998
AcadLvl	3	1	1	0.2772	0.2131	1.6927	0.1933	0.0751	1.319
AcadLvl	4	1	1	-0.4504	0.5822	0.5983	0.4392	-0.0288	0.637
AcadLvl	5	1	1	-0.2636	0.4841	0.2966	0.5860	-0.0225	0.768
Hon_Stand		1	1	0.1488	0.2569	0.3352	0.5626	0.0203	1.160
Gender		1	1	-0.1660	0.1303	1.6225	0.2027	-0.0450	0.847
Race	1	1	1	-0.1479	0.1825	0.6562	0.4179	-0.0303	0.863
Race	2	1	1	-0.0352	0.2202	0.0256	0.8728	-0.00579	0.965
Race	3	1	1	-0.0283	0.1591	0.0315	0.8591	-0.00673	0.972
Race	4	1	1	0.2076	0.2994	0.4809	0.4880	0.0250	1.231
Race	5	1	1	-0.3962	0.9290	0.1819	0.6697	-0.0147	0.673
Race	6	1	1	0.2924	0.3762	0.6042	0.4370	0.0275	1.340
Race	7	1	1	1.5188	1.1052	1.8884	0.1694	0.0617	4.567
Age		1	1	-0.0456	0.0232	3.8599	0.0495	-0.0820	0.955
Degree	1	1	1	14.2352	1214.7	0.0001	0.9906	0.2367	1521434
Degree	2	1	1	0.0508	1.4274	0.0013	0.9716	0.00119	1.052
Degree	3	1	1	0.0529	0.1962	0.0727	0.7875	0.0100	1.054
Degree	5	1	1	0.1800	0.3883	0.2148	0.6430	0.0159	1.197
Degree	6	1	1	1.0648	0.6056	3.0916	0.0787	0.0681	2.900
Degree	7	1	1	-14.3218	1214.7	0.0001	0.9906	-0.2382	0.000
Degree	8	1	1	14.1148	1214.7	0.0001	0.9907	0.2347	1348930
Degree	9	1	1	-0.3772	0.7745	0.2372	0.6262	-0.0166	0.686
Degree	10	1	0	0	.	.	.	.	.
Degree	11	1	1	0.1087	0.1770	0.3772	0.5391	0.0241	1.115
Degree	12	1	1	-14.2604	857.9	0.0003	0.9867	-0.3352	0.000
Degree	13	1	1	-0.2653	0.5330	0.2477	0.6187	-0.0170	0.767
Degree	14	1	1	-0.8140	1.2441	0.4281	0.5129	-0.0234	0.443
Degree	15	1	1	0.7686	1.2343	0.3878	0.5335	0.0221	2.157
Degree	16	1	1	0.6549	0.7787	0.7073	0.4003	0.0307	1.925

Parameter		Term	DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq	Standardized Estimate	Exp(Est)
Degree	17	1	1	-14.1531	1214.7	0.0001	0.9907	-0.2354	0.000
Degree	18	1	1	-0.5798	1.2449	0.2169	0.6414	-0.0167	0.560
Degree	19	1	1	14.9019	1214.7	0.0002	0.9902	0.2478	2963486
Degree	20	1	1	-14.4939	1214.7	0.0001	0.9905	-0.2410	0.000
Degree	21	1	1	-0.6400	0.6075	1.1100	0.2921	-0.0367	0.527
Degree	22	1	1	-0.4625	0.6057	0.5831	0.4451	-0.0265	0.630
Degree	23	1	1	-0.5291	1.2476	0.1799	0.6715	-0.0152	0.589
Degree	24	1	1	14.1612	1214.7	0.0001	0.9907	0.2355	1412924
Degree	25	1	1	-0.0778	1.4227	0.0030	0.9564	-0.00183	0.925
Degree	27	1	1	14.2733	1214.7	0.0001	0.9906	0.2374	1580561

Table 82: Fall Lab Midterm Exam Propensity Score Odds Ratio Estimates

Effect	Term	Point Estimate	95% Wald Confidence Limits	
AcadLvl 2 vs 1	1	0.998	0.695	1.432
AcadLvl 3 vs 1	1	1.319	0.869	2.003
AcadLvl 4 vs 1	1	0.637	0.204	1.995
AcadLvl 5 vs 1	1	0.768	0.297	1.984
Hon_Stand	1	1.160	0.701	1.920
Gender	1	0.847	0.656	1.094
Race 1 vs 8	1	0.863	0.603	1.234
Race 2 vs 8	1	0.965	0.627	1.486
Race 3 vs 8	1	0.972	0.712	1.328
Race 4 vs 8	1	1.231	0.684	2.213
Race 5 vs 8	1	0.673	0.109	4.156
Race 6 vs 8	1	1.340	0.641	2.800
Race 7 vs 8	1	4.567	0.523	39.845
Age	1	0.955	0.913	1.000
Degree 1 vs 4	1	>999.999	<0.001	>999.999
Degree 2 vs 4	1	1.052	0.064	17.262
Degree 3 vs 4	1	1.054	0.718	1.549
Degree 5 vs 4	1	1.197	0.559	2.563

Effect	Term	Point Estimate	95% Wald Confidence Limits	
Degree 6 vs 4	1	2.900	0.885	9.504
Degree 7 vs 4	1	<0.001	<0.001	>999.999
Degree 8 vs 4	1	>999.999	<0.001	>999.999
Degree 9 vs 4	1	0.686	0.150	3.129
Degree 11 vs 4	1	1.115	0.788	1.577
Degree 12 vs 4	1	<0.001	<0.001	>999.999
Degree 13 vs 4	1	0.767	0.270	2.180
Degree 14 vs 4	1	0.443	0.039	5.075
Degree 15 vs 4	1	2.157	0.192	24.234
Degree 16 vs 4	1	1.925	0.418	8.856
Degree 17 vs 4	1	<0.001	<0.001	>999.999
Degree 18 vs 4	1	0.560	0.049	6.425
Degree 19 vs 4	1	>999.999	<0.001	>999.999
Degree 20 vs 4	1	<0.001	<0.001	>999.999
Degree 21 vs 4	1	0.527	0.160	1.734
Degree 22 vs 4	1	0.630	0.192	2.064
Degree 23 vs 4	1	0.589	0.051	6.795
Degree 24 vs 4	1	>999.999	<0.001	>999.999
Degree 25 vs 4	1	0.925	0.057	15.037
Degree 27 vs 4	1	>999.999	<0.001	>999.999

Table 83: Fall Lab Midterm Exam Propensity Score Association of Predicted Probabilities and Observed Responses

Percent Concordant	59.1	Somers' D	0.187
Percent Discordant	40.5	Gamma	0.187
Percen Tied	0.4	Tau-a	0.093
Pairs	301644	c	0.593

Table 84: Fall Lab Midterm Exam Propensity Score Partition for the Hosmer and Lemeshow Test

		Term = 1		Term = 0	
Group	Total	Observed	Expected	Observed	Expected
1	110	38	38.92	72	71.08
2	111	55	50.19	56	60.81
3	110	51	52.57	59	57.43
4	110	49	54.64	61	55.36
5	118	58	60.58	60	57.42
6	111	61	58.11	50	52.89
7	111	63	59.93	48	51.07
8	112	63	63.08	49	48.92
9	122	72	71.54	50	50.46
10	84	57	57.44	27	26.56

Table 85: Fall Lab Midterm Exam Propensity Score Hosmer and Lemeshow Goodness of Fit Test

Chi-Square	DF	Pr > ChiSq
3.0090	8	0.9338

Table 86: Fall Lab Midterm Exam Propensity Score Classification Table

	Correct		Incorrect		Percentages				
Prob Level	Event	Non-Event	Event	Non-Event	Correct	Sensi-tivity	Speci-ficity	False POS	False NEG
0.000	567	0	532	0	51.6	100.0	0.0	48.4	.
0.020	567	5	527	0	52.0	100.0	0.9	48.2	0.0
0.040	567	5	527	0	52.0	100.0	0.9	48.2	0.0
0.060	566	5	527	1	52.0	99.8	0.9	48.2	16.7
0.080	566	5	527	1	52.0	99.8	0.9	48.2	16.7
0.100	564	5	527	3	51.8	99.5	0.9	48.3	37.5
0.120	564	5	527	3	51.8	99.5	0.9	48.3	37.5
0.140	563	5	527	4	51.7	99.3	0.9	48.3	44.4
0.160	562	5	527	5	51.6	99.1	0.9	48.4	50.0
0.180	562	5	527	5	51.6	99.1	0.9	48.4	50.0
0.200	562	5	527	5	51.6	99.1	0.9	48.4	50.0
0.220	560	5	527	7	51.4	98.8	0.9	48.5	58.3
0.240	560	6	526	7	51.5	98.8	1.1	48.4	53.8
0.260	559	8	524	8	51.6	98.6	1.5	48.4	50.0
0.280	558	9	523	9	51.6	98.4	1.7	48.4	50.0
0.300	556	9	523	11	51.4	98.1	1.7	48.5	55.0
0.320	552	11	521	15	51.2	97.4	2.1	48.6	57.7
0.340	548	14	518	19	51.1	96.6	2.6	48.6	57.6
0.360	540	20	512	27	51.0	95.2	3.8	48.7	57.4
0.380	536	23	509	31	50.9	94.5	4.3	48.7	57.4
0.400	529	32	500	38	51.0	93.3	6.0	48.6	54.3
0.420	523	46	486	44	51.8	92.2	8.6	48.2	48.9
0.440	505	62	470	62	51.6	89.1	11.7	48.2	50.0
0.460	464	89	443	103	50.3	81.8	16.7	48.8	53.6
0.480	413	138	394	154	50.1	72.8	25.9	48.8	52.7
0.500	371	202	330	196	52.1	65.4	38.0	47.1	49.2
0.520	282	266	266	285	49.9	49.7	50.0	48.5	51.7
0.540	204	357	175	363	51.0	36.0	67.1	46.2	50.4
0.560	144	396	136	423	49.1	25.4	74.4	48.6	51.6
0.580	87	446	86	480	48.5	15.3	83.8	49.7	51.8

	Correct		Incorrect		Percentages				
Prob Level	Event	Non-Event	Event	Non-Event	Correct	Sensi-tivity	Speci-ficity	False POS	False NEG
0.600	41	482	50	526	47.6	7.2	90.6	54.9	52.2
0.620	31	509	23	536	49.1	5.5	95.7	42.6	51.3
0.640	21	518	14	546	49.0	3.7	97.4	40.0	51.3
0.660	20	521	11	547	49.2	3.5	97.9	35.5	51.2
0.680	17	522	10	550	49.0	3.0	98.1	37.0	51.3
0.700	17	522	10	550	49.0	3.0	98.1	37.0	51.3
0.720	17	522	10	550	49.0	3.0	98.1	37.0	51.3
0.740	14	522	10	553	48.8	2.5	98.1	41.7	51.4
0.760	12	523	9	555	48.7	2.1	98.3	42.9	51.5
0.780	11	524	8	556	48.7	1.9	98.5	42.1	51.5
0.800	9	524	8	558	48.5	1.6	98.5	47.1	51.6
0.820	7	526	6	560	48.5	1.2	98.9	46.2	51.6
0.840	5	526	6	562	48.3	0.9	98.9	54.5	51.7
0.860	5	527	5	562	48.4	0.9	99.1	50.0	51.6
0.880	5	530	2	562	48.7	0.9	99.6	28.6	51.5
0.900	5	530	2	562	48.7	0.9	99.6	28.6	51.5
0.920	5	531	1	562	48.8	0.9	99.8	16.7	51.4
0.940	5	532	0	562	48.9	0.9	100.0	0.0	51.4
0.960	5	532	0	562	48.9	0.9	100.0	0.0	51.4
0.980	5	532	0	562	48.9	0.9	100.0	0.0	51.4
1.000	0	532	0	567	48.4	0.0	100.0	.	51.6

APPENDIX L: PROPENSITY SCORE ANALYSIS RESULTS FOR SPRING LAB PRACTICAL FINAL EXAM SCORES

Table 87: Spring Lab Final Exam Propensity Score Model Fit Statistics

Model Fit Statistics

Criterion	Intercept Only	Intercept and Covariates
AIC	1097.787	1118.248
SC	1102.462	1300.605
-2 Log L	1095.787	1040.248

Table 88: Spring Lab Final Exam Propensity Score R^2 Statistics

R-Square	0.0676	Max-rescaled R-Square	0.0903

Table 89: Spring Lab Final Exam Propensity Score Testing Global Null Hypothesis

Test	Chi-Square	DF	Pr > ChiSq
Likelihood Ratio	55.5385	38	0.0329
Score	46.7121	38	0.1570
Wald	24.4087	38	0.9571

Table 90: Spring Lab Final Exam Propensity Score Type 3 Analysis of Effects

Effect	DF	Wald Chi-Square	Pr > ChiSq
AcadLvl	4	3.6774	0.4514
Gender	1	0.2731	0.6013
Race	9	6.2025	0.7195
Age	1	1.3055	0.2532
Degree	23	10.0187	0.9912

Table 91: Spring Lab Final Exam Propensity Score Analysis of Maximum Likelihood Estimates

Parameter		Term	DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq	Standardized Estimate	Exp(Est)
Intercept		1	1	-0.7178	0.7177	1.0002	0.3173		0.488
AcadLvl	2	1	1	-0.0268	0.2555	0.0110	0.9165	-0.00696	0.974
AcadLvl	3	1	1	0.1621	0.2757	0.3456	0.5566	0.0446	1.176
AcadLvl	4	1	1	-13.8400	739.0	0.0004	0.9851	-0.8088	0.000
AcadLvl	5	1	1	1.9258	1.1285	2.9124	0.0879	0.1186	6.861
Gender		1	1	0.0830	0.1589	0.2731	0.6013	0.0221	1.087
Race	1	1	1	-0.2477	0.2475	1.0018	0.3169	-0.0433	0.781
Race	2	1	1	-0.4267	0.2470	2.9829	0.0841	-0.0750	0.653
Race	3	1	1	0.0443	0.1798	0.0607	0.8054	0.0111	1.045
Race	4	1	1	0.0516	0.3800	0.0184	0.8920	0.00576	1.053
Race	5	1	1	13.1600	738.7	0.0003	0.9858	0.2576	519175.7
Race	6	1	1	0.7154	0.6122	1.3657	0.2426	0.0520	2.045
Race	7	1	1	-0.4159	1.0819	0.1478	0.7007	-0.0163	0.660
Race	20	1	1	-25.7400	1044.9	0.0006	0.9803	-0.5039	0.000
Race	21	1	1	-25.5076	1044.9	0.0006	0.9805	-0.4994	0.000
Age		1	1	0.0395	0.0346	1.3055	0.2532	0.0621	1.040
Degree	1	1	1	12.8006	738.7	0.0003	0.9862	0.4335	362443.4
Degree	2	1	1	-13.5723	739.0	0.0003	0.9853	-0.2657	0.000
Degree	3	1	1	0.1867	0.2538	0.5412	0.4619	0.0346	1.205
Degree	5	1	1	-0.0511	0.4271	0.0143	0.9048	-0.00502	0.950
Degree	6	1	1	-0.6121	0.5265	1.3516	0.2450	-0.0489	0.542
Degree	7	1	1	-13.1617	739.0	0.0003	0.9858	-0.2577	0.000
Degree	8	1	1	0.1222	0.6914	0.0312	0.8597	0.00714	1.130
Degree	9	1	1	12.4340	739.0	0.0003	0.9866	0.6855	251211.1
Degree	10	1	1	-0.3112	0.2013	2.3897	0.1221	-0.0800	0.733
Degree	11	1	1	12.8480	738.7	0.0003	0.9861	0.2515	380034.3
Degree	12	1	1	-13.3707	739.0	0.0003	0.9856	-0.2618	0.000
Degree	13	1	1	-0.6715	0.6186	1.1785	0.2777	-0.0452	0.511
Degree	14	1	1	-0.8562	0.8279	1.0697	0.3010	-0.0442	0.425
Degree	15	1	1	-13.6586	739.0	0.0003	0.9853	-0.2674	0.000

Parameter		Term	DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq	Standardized Estimate	Exp(Est)
Degree	16	1	1	-13.3413	522.4	0.0007	0.9796	-0.3692	0.000
Degree	17	1	1	-15.7303	739.0	0.0005	0.9830	-0.3080	0.000
Degree	18	1	1	12.7698	738.7	0.0003	0.9862	0.2500	351434.9
Degree	19	1	1	1.3279	1.1079	1.4364	0.2307	0.0635	3.773
Degree	20	1	1	-1.1723	1.2445	0.8874	0.3462	-0.0397	0.310
Degree	21	1	1	12.7295	738.7	0.0003	0.9863	0.2492	337559.2
Degree	22	1	1	-13.5280	739.0	0.0003	0.9854	-0.2649	0.000
Degree	23	1	1	12.9735	521.0	0.0006	0.9801	0.3590	430837.5
Degree	24	1	0	0	.	.	.	.	.
Degree	25	1	1	-13.6981	739.0	0.0003	0.9852	-0.2682	0.000

Table 92: Spring Lab Final Exam Propensity Score Odds Ratio Estimates

Effect	Term	Point Estimate	95% Wald Confidence	Limits
AcadLvl 2 vs 1	1	0.974	0.590	1.606
AcadLvl 3 vs 1	1	1.176	0.685	2.019
AcadLvl 4 vs 1	1	<0.001	<0.001	>999.999
AcadLvl 5 vs 1	1	6.861	0.751	62.653
Gender	1	1.087	0.796	1.484
Race 1 vs 8	1	0.781	0.481	1.268
Race 2 vs 8	1	0.653	0.402	1.059
Race 3 vs 8	1	1.045	0.735	1.487
Race 4 vs 8	1	1.053	0.500	2.218
Race 5 vs 8	1	>999.999	<0.001	>999.999
Race 6 vs 8	1	2.045	0.616	6.789
Race 7 vs 8	1	0.660	0.079	5.500
Race 20 vs 8	1	<0.001	<0.001	>999.999
Race 21 vs 8	1	<0.001	<0.001	>999.999
Age	1	1.040	0.972	1.113

Effect	Term	Point Estimate	95% Wald Confidence Limits	
Degree 1 vs 4	1	>999.999	<0.001	>999.999
Degree 2 vs 4	1	<0.001	<0.001	>999.999
Degree 3 vs 4	1	1.205	0.733	1.982
Degree 5 vs 4	1	0.950	0.411	2.195
Degree 6 vs 4	1	0.542	0.193	1.522
Degree 7 vs 4	1	<0.001	<0.001	>999.999
Degree 8 vs 4	1	1.130	0.291	4.381
Degree 9 vs 4	1	>999.999	<0.001	>999.999
Degree 10 vs 4	1	0.733	0.494	1.087
Degree 11 vs 4	1	>999.999	<0.001	>999.999
Degree 12 vs 4	1	<0.001	<0.001	>999.999
Degree 13 vs 4	1	0.511	0.152	1.717
Degree 14 vs 4	1	0.425	0.084	2.152
Degree 15 vs 4	1	<0.001	<0.001	>999.999
Degree 16 vs 4	1	<0.001	<0.001	>999.999
Degree 17 vs 4	1	<0.001	<0.001	>999.999
Degree 18 vs 4	1	>999.999	<0.001	>999.999
Degree 19 vs 4	1	3.773	0.430	33.095
Degree 20 vs 4	1	0.310	0.027	3.550
Degree 21 vs 4	1	>999.999	<0.001	>999.999
Degree 22 vs 4	1	<0.001	<0.001	>999.999
Degree 23 vs 4	1	>999.999	<0.001	>999.999
Degree 25 vs 4	1	<0.001	<0.001	>999.999

Table 93: Spring Lab Final Exam Propensity Score Association of Predicted Probabilities and Observed Responses

Percent Concordant	61.1	Somers' D	0.228
Percent Discordant	38.3	Gamma	0.229
Percent Tied	0.6	Tau-a	0.113
Pairs	156510	c	0.614

Table 94: Spring Lab Final Exam Propensity Score Partition for the Hosmer and Lemeshow Test

		Term = 1		Term = 0	
Group	Total	Observed	Expected	Observed	Expected
1	80	23	24.91	57	55.09
2	79	33	35.36	46	43.64
3	76	41	36.88	35	39.12
4	79	44	40.88	35	38.12
5	81	49	43.03	32	37.97
6	81	36	43.93	45	37.07
7	85	51	47.34	34	37.66
8	80	39	46.64	41	33.36
9	82	56	51.05	26	30.95
10	70	51	52.98	19	17.02

Table 95: Spring Lab Final Exam Propensity Score Hosmer and Lemeshow Goodness of Fit Test

Chi-Square	DF	Pr > ChiSq
11.9890	8	0.1517

Table 96: Spring Lab Final Exam Propensity Score Classification Table

	Correct		Incorrect		Percentages				
Prob Level	Event	Non-Event	Event	Non-Event	Correct	Sensi-tivity	Speci-ficity	False POS	False NEG
0.000	423	0	370	0	53.3	100.0	0.0	46.7	.
0.020	423	12	358	0	54.9	100.0	3.2	45.8	0.0
0.040	423	12	358	0	54.9	100.0	3.2	45.8	0.0
0.060	423	12	358	0	54.9	100.0	3.2	45.8	0.0
0.080	423	12	358	0	54.9	100.0	3.2	45.8	0.0
0.100	423	12	358	0	54.9	100.0	3.2	45.8	0.0
0.120	421	12	358	2	54.6	99.5	3.2	46.0	14.3
0.140	421	12	358	2	54.6	99.5	3.2	46.0	14.3
0.160	420	12	358	3	54.5	99.3	3.2	46.0	20.0
0.180	420	12	358	3	54.5	99.3	3.2	46.0	20.0
0.200	419	12	358	4	54.4	99.1	3.2	46.1	25.0
0.220	417	12	358	6	54.1	98.6	3.2	46.2	33.3
0.240	417	12	358	6	54.1	98.6	3.2	46.2	33.3
0.260	417	12	358	6	54.1	98.6	3.2	46.2	33.3
0.280	417	16	354	6	54.6	98.6	4.3	45.9	27.3
0.300	415	18	352	8	54.6	98.1	4.9	45.9	30.8
0.320	414	20	350	9	54.7	97.9	5.4	45.8	31.0
0.340	414	20	350	9	54.7	97.9	5.4	45.8	31.0
0.360	412	24	346	11	55.0	97.4	6.5	45.6	31.4
0.380	411	24	346	12	54.9	97.2	6.5	45.7	33.3
0.400	403	31	339	20	54.7	95.3	8.4	45.7	39.2
0.420	385	44	326	38	54.1	91.0	11.9	45.9	46.3
0.440	379	58	312	44	55.1	89.6	15.7	45.2	43.1
0.460	359	73	297	64	54.5	84.9	19.7	45.3	46.7
0.480	340	101	269	83	55.6	80.4	27.3	44.2	45.1
0.500	326	119	251	97	56.1	77.1	32.2	43.5	44.9
0.520	270	148	222	153	52.7	63.8	40.0	45.1	50.8
0.540	191	191	179	232	48.2	45.2	51.6	48.4	54.8
0.560	142	260	110	281	50.7	33.6	70.3	43.7	51.9
0.580	118	290	80	305	51.5	27.9	78.4	40.4	51.3

	Correct		Incorrect			Percentages			
Prob Level	Event	Non-Event	Event	Non-Event	Correct	Sensi-tivity	Speci-ficity	False POS	False NEG
0.600	92	313	57	331	51.1	21.7	84.6	38.3	51.4
0.620	74	330	40	349	50.9	17.5	89.2	35.1	51.4
0.640	57	341	29	366	50.2	13.5	92.2	33.7	51.8
0.660	40	346	24	383	48.7	9.5	93.5	37.5	52.5
0.680	28	355	15	395	48.3	6.6	95.9	34.9	52.7
0.700	23	360	10	400	48.3	5.4	97.3	30.3	52.6
0.720	22	361	9	401	48.3	5.2	97.6	29.0	52.6
0.740	22	362	8	401	48.4	5.2	97.8	26.7	52.6
0.760	20	363	7	403	48.3	4.7	98.1	25.9	52.6
0.780	18	364	6	405	48.2	4.3	98.4	25.0	52.7
0.800	17	366	4	406	48.3	4.0	98.9	19.0	52.6
0.820	14	367	3	409	48.0	3.3	99.2	17.6	52.7
0.840	13	367	3	410	47.9	3.1	99.2	18.8	52.8
0.860	12	367	3	411	47.8	2.8	99.2	20.0	52.8
0.880	11	367	3	412	47.7	2.6	99.2	21.4	52.9
0.900	10	367	3	413	47.5	2.4	99.2	23.1	52.9
0.920	9	368	2	414	47.5	2.1	99.5	18.2	52.9
0.940	8	369	1	415	47.5	1.9	99.7	11.1	52.9
0.960	7	369	1	416	47.4	1.7	99.7	12.5	53.0
0.980	7	370	0	416	47.5	1.7	100.0	0.0	52.9
1.000	0	370	0	423	46.7	0.0	100.0	.	53.3

APPENDIX M: PROPENSITY SCORE ANALYSIS RESULTS FOR SPRING LAB MIDTERM SCORES

Table 97: Spring Lab Midterm Exam Propensity Score Model Fit Statistics

Criterion	Intercept Only	Intercept and Covariates
AIC	1097.787	1118.248
SC	1102.462	1300.605
-2 Log L	1095.787	1040.248

Table 98: Spring Lab Midterm Exam Propensity Score R^2 Statistics

R-Square	0.0676	Max-rescaled R-Square	0.0903

Table 99: Spring Lab Midterm Exam Propensity Score Testing Global Null Hypothesis

Test	Chi-Square	DF	Pr > ChiSq
Likelihood Ratio	55.5385	38	0.0329
Score	46.7121	38	0.1570
Wald	24.4087	38	0.9571

Table 100: Spring Lab Midterm Exam Propensity Score Type 3 Analysis of Effects

Effect	DF	Wald Chi-Square	Pr > ChiSq
AcadLvl	4	3.6774	0.4514
Gender	1	0.2731	0.6013
Race	9	6.2025	0.7195
Age	1	1.3055	0.2532
Degree	23	10.0187	0.9912

Table 101: Spring Lab Midterm Exam Propensity Score Analysis of Maximum Likelihood Estimates

Parameter		Term	DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq	Standardized Estimate	Exp(Est)
Intercept		1	1	-0.7178	0.7177	1.0002	0.3173		0.488
AcadLvl	2	1	1	-0.0268	0.2555	0.0110	0.9165	-0.00696	0.974
AcadLvl	3	1	1	0.1621	0.2757	0.3456	0.5566	0.0446	1.176
AcadLvl	4	1	1	-13.8400	739.0	0.0004	0.9851	-0.8088	0.000
AcadLvl	5	1	1	1.9258	1.1285	2.9124	0.0879	0.1186	6.861
Gender		1	1	0.0830	0.1589	0.2731	0.6013	0.0221	1.087
Race	1	1	1	-0.2477	0.2475	1.0018	0.3169	-0.0433	0.781
Race	2	1	1	-0.4267	0.2470	2.9829	0.0841	-0.0750	0.653
Race	3	1	1	0.0443	0.1798	0.0607	0.8054	0.0111	1.045
Race	4	1	1	0.0516	0.3800	0.0184	0.8920	0.00576	1.053
Race	5	1	1	13.1600	738.7	0.0003	0.9858	0.2576	519175.7
Race	6	1	1	0.7154	0.6122	1.3657	0.2426	0.0520	2.045
Race	7	1	1	-0.4159	1.0819	0.1478	0.7007	-0.0163	0.660
Race	20	1	1	-25.7400	1044.9	0.0006	0.9803	-0.5039	0.000
Race	21	1	1	-25.5076	1044.9	0.0006	0.9805	-0.4994	0.000
Age		1	1	0.0395	0.0346	1.3055	0.2532	0.0621	1.040
Degree	1	1	1	12.8006	738.7	0.0003	0.9862	0.4335	362443.4
Degree	2	1	1	-13.5723	739.0	0.0003	0.9853	-0.2657	0.000
Degree	3	1	1	0.1867	0.2538	0.5412	0.4619	0.0346	1.205
Degree	5	1	1	-0.0511	0.4271	0.0143	0.9048	-0.00502	0.950
Degree	6	1	1	-0.6121	0.5265	1.3516	0.2450	-0.0489	0.542
Degree	7	1	1	-13.1617	739.0	0.0003	0.9858	-0.2577	0.000
Degree	8	1	1	0.1222	0.6914	0.0312	0.8597	0.00714	1.130
Degree	9	1	1	12.4340	739.0	0.0003	0.9866	0.6855	251211.1
Degree	10	1	1	-0.3112	0.2013	2.3897	0.1221	-0.0800	0.733
Degree	11	1	1	12.8480	738.7	0.0003	0.9861	0.2515	380034.3
Degree	12	1	1	-13.3707	739.0	0.0003	0.9856	-0.2618	0.000
Degree	13	1	1	-0.6715	0.6186	1.1785	0.2777	-0.0452	0.511
Degree	14	1	1	-0.8562	0.8279	1.0697	0.3010	-0.0442	0.425
Degree	15	1	1	-13.6586	739.0	0.0003	0.9853	-0.2674	0.000
Degree	16	1	1	-13.3413	522.4	0.0007	0.9796	-0.3692	0.000

Parameter		Term	DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq	Standardized Estimate	Exp(Est)
Degree	17	1	1	-15.7303	739.0	0.0005	0.9830	-0.3080	0.000
Degree	18	1	1	12.7698	738.7	0.0003	0.9862	0.2500	351434.9
Degree	19	1	1	1.3279	1.1079	1.4364	0.2307	0.0635	3.773
Degree	20	1	1	-1.1723	1.2445	0.8874	0.3462	-0.0397	0.310
Degree	21	1	1	12.7295	738.7	0.0003	0.9863	0.2492	337559.2
Degree	22	1	1	-13.5280	739.0	0.0003	0.9854	-0.2649	0.000
Degree	23	1	1	12.9735	521.0	0.0006	0.9801	0.3590	430837.5
Degree	24	1	0	0	.	.	.	.	.
Degree	25	1	1	-13.6981	739.0	0.0003	0.9852	-0.2682	0.000

Table 102: Spring Lab Midterm Exam Propensity Score Odds Ratio Estimates

Effect	Term	Point Estimate	95% Wald Confidence	Limits
AcadLvl 2 vs 1	1	0.974	0.590	1.606
AcadLvl 3 vs 1	1	1.176	0.685	2.019
AcadLvl 4 vs 1	1	<0.001	<0.001	>999.999
AcadLvl 5 vs 1	1	6.861	0.751	62.653
Gender	1	1.087	0.796	1.484
Race 1 vs 8	1	0.781	0.481	1.268
Race 2 vs 8	1	0.653	0.402	1.059
Race 3 vs 8	1	1.045	0.735	1.487
Race 4 vs 8	1	1.053	0.500	2.218
Race 5 vs 8	1	>999.999	<0.001	>999.999
Race 6 vs 8	1	2.045	0.616	6.789
Race 7 vs 8	1	0.660	0.079	5.500
Race 20 vs 8	1	<0.001	<0.001	>999.999
Race 21 vs 8	1	<0.001	<0.001	>999.999
Age	1	1.040	0.972	1.113
Degree 1 vs 4	1	>999.999	<0.001	>999.999
Degree 2 vs 4	1	<0.001	<0.001	>999.999
Degree 3 vs 4	1	1.205	0.733	1.982
Degree 5 vs 4	1	0.950	0.411	2.195
Degree 6 vs 4	1	0.542	0.193	1.522
Degree 7 vs 4	1	<0.001	<0.001	>999.999
Degree 8 vs 4	1	1.130	0.291	4.381
Degree 9 vs 4	1	>999.999	<0.001	>999.999
Degree 10 vs 4	1	0.733	0.494	1.087

Effect		Term	Point Estimate	95% Wald Confidence Limits	
Degree	11 vs 4	1	>999.999	<0.001	>999.999
Degree	12 vs 4	1	<0.001	<0.001	>999.999
Degree	13 vs 4	1	0.511	0.152	1.717
Degree	14 vs 4	1	0.425	0.084	2.152
Degree	15 vs 4	1	<0.001	<0.001	>999.999
Degree	16 vs 4	1	<0.001	<0.001	>999.999
Degree	17 vs 4	1	<0.001	<0.001	>999.999
Degree	18 vs 4	1	>999.999	<0.001	>999.999
Degree	19 vs 4	1	3.773	0.430	33.095
Degree	20 vs 4	1	0.310	0.027	3.550
Degree	21 vs 4	1	>999.999	<0.001	>999.999
Degree	22 vs 4	1	<0.001	<0.001	>999.999
Degree	23 vs 4	1	>999.999	<0.001	>999.999
Degree	25 vs 4	1	<0.001	<0.001	>999.999

Table 103: Spring Lab Midterm Exam Propensity Score Association of Predicted Probabilities and Observed Responses

Percent Concordant	61.1	Somers' D	0.228
Percent Discordant	38.3	Gamma	0.229
Percent Tied	0.6	Tau-a	0.113
Pairs	156510	c	0.614

Table 104: Spring Lab Midterm Exam Propensity Score Partition for the Hosmer and Lemeshow Test

		Term = 1		Term = 0	
Group	Total	Observed	Expected	Observed	Expected
1	80	23	24.91	57	55.09
2	79	33	35.36	46	43.64
3	76	41	36.88	35	39.12
4	79	44	40.88	35	38.12
5	81	49	43.03	32	37.97
6	81	36	43.93	45	37.07
7	85	51	47.34	34	37.66
8	80	39	46.64	41	33.36
9	82	56	51.05	26	30.95
10	70	51	52.98	19	17.02

Table 105: Spring Lab Midterm Exam Propensity Score Hosmer and Lemesho Goodness of Fit Test

Chi-Square	DF	Pr > ChiSq
11.9890	8	0.1517

Table 106: Spring Lab Midterm Exam Propensity Score Classification Table

	Correct		Incorrect		Percentages				
Prob Level	Event	Non-Event	Event	Non-Event	Correct	Sensi-tivity	Speci-ficity	False POS	False NEG
0.000	423	0	370	0	53.3	100.0	0.0	46.7	.
0.020	423	12	358	0	54.9	100.0	3.2	45.8	0.0
0.040	423	12	358	0	54.9	100.0	3.2	45.8	0.0
0.060	423	12	358	0	54.9	100.0	3.2	45.8	0.0
0.080	423	12	358	0	54.9	100.0	3.2	45.8	0.0
0.100	423	12	358	0	54.9	100.0	3.2	45.8	0.0
0.120	421	12	358	2	54.6	99.5	3.2	46.0	14.3
0.140	421	12	358	2	54.6	99.5	3.2	46.0	14.3
0.160	420	12	358	3	54.5	99.3	3.2	46.0	20.0
0.180	420	12	358	3	54.5	99.3	3.2	46.0	20.0
0.200	419	12	358	4	54.4	99.1	3.2	46.1	25.0
0.220	417	12	358	6	54.1	98.6	3.2	46.2	33.3
0.240	417	12	358	6	54.1	98.6	3.2	46.2	33.3
0.260	417	12	358	6	54.1	98.6	3.2	46.2	33.3
0.280	417	16	354	6	54.6	98.6	4.3	45.9	27.3
0.300	415	18	352	8	54.6	98.1	4.9	45.9	30.8
0.320	414	20	350	9	54.7	97.9	5.4	45.8	31.0
0.340	414	20	350	9	54.7	97.9	5.4	45.8	31.0
0.360	412	24	346	11	55.0	97.4	6.5	45.6	31.4
0.380	411	24	346	12	54.9	97.2	6.5	45.7	33.3
0.400	403	31	339	20	54.7	95.3	8.4	45.7	39.2
0.420	385	44	326	38	54.1	91.0	11.9	45.9	46.3
0.440	379	58	312	44	55.1	89.6	15.7	45.2	43.1
0.460	359	73	297	64	54.5	84.9	19.7	45.3	46.7
0.480	340	101	269	83	55.6	80.4	27.3	44.2	45.1

	Correct		Incorrect			Percentages			
Prob Level	Event	Non-Event	Event	Non-Event	Correct	Sensi-tivity	Speci-ficity	False POS	False NEG
0.520	270	148	222	153	52.7	63.8	40.0	45.1	50.8
0.540	191	191	179	232	48.2	45.2	51.6	48.4	54.8
0.560	142	260	110	281	50.7	33.6	70.3	43.7	51.9
0.580	118	290	80	305	51.5	27.9	78.4	40.4	51.3
0.600	92	313	57	331	51.1	21.7	84.6	38.3	51.4
0.620	74	330	40	349	50.9	17.5	89.2	35.1	51.4
0.640	57	341	29	366	50.2	13.5	92.2	33.7	51.8
0.660	40	346	24	383	48.7	9.5	93.5	37.5	52.5
0.680	28	355	15	395	48.3	6.6	95.9	34.9	52.7
0.700	23	360	10	400	48.3	5.4	97.3	30.3	52.6
0.720	22	361	9	401	48.3	5.2	97.6	29.0	52.6
0.740	22	362	8	401	48.4	5.2	97.8	26.7	52.6
0.760	20	363	7	403	48.3	4.7	98.1	25.9	52.6
0.780	18	364	6	405	48.2	4.3	98.4	25.0	52.7
0.800	17	366	4	406	48.3	4.0	98.9	19.0	52.6
0.820	14	367	3	409	48.0	3.3	99.2	17.6	52.7
0.840	13	367	3	410	47.9	3.1	99.2	18.8	52.8
0.860	12	367	3	411	47.8	2.8	99.2	20.0	52.8
0.880	11	367	3	412	47.7	2.6	99.2	21.4	52.9
0.900	10	367	3	413	47.5	2.4	99.2	23.1	52.9
0.920	9	368	2	414	47.5	2.1	99.5	18.2	52.9
0.940	8	369	1	415	47.5	1.9	99.7	11.1	52.9
0.960	7	369	1	416	47.4	1.7	99.7	12.5	53.0
0.980	7	370	0	416	47.5	1.7	100.0	0.0	52.9
1.000	0	370	0	423	46.7	0.0	100.0	.	53.3

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