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## An Investigation of the Impacts of Face-to-Face and Virtual Laboratories in an Introductory Biology Course on Students' Motivation to Learn Biology.

Amber Reece  
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AN INVESTIGATION OF THE IMPACTS OF FACE-TO-FACE AND  
VIRTUAL LABORATORIES IN AN INTRODUCTORY BIOLOGY COURSE  
ON STUDENTS' MOTIVATION TO LEARN BIOLOGY

by

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A dissertation submitted in partial fulfillment of the requirements  
for the degree of Doctor of Philosophy  
in the College of Education and Human Performance  
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## ABSTRACT

The objective of this study was to evaluate and compare the effects of face-to-face and virtual laboratories in a large-enrollment introductory biology course on students' motivation to learn biology. The laboratory component of post-secondary science courses is where students have opportunities for frequent interactions with instructors and their peers (Seymour & Hewitt, 1997; Seymour, Melton, Wiese, & Pederson-Gallegos, 2005) and is often relied upon for promoting interest and motivation in science learning (Hofstein & Lunetta, 2003; Lunetta, Hofstein, & Clough, 2007). However, laboratory courses can be resource intensive (Jenkins, 2007), leading post-secondary science educators to seek alternative means of laboratory education such as virtual laboratories. Scholars have provided evidence that student achievement in virtual laboratories can be equal to, if not higher than, that of students in face-to-face laboratories (Akpan & Strayer, 2010; Finkelstein et al., 2005; Huppert, Lomask, & Lazarowitz, 2002). Yet, little research on virtual laboratories has been conducted on affective variables such as motivation to learn science.

Motivation to learn biology was measured at the beginning and end of the semester using the Biology Motivation Questionnaire © (Glynn, Brickman, Armstrong, & Taasobshirazi, 2011) and compared between the face-to-face and virtual laboratory groups. Characteristics of the two laboratory environments were measured at the end of the semester by the Distance Education Learning Environment Survey (Walker & Fraser, 2005). Interviews with 12 participants were conducted three times throughout the semester in the phenomenological style of qualitative data collection. The quantitative survey data and qualitative interview and

observation data were combined to provide a thorough image of the face-to-face and virtual laboratory environments and their impacts on students' motivation to learn biology.

Statistical analyses provided quantifiable evidence that the novel virtual laboratory environment did not have a differential effect on students' motivation to learn biology, with this finding being supported by the qualitative results. Comparison of the laboratory environments showed that students in the face-to-face labs reported greater instructional support, student interaction and collaboration, relevance of the lab activities, and authentic learning experiences than the students in the virtual labs. Qualitative results indicated the teaching assistants in the face-to-face labs were an influential factor in sustaining students' motivation by providing immediate feedback and instructional support in and out of the laboratory environment. In comparison, the virtual laboratory students often had to redo their lab exercises multiple times because of unclear directions and system glitches, potential barriers to persistence of motivation. The face-to-face students also described the importance of collaborative experiences and hands-on activities while the virtual laboratory students appreciated the convenience of working at their own pace, location, and time. According to social cognitive theory (Bandura, 1986, 2001), the differences in the learning environments reported by the students should have had ramifications for their motivation to learn biology, yet this did not hold true for the students in this study. Therefore, while these laboratory environments are demonstrably different, the virtual laboratories did not negatively impact students' motivation to learn biology and could be an acceptable replacement for face-to-face laboratories in an introductory biology course.

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## CHAPTER ONE: INTRODUCTION

The need for a scientifically literate citizenry is more important than ever. Today, the average American is confronted with complex topics such as global climate change, childhood vaccines, and genetically modified foods. The ability to make informed decisions on these controversial topics hinges on an understanding of basic scientific concepts and skills such as the ability to evaluate scientific evidence and claims. Yet, public understanding of scientific findings is often influenced more by emotional and political factors than by evidence. Accordingly, recent polls have shown there are large differences between the public and scientists' views on issues such as evolution, genetically modified foods, and the use of animals in research (Funk & Rainie, 2015). Furthermore, many Americans remain skeptical of concepts, such as the origin of the universe, that scientists consider truths (Associated Press, 2014). In contrast, a large proportion of both the general public (84%) and scientists (71%) are critical of the quality of K-12 science, technology, engineering, and mathematics (STEM) education in the United States (Funk & Rainie, 2015). Seventy-five percent of scientists' agree that too little K-12 STEM education "is a major factor in the public's limited knowledge about science" (Funk & Rainie, 2015, para. 4).

In the education realm, U.S. student performance on national (National Center for Educational Statistics, 2012) and international (OECD, 2014) assessments of science have remained stagnant, despite many state and federal initiatives and reform efforts (e.g. Affeldt, 2015; Russell, Meredith, Childs, Stein, & Prine, 2014; Webber et al., 2014). At the college level, many students are required to take one to two introductory science courses, often without a laboratory component, depending on their major (e.g. *University of Central Florida 2014-2015 Undergraduate Catalog*, 2014). At large universities, these courses can have enrollments of

upwards of 400 students per section (e.g. Allen & Tanner, 2005; Harackiewicz et al., 2014; Ueckert, Adams, & Lock, 2011), with one instructor teaching multiple sections per semester. This educational environment can be prohibitive to factors that are known to foster students' motivation to learn science, such as student-instructor interactions, collaborative learning, and active learning (American Association for the Advancement of Science, 2009). Furthermore, the American Association for the Advancement of Science (2009) and the National Academies of Science (2003) have made recommendations for transforming undergraduate biology education such as providing time for cooperative learning and inquiry activities that rely on the laboratory portion of these courses.

The laboratory has long been viewed as the province of hands-on work (Lunetta et al., 2007), which has been reported as the most significant factor in sustaining high school and undergraduate students' interest in STEM (Vanmeter-Adams, Frankenfeld, Bases, Espina, & Liotta, 2014). The seminal work by Seymour and Hewitt (1997) describes multiple factors that influence students' decision to leave a STEM major, including competitive science classes and a perceived lack of prior knowledge about science. Yet, the most common reason provided by students switching out of STEM was loss of interest in their STEM major (Seymour & Hewitt, 1997), suggesting that motivation to learn science is an important factor in retention in STEM.

### Statement of the Problem

At many universities introductory biology courses can be characterized by large enrollment (200-400 students) lecture sections with smaller enrollment (24-48 students) laboratory sections (e.g. Allen & Tanner, 2005; Harackiewicz et al., 2014; Ueckert et al., 2011).

The lecture portion of the course is often content-driven with little time for students to interact with their instructor or peers, factors known to be important to students' academic achievement and retention (American Association for the Advancement of Science, 2009; Pascarella & Terenzini, 2005). The laboratory component of science courses are often relied upon for instilling positive attitudes toward science, developing collaborative abilities, promoting interest and motivation, and enhancing communication skills (Hofstein & Lunetta, 1982, 2003; Lunetta et al., 2007). However, laboratory courses are resource intensive (Blosser, 1980; Jenkins, 2007) and, thus, have become a critical juncture between the large-scale efficiency of science education at the university level and the benefits of small group, hands-on learning. Some post-secondary science educators and administrators view virtual laboratories as a potential solution to these competing pressures (Akpan, 2001). While scholars have provided evidence that student achievement in virtual laboratories is equal to, if not higher than, that of students in face-to-face laboratories (Akpan & Strayer, 2010; Finkelstein et al., 2005; Huppert et al., 2002), little is known about the impact of virtual laboratories on students' motivation to learn science, an important factor in sustaining student engagement and interest in science learning.

### Rationale for the Study

Substantial changes to a learning environment should be thoroughly investigated before widespread adoption occurs (Fraser, 2007). This is especially important in a setting that has the potential to influence a large number of students at an early point in their science career where motivation is integral in sustaining engagement in the subject matter. However, motivation is an understudied construct within the affective domain of science education research, especially at

the post-secondary level (Koballa & Glynn, 2007). Accordingly, scholars have called for the use of varied methodological approaches in investigating motivation to learn science (Koballa & Glynn, 2007; Velayutham, Aldridge, & Fraser, 2011).

A majority of the research on motivation to learn science has utilized quantitative data collection methods (e.g. Glynn, Brickman, Armstrong, & Taasobshirazi, 2011; Machina & Gokhale, 2010; Schaefer, Epperson, & Nauta, 1997; Velayutham, Aldridge, & Fraser, 2011) and there is a need for more informed understanding of the impact of the learning environment on student attitudes and motivation to learn using qualitative or mixed methods research techniques (Fraser, 2007; Koballa & Glynn, 2007). More specific to this project, no studies of virtual labs have described their effect on student motivation beyond a few quantitative survey questions, rendering qualitative approaches to this topic necessary and important. This project was also timely and significant because student attitudes toward science can play a major role in persistence in a STEM major (Hernandez, Schultz, Estrada, Woodcock, & Chance, 2013) and there is a national focus on creating an additional one million STEM majors (President's Council of Advisors on Science and Technology, 2012).

Practical implications of this research include providing developers of virtual laboratory platforms with information on the factors that influence student motivation and engagement. Science educators, especially instructors of introductory science courses, will benefit from a more nuanced understanding of the experiences students have in face-to-face and virtual laboratories. The application of the Biology Motivation Questionnaire and Distance Education Learning Environment Survey to a different population will provide additional validity to these instruments and information to the science education research community.



## Research Goals and Research Questions

There were three main goals in this research study. The first goal was to document students' motivation to learn biology at the beginning and end of the semester for group comparisons. The second goal was to identify characteristics of the laboratory environments that were critical to sustaining students' motivation to learn biology throughout the semester. The last goal was to describe students' experiences in the face-to-face and virtual laboratories to provide a more nuanced understanding of the influence of these learning environments on students' motivation to learn biology.

These goals were investigated by four research questions in this mixed methods research study. The first three questions were addressed through quantitative methods, while the fourth question was qualitative in nature.

Research question 1: How does motivation to learn biology differ over the course of the semester between students in a virtual laboratory group and a face-to-face laboratory group?

Research question 2: What differences exist between the learning environments of the face-to-face and virtual laboratories?

Research Question 3: Which factors of the laboratory environments are most influential on students' motivation to learn biology?

Research question 4: What are the experiences of undergraduate students in face-to-face and virtual laboratories in a university introductory biology course?

## Conceptual Framework

The conceptual framework for this study was based on Albert Bandura's (1986, 2001) social cognitive theory, where behavior is conceptualized as the product of interactions between various characteristics of the individual and the environment. Thus, factors in the learning environment of an introductory biology laboratory course were examined to determine their influence on students' motivation to learn biology. Motivation to learn biology can be defined as "an internal state that arouses, directs, and sustains students' [biology-learning] behavior" (Koballa & Glynn, 2007, Chapter 4) and, in this study, has four contributing inputs: self-efficacy, intrinsic motivation, self-determination, and extrinsic motivation. Previous studies have found self-efficacy to be the most influential of these constructs (Glynn et al., 2011). Factors of the learning environment such as student collaboration, active learning, and instructor support were postulated to impact these motivational inputs and thereby have possible consequences for long-term outcomes such as retention of STEM majors and the production of a scientifically literate citizenry.

In this research study, the elements of Bandura's (1986) triad of social cognitive theory are viewed as motivation to learn biology, the students in the Biology I course, and the assigned learning environment (Figure 1). In this conceptualization, motivation to learn biology is viewed as the product of an individual's characteristics and the assigned laboratory environment. However, an individual's motivation to learn biology may influence their actions in the laboratory environment. For example, a student with low motivation to learn biology may have poor attendance or not participate in group activities. And likewise, an individual's motivation to

learn biology may influence characteristics such as choice of a science major or prior science courses.

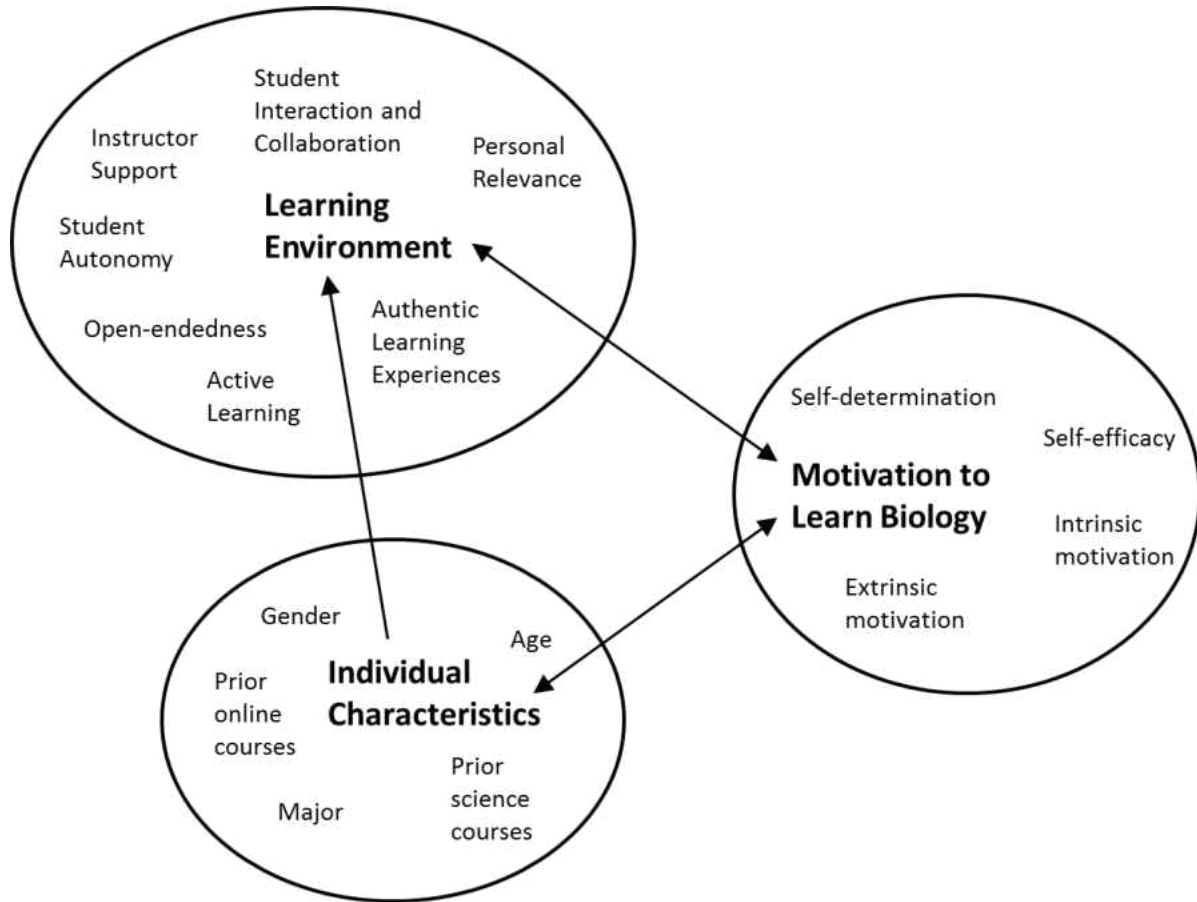


Figure 1. Conceptual framework for this study based on the social cognitive theory.

An individual's characteristics can also impact his or her actions in the laboratory environment. For instance, a student majoring in computer science may have a different reaction to the implementation of virtual labs in an introductory biology course compared to a biomedical major. It is important to note that this model does not use a bidirectional arrow between the laboratory environment and individual characteristics. The laboratory environment is not conceptualized as having a direct influence on an individual's characteristics, whether they are

innate (e.g., gender, ethnicity) or not (e.g., choice of major). In summary, this application of social cognitive theory predicts bidirectional interactions between motivation to learn biology and the laboratory environment, motivation to learn biology and individual characteristics, but not between the laboratory environment and individual characteristics.

Social cognitive theory has also been applied extensively by those interested in understanding classroom motivation, learning, and achievement (e.g. Bandura & Schunk, 1981; Glynn, Taasoobshirazi, & Brickman, 2007; Schunk & Pajares, 2001; Schunk, Pintrich, & Meece, 2008). Through the lens of the social cognitive framework, students are seen as possessing a self-regulating system that affects their beliefs and supports their development of motivation to encourage positive cognitive and affective behaviors (Bandura, 1991b). This self-regulatory system is composed of five main constructs, (1) intrinsic motivation, (2) extrinsic motivation, (3) goal orientation, (4) self-determination, and (5) self-efficacy, that can contribute to a student's motivation to learn (Schunk & Pajares, 2001). Koballa and Glynn (2007) note the creation of many motivational constructs in the current body of science education research and Schunk (2000) advocates using "extant conceptualizations" (p. 116) in identifying and describing motivational constructs to ease in interpretation and application of research results. Thus, the motivational constructs used in this research project have been identified by multiple authors as important contributors to students' motivation to learn science and standard definitions are utilized (e.g., Koballa & Glynn, 2007; Schunk et al., 2008; Schunk, 2000). For example, it is important to distinguish between intrinsic and extrinsic motivation. An intrinsically motivated student chooses to perform tasks, such as joining a science club, for personal fulfillment instead of for reward. Students who perform solely for the purpose of earning a grade or reward (e.g. a

trophy or parental approval) or to avoid punishment are extrinsically motivated (Schunk et al., 2008). Self-efficacy is a highly studied construct of motivation that can be defined as the belief that one can successfully perform an action or behavior (Bandura, 1986). In science, this could be the belief that one has the ability to master a certain concept, perform an experiment, or succeed on an exam. Self-determination is often identified as a component variable of motivation. For this research study, self-determination can be defined as the control students believe they have over their learning of science (Black & Deci, 2000). An understanding of these motivational constructs is needed in order to understand the ways they affect student learning and engagement and how they interact with contextual factors such as the learning environment.

Bandura's (1986) interdependent triad recognizes the importance of the environment on human learning and behavior. Scholars have shown that student perceptions of the learning environment can be a predictor of student learning outcomes (e.g., Fraser, 2012). However, this construct is often overlooked in assessments at the university level. When students' perceive an educational environment as gratifying, open, and positive, they are more likely to possess positive attitudes, have improved achievement (Fraser, 2007), and thus, are also likely to have greater motivation to learn (Koballa & Glynn, 2007). In social cognitive theory, motivation impacts self-regulation by enabling students to engage and sustain in actions that will positively impact their learning (Bandura, 1991a). However, because motivation to learn can be influenced by the learning environment (Fraser, 2007), any manipulation of the learning environment, such as the implementation of virtual labs, should be thoroughly examined.

## Overview of Methods and Methodology

This mixed methods research study paired quantitative assessments of students' motivation to learn biology and their perceptions of the laboratory learning environment with in-depth interviews in the phenomenological methodology. Participants for the interviews were chosen based on their motivation level from a beginning-of-course survey and were interviewed three times throughout the semester. An end-of-course survey was administered to determine whether changes in students' motivation to learn biology or their perceptions of the laboratory environment existed. These data (quantitative and qualitative) were combined to provide a well-rounded perspective of students' motivation to learn biology in face-to-face and virtual laboratories.

## Assumptions

In this study, it was assumed that students answered the questions on the beginning- and end-of-semester surveys truthfully. It was also assumed that students who participated in the individual interviews were open and honest with the researcher. Furthermore, it was assumed that the instruments utilized in this study measured their intended constructs.

## Summary

Many universities have responded to increasing enrollments by offering online courses. Laboratory science courses can play a significant role in student persistence in STEM fields, and this trend towards online courses is broadening to include laboratory courses. In the sciences, virtual labs can supplement or replace resource intensive face-to-face laboratory exercises. These

virtual learning environments are often evaluated for comparable instruction and student performance as the classroom, but other criteria such as student experiences and motivational factors warrant consideration as well, because these factors may be equally or more important in recruitment and retention than performance and achievement. Both qualitative and quantitative methodologies should be utilized to obtain a more nuanced understanding of students' experiences in the novel learning environment of virtual laboratories.

### Definitions

Asynchronous learning: online course material is available to students without regard to time or day; can be for a limited interval (Hallyburton & Lunsford, 2013)

Attitude: “positive or negative feeling about a particular object or behavior” (Butler, 1999)

Extrinsic motivation: motivation to perform an activity as a means to an end or for an external motive (Koballa & Glynn, 2007)

Face-to-face laboratories: also referred to as traditional or physical laboratories, this format requires students and teachers to meet in person at a specified time to complete laboratory activities (Hallyburton & Lunsford, 2013)

Intrinsic motivation: “motivation to perform an activity for its own sake” (Koballa & Glynn, 2007, Chapter 4)

Motivation: “an internal state that arouses, directs, and sustains students' behavior” (Koballa & Glynn, 2007, Chapter 4)

Motivation to learn biology: “an internal state that arouses, directs, and sustains students’ [biology-learning] behavior” (Koballa & Glynn, 2007, Chapter 4); measured by the Biology Motivation Questionnaire II (Glynn et al., 2011)

Motivation to learn science: “an internal state that arouses, directs, and sustains science-learning behavior” (Glynn et al., 2011, p. 1160)

Self-determination: “the ability to have choices and some degree of control in what we do and how we do it” (Koballa & Glynn, 2007, Chapter 4)

Self-efficacy: “beliefs in one’s capabilities to organize and execute the courses of action required to produce given attainments” (Bandura, 1997, p. 3)

Simulation: a computer program that models a system or process (Scalise et al., 2011)

Synchronous learning: student access to course material and/or instructor are dictated by an established schedule of class meetings

Virtual laboratories: a simulation of a laboratory experiment with virtual materials, tools, and equipment that replicate the experience of a traditional laboratory (Scalise et al., 2011)

### Organization of the Dissertation

Chapter 1 of this dissertation lays the foundation for the research described in the subsequent chapters by introducing the research problem, its significance, the research questions, and a brief outline of the research design. The conceptual framework that guided the research study, assumptions, and definitions are also described. Chapter 2 is a review and critique of previous research relevant to this study. A detailed description of the methods utilized in this study is provided in Chapter 3. The quantitative results related to research questions 1, 2, and 3



are presented in Chapter 4, while the qualitative results related to research question 4 are detailed in Chapter 5. Finally, Chapter 6 includes a discussion of these combined results and the concomitant research questions, their implications, and recommendations for future research.

## **CHAPTER TWO: LITERATURE REVIEW**

This chapter presents a summary of the literature on three topics: (a) social cognitive theory, (2) motivation to learn science, and (3) virtual laboratories in science. The first section lays the foundation for the conceptual framework utilized in this study by reviewing the literature on five core concepts in social cognitive research. The second section contains a review of the research on motivation to learn science, identifies gaps in the literature and reviews four main themes: (1) methodological approaches, (2) differences in motivation to learn science across populations of students, (3) the influence of the learning environment, and (4) the use of different theoretical approaches. The third section documents the history of the traditional laboratory and the use of virtual laboratories in science education. This portion of the review is thematically organized by the methodologies used and research on the cognitive and affective domains within virtual laboratories. A critique of the research on each of these major sections is provided as a synthesis of the status of the research literature. The chapter concludes with an explanation of how this review contributed to the current study.

### Social Cognitive Theory

Social cognitive theory integrates many ideas, concepts, and processes into an overall framework for understanding human functioning. Five core concepts from Bandura's works (1986, 1991a, 1991b, 2001) are described here. Examples of the application of these constructs to science education research and/ or classroom teaching and learning are also provided.

The first construct, observational modeling and learning, can be considered the foundation of social cognitive theory. This is the belief that individuals learn new behaviors

through the observations of others in social interactions, educational settings, or other media (Bandura, 1986). Therefore, new behaviors are not learned solely by individuals initiating them and either failing or succeeding, but rather, by the imitation of behaviors modeled by others. Modeling can occur through direct, live observations of behaviors and actions or indirect forms such as verbal and written behaviors. Therefore, students can learn not only from observing their teachers and parents, but also vicariously from their peers. This collaborative support can “provide an opportunity for explicit discussion of scientific concepts and reflection” (Schraw, Crippen, & Hartley, 2006, p. 120). Furthermore, science educators use modeling to demonstrate proper use of laboratory equipment and procedures (e.g. Hayes, Smith, & Eick, 2005), engage students in scientific topics (e.g. Renney, Brewer, & Mooibroek, 2013), and to increase student conceptual understanding (e.g. McKee, Williamson, & Ruebush, 2007).

The second core concept of social cognitive theory is outcome expectations. These are the consequences that arise from one’s actions and reflect an individual’s beliefs about what will most likely ensue if particular behaviors are performed (Bandura, 1986; Schunk & Pajares, 2001). For example, a student may believe that she will be rewarded for assisting another student during class or punished for not paying attention during class. Consequently, her behavior may be mediated by the expected outcome. This construct is often studied in the context of career outcome expectations (e.g. Domene, Socholotiuk, & Woitowicz, 2011; Z. Hazari, Sonnert, Sadler, & Shanahan, 2010).

The third construct, self-efficacy, has become an influential and prominently studied concept within social cognitive theory (e.g. Bolshakova, Johnson, & Czerniak, 2011; DiBenedetto & Bembenuddy, 2013; Schunk & Pajares, 2001). Bandura (1986) describes self-

efficacy as one's belief about whether they will be successful at a given task and theorizes that there are reciprocal interfaces among self-efficacy, achievement, and specific environmental factors. Biology education researchers (Lawson, Banks, & Logvin, 2007) have shown that science self-efficacy in an introductory biology course can be predicted by reasoning ability, but reasoning ability is not predicted by self-efficacy. Thus, students who overestimate their abilities can have subpar achievement.

The fourth core concept is goal setting. Goals are described as cognitive representations of anticipated outcomes and goal setting behavior is another highly studied tenet of social cognitive theory (Meece, Anderman, & Anderman, 2006). Bandura (1986) suggests that goals prompt self-monitoring and regulation and can increase cognitive reactions by specifying the requirements for success. Self-motivation has been found to be highest when goal-setting behavior is combined with feedback as compared to the use of these two conditions alone (Bandura, 1991b). In education, learning goals are defined as "explicit statements about abilities, attitudes, skills, and knowledge that should be acquired by a student through completion of some instructional event" (Duis, Schafer, Nussbaum, & Stewart, 2013, p. 1144). Clearly communicated learning goals have been shown to improve the quality of learning (Marsh, 2007) while curriculum design, instruction, and assessment can be informed by the systematic development of learning goals (Duis et al., 2013).

The last construct in social cognitive theory, self-regulation, has led to a large field of educational research on self-regulated learning (e.g. Schraw et al., 2006; Velayutham, Aldridge, & Fraser, 2012). Bandura (2001) describes self-regulation as the "control over the nature and quality of one's life" (p. 1). Social cognitive theories of self-regulation assume that self-

regulation is dependent on goal setting and initially emphasized three sub-processes: self-observation, self-judgment, and self-reaction (Bandura, 1986). Most educational research now identifies the three components of self-regulated learning as cognition, metacognition, and motivation (Schraw, 1998). Schraw, Crippen, and Hartley (2006) identified six instructional strategies that are key to improving self-regulation in science classes: (1) the use of collaborative learning, (2) inquiry based instruction, (3) problem solving instruction, (4) the use of mental models, (5) technology enhanced instruction, and (6) “the role of beliefs such as self-efficacy and epistemological world views” (p. 111). Social cognitive theory has had a strong influence on some of the recommended strategies.

Three broad types of motivators are described in social cognitive theory (Bandura, 1991a). The first is biological motivation where internal and/ or external events activate a potential physiological condition. Bandura (1991a) cites the example of an infant that becomes restless when she or she expects to be fed, not just when he or she has become hungry. Thus, cognitive mechanisms have an impact as well as biological needs. The second type of motivator can be described as social incentive motivation where positive experiences occur in combination with expressions of interest and approval by others and negative experiences concur with disapproval. The third type is cognitively generated motivation where individuals use self-regulating behaviors to motivate themselves. Bandura (1991a) alleges that “the capability for self-motivation and purposive action is rooted in cognitive activity” and that “most human behavior is activated and regulated over extended periods by anticipatory and self-reactive mechanisms” (p. 71). Thus, the interconnectedness of self-regulating behaviors, motivation, and cognitive achievement can be seen within social cognitive theory.

## Motivation to Learn Science

Before beginning a review of the literature on motivation to learn science, it is important to first define the term. There is a general consensus on the definition of motivation: “the process whereby goal-directed activity is instigated and sustained” (Schunk et al., 2008, p. 4). In education, we are interested in students’ motivation to learn, which is the perpetuation of goal-directed behavior in order to attain knowledge and skills (Schunk et al., 2008), which can then be extended to student learning of science content and skills. While no published reviews of the literature on motivation to learn science were found, other scholars (e.g. Fortus & Vedder-Weiss, 2014) have noted that motivation to learn science has often been conceptualized as attitudes toward science (e.g. Osborne, Simon, & Collins, 2003) or interest in science (e.g. Swarat, Ortony, & Revelle, 2012). Koballa and Glynn (2007) note that “motivation has not been manipulated or assessed as frequently as attitudes by science education researchers” (Chapter 4). While there is overlap between these constructs, this review will focus on studies of overall motivation to learn science and its component variables such as science self-efficacy and extrinsic motivation in an effort to provide some measure of clarity on this topic. Several themes emerged from the research on motivation to learn science and will be reviewed here: (1) methodological approaches, (2) differences in motivation to learn science across student populations, (3) the influence of the learning environment, and (4) theoretical approaches.

### Methodological Approaches to Research on Motivation to Learn Science

Two main investigative approaches were identified within the research on motivation to learn science. The first is the use of an intervention such as a new instructional method and its

effect on students' motivation to learn science (e.g. Liu, Horton, Olmanson, & Toprac, 2011). The second approach involves the correlation of students' motivation to learn science with variables such as gender (e.g. DeBacker & Nelson, 2000), achievement (e.g. Glynn, Taasoobshirazi, & Brickman, 2007), and learning environment characteristics (e.g. Pascarella, Walberg, Junker, & Haertel, 1981) through self-report instruments. Examples of these instruments include the *Intrinsic Motivation Inventory* (Liu et al., 2011), the *Science Motivation Questionnaire II* (Glynn et al., 2011), and the *Students' Adaptive Learning Engagement in Science Questionnaire* (Velayutham et al., 2011). Both of these methodological approaches emphasized quantitative measurements with little inclusion of qualitative methodologies.

Qualitative or mixed methods research is not as common in the literature on motivation to learn science as in attitudinal research, but can provide great insight into the experiences of science students. Koballa and Glynn (2007) "recommend that quantitative data gathered with the use of attitude scales be coupled with other forms of data, such as that collected via individual and group interviews, student drawings, log books, and photographs, to provide a more informed understanding" of student perspectives on learning science (Chapter 4). For example, the use of student essays or open-ended questions in a mixed methods approach can provide triangulating information for quantitative data. Bryan et al. (2011) found that highly motivated high school students (as determined by questionnaire data) were more likely to make statements about enjoying the challenges of learning science and placed a high value on science education, while students with low science motivation only enjoyed science classes when they were fun or could pick their group members for activities and projects.

Approaches such as case study analysis have been used to identify patterns of motivation ranging from intrinsically motivated to learn science to negatively motivated to learn science and task resistant within a sixth grade science class (Lee & Brophy, 1996). These researchers were able to make distinctions between motivation to learn and intrinsic motivation and provided evidence that intrinsic motivation can be task specific rather than a general disposition towards a subject area. Subtle differences such as these are often not captured in the use of purely quantitative assessments, emphasizing the need for varied methods of research on a single topic.

Similarly, Osborne and Collins (2000) conducted focus groups with high school students on their experiences in science education and found they desired more autonomy in their learning opportunities such as laboratory experiences, extended investigations, and discussions. These studies show the rich, thick data that can be collected through the use of varied approaches on the complex topic of motivation to learn science and the valuable information that can be provided to science educators.

#### Research across Student Populations within Motivation to Learn Science

When examining motivation to learn science, research on student populations can provide valuable information. This review will examine research on students by age/ grade level and gender. Trends within these populations can inform scholars as to gaps in the literature or areas of dispute that need further research focus for clarity.

All science educators should be concerned about their students' motivation to learn science, but this is an often overlooked research topic within the post-secondary domain. For example, there is a wealth of research on students' motivation to learn science in high school



(Britner, 2008; Bryan et al., 2011; DeBacker & Nelson, 2000; Nolen & Haladyna, 1990; Nolen, 2003; Stake & Mares, 2005; Velayutham et al., 2012; Velayutham & Aldridge, 2012; Wang & Reeves, 2006; Zeyer & Wolf, 2010), middle school (Anderman & Young, 1994; Liu et al., 2011; Mistler-Jackson & Butler Songer, 2000; Sevinç, Özmen, & Yiğit, 2011; Vedder-Weiss & Fortus, 2011; Weinberg, Basile, & Albright, 2011), and elementary school (Lee & Brophy, 1996; Mantzicopoulos, Patrick, & Samarapungavan, 2008; Meece & Jones, 1996; Milner, Templin, & Czerniak, 2010). In comparison, only a handful of studies of college students' motivation to learn science were found. Lawson, Banks, and Logvin (2007) compared the relationships of self-efficacy and reasoning ability to achievement in an introductory biology course and found reasoning ability was a strong predictor of self-efficacy, but not vice versa. Glynn et al. (2007) used structural equation modeling to examine the relationships between motivation to learn science, science achievement, and students' beliefs in the relevance of science to their career in non-science majors in an introductory science course and found that motivation influenced achievement and students' belief in the relevance of science to their career influenced their motivation. Two studies creating and validating a survey instrument for assessing students' motivation to learn science were found (Glynn et al., 2011; Glynn, Taasoobshirazi, & Brickman, 2009). The instrument developed by Glynn et al. (2009) showed that college students' motivation to learn science was related to their high school preparation in science and GPA in science courses. A study using a revised version of the same questionnaire found that science majors had higher motivation than non-science majors and self-efficacy was strongly related to students' science course GPAs (Glynn et al., 2011). These studies provide valuable information

for science educators, but further investigations such as novel environments and new technologies would also be beneficial.

One general trend that has emerged from the abundance of research on K-12 populations is that elementary students typically have positive attitudes toward science and high motivation to learn science, but a decline is observed from there to middle school and even more in high school (Butler, 1999; Meece, Glienke, & Burg, 2006; Osborne et al., 2003; Piburn & Baker, 1993). However, other scholars argue declining motivation is not always the case (Vedder-Weiss & Fortus, 2011, 2012). The decline in motivation to learn science is often attributed to differences in the educational environment from the early to middle years of school (Anderman & Young, 1994; Meece, Anderman, et al., 2006), underlining the need for an in depth understanding of the factors in the learning environment that are most influential on this construct.

Gender is an often examined variable in science education due to perceived gaps in academic achievement (Meece, Glienke, et al., 2006; Meece & Jones, 1996) and, at the post-secondary level, enrollment in and success in STEM majors (Eddy, Brownell, & Wenderoth, 2014; Gatta & Trigg, 2001). Research on science self-efficacy has repeatedly shown that males are more efficacious than females (Britner, 2008; DeBacker & Nelson, 2000), even when females perform on par or better than males (Britner, 2008; Meece, Glienke, et al., 2006; Pajares, 1996) and that these differences in competency can begin at an early age. For instance, Meece and Jones (1996) found that differences in motivation of fifth and sixth graders were strongly related to ability level rather than gender. Also, differences in motivation to learn science between the genders may be due to cultural stereotypes about scientists and socio-cultural

factors, rather than innate gender differences (Meece, Glienke, et al., 2006; Pajares, 1996). For example, a study of high school students found that males were more likely to hold stereotyped views of science when compared to females (DeBacker & Nelson, 2000). Other scholars have provided evidence that females and males have comparable motivation at the high school level (Bryan et al., 2011) and college level (Glynn et al., 2007). At the college level, a study of non-science majors in a large-enrollment science course found no differences in motivation between the genders, but women were more likely to believe science was relevant to their careers (Glynn et al., 2007). These studies demonstrate the lack of consensus on how gender influences motivation and the need for further investigation in this area.

#### Research on the Learning Environment and Motivation to Learn Science

The environment in which learning takes place can be powerfully influential on student outcomes (Fraser, 2012). Scholars have found that students often report positive perceptions of science in general, but possess negative perceptions of learning science in school (Osborne & Collins, 2001; Osborne et al., 2003). Meece et al. (2006) estimated that classroom differences account for as much as 35% of the variation in students' goal orientations. For instance, an earlier study showed that small-group work increased student confidence, time on task, and motivation compared to whole-class work (Meece & Jones, 1996). The number of interactions between students and students and their science teachers (Piburn & Baker, 1993), teacher support (Velayutham & Aldridge, 2012), teaching strategies (Hanrahan, 1998; Osborne et al., 2003; Piburn & Baker, 1993), student cohesiveness (Velayutham & Aldridge, 2012) and perception of the content topic (Bathgate, Schunn, & Correnti, 2014; Glynn et al., 2007; Osborne & Collins,

2000) have all been shown to influence students' perception of their science learning environment. School culture has also been shown to influence students' motivation to learn science through an increased sense of autonomy and a focus on mastery goals (Vedder-Weiss & Fortus, 2011, 2012). From these studies, it is evident that environmental aspects ranging from instructional techniques to school culture can all influence students' motivation to learn science.

### Theoretical Approaches to Research on Motivation to Learn Science

Scholars have applied many theories in their investigations into the topic of motivation to learn science, but this review will focus on four theoretical frameworks: (1) empathizing-systemizing theory of cognitive science, (2) achievement goal theory, (3) self-determination theory, and (4) social cognitive theory. A description of each framework and relevant findings from the research are provided.

In the *empathizing-systemizing theoretical approach*, a student with a systemizing brain type is able to “perceive physical things and understand these objects and their function in the context of a system” (Zeyer et al., 2013, p. 1048) while a student with an empathizing brain type possesses the ability to “identify and perceive mental states” and “is concerned with understanding people and their psychological makeup” (Zeyer et al., 2013, p. 1048). A positive relationship was found between systemizing cognitive style and motivation to learn science in secondary students, but an empathizing style did not have any influence (Zeyer et al., 2013). Furthermore, male students tended to have a more systemizing brain type while female students showed a more empathizing one (Zeyer & Wolf, 2010; Zeyer et al., 2013). Other scholars have supported this work by confirming that females are more likely to score higher on the

empathizing scale than males and have also shown that scientists score higher on the systemizing scale than those in the humanities (Billington, Baron-Cohen, & Wheelwright, 2007; Focquaert, Steven, Wolford, Colden, & Gazzaniga, 2007). This type of research illustrates and emphasizes innate differences between the genders, but provides little useful information or recommendations on how to close the gender gap in the STEM fields.

*Self-determination theory* is another theory applied to research on motivation in science education and suggests that motivated behaviors vary in the degree to which they are autonomous or controlled (Deci, Vallerand, Pelletier, & Ryan, 1991; Pintrich, 2003). Autonomous behaviors are undertaken out of one's own desire and, thus, are intrinsically motivated. Controlled behaviors stem from an external source, often depend on the social environment, and are extrinsically motivated. An application of self-determination theory to an investigation of students' course-specific self-regulation and their perceptions of autonomy support by their instructors revealed that students who took a college-level organic chemistry course for autonomous reasons had higher perceived competence and interest/ enjoyment and lower anxiety about the course and grade-focused performance goals (Black & Deci, 2000). Likewise, perception of instructors' support of student autonomy predicted the same outcomes as well as students' performance in the course. Thus, as science educators it is important we use instructional techniques that promote students' sense of autonomy and ability to make choices in order to increase their science self-efficacy and intrinsic motivation to learn science.

*Achievement goal theory* attempts to explain students' motivation to learn science in relation to their goal orientation: either mastery goals orientation or performance goals orientation (Meece, Anderman, et al., 2006). Anderman and Young (1994) demonstrated that

students with high science self-efficacy who value science were more likely to be mastery focused, while students who were performance focused tended not to be mastery focused. Also, instructional techniques that emphasized students' performance in science may influence students to be less oriented towards mastery goals (Anderman & Young, 1994). Similarly, research by Vedder-Weiss and Fortus (2013) showed that personal mastery goal orientation was the primary predictor of adolescent students' motivation to engage in science learning in and out of school. In other words, students who desire science competency as opposed to a good science grade are more likely to be engaged in science learning activities in and out of school, an indication of their motivation to learn science. From these studies one can conclude that instructional techniques that promote a competitive classroom environment where student performance is emphasized can be detrimental to increasing students' motivation to learn science. For example, classes with high stakes assessments, such as the typical college science course with only three or four exams, could inadvertently be emphasizing performance goals over mastery goals and impacting students' motivation to learn science.

*Social cognitive theory*, where behavior is seen as the product of an individual's characteristics interacting with characteristics of an environment (Bandura, 1986, 2001), has also been applied to motivational research. For example, a study of non-science majors in an introductory biology course found that motivation to learn science had a direct influence on student achievement in the course and that motivation was influenced by students' belief in the relevance of science to their careers (Glynn et al., 2007). A similar study of high school students in introductory science courses found that self-efficacy, a contributing factor to motivation, was the most related to achievement (Bryan et al., 2011). Student essays and interviews identified

aspects such as inspiring teachers, career goals, and collaborative learning activities as promoting motivation to learn science. The findings from these studies make evident the importance of making science concepts relevant and the need for social interactions in the classroom environment. However, at many universities, introductory science courses have large enrollments that hinder the fostering of social interactions such as small group work, and college professors often feel pressured to cover a large amount of material, leaving little time for instructional techniques that emphasize application of the information.

The four theoretical frameworks described here highlight the various ways that science education researchers approach investigations into students' motivation to learn science. Some overlap can be found among these approaches, such as the importance of instructional techniques that promote student directed learning and the importance of the classroom environment. This information can inform science educators on ways to improve students' motivation and success in the sciences.

### Critique of the Research on Motivation to Learn Science

This section reviewed four themes within the literature on motivation to learn science. First, the common approaches to investigating students' motivation to learn science were examined. Second, research across student populations within motivation research was examined. Third, the role of the learning environment on motivation to learn science was described. And last, four theoretical approaches to the investigation of motivation to learn science were described and analyzed.

Approaches to the investigation of students' motivation to learn science were found to span the breadth of the quantitative to qualitative continuum. Quantitative approaches were the most often found in the literature followed by mixed methods research. Few purely qualitative studies were found in this survey of the literature. More specifically, many studies included the use of quantitative surveys to assess students' motivation to learn science in response to an intervention or in correlation with other variables. These types of studies are important due to their ability to describe patterns of motivation across and within large groups of students, but lack in-depth information on the exact experiences that influence students' motivation to learn science. Such data are only provided through the use of qualitative methodologies, which can provide a voice to our subjects.

The research on motivation to learn science across grade levels has shown a fairly consistent trend of declining motivation from elementary, to middle, and even through high school (Osborne et al., 2003). Yet, little is known about college students' motivation to learn science. The seminal work by Seymour and Hewitt (1997) found that many students who switch out of STEM majors during their first and second years of college cite a declining interest in their major, not academic difficulties, indicating a loss of motivation to learn science post K-12 schooling. Comparatively, there is a wealth of research on, but lack of consensus on the influence of gender on motivation to learn science. However, there is a body of evidence suggesting that males are more likely to have to high science self-efficacy compared to females. Scholars in this area have cautioned against the correlation of gender and motivation in isolation from other important variables such as environment and ability (Meece & Jones, 1996). Clearly,



more research on these subjects, college students and gender, is needed to further understand their association with motivation to learn science.

The influence of the learning environment on students' motivation to learn science cannot be overstated. And while scholars have identified factors that play a key role in students' motivation to learn science, these should be investigated in other contexts such as the college setting where it is often the end of compulsory science education for most students and a change in the learning environment for those who do persist in enrolling in science courses. At large, research universities, most introductory science courses share a similar format: large enrollments of 200 – 400 students in a large lecture hall in a class that meets two to three times per week. These students often have little interaction with their instructors, a very different atmosphere from K-12 science education.

Science education scholars have used a variety of theoretical frameworks ranging from cognitive centered to goal oriented to social based in their investigations of motivation to learn science. One concern with the use of cognitive theories, such as the empathizing-systemizing theory, is the focus on individual characteristics that some consider innate or inherent, with little consideration of the effects of the learning environment. Theories such as self-determination and achievement goal theory can be applied in ways that inform science educators on the use of appropriate instructional techniques to increase students' motivation to learn science. In contrast, social cognitive theory directly takes into account the influence of the learning environment and social interactions along with individual characteristics to provide a comprehensive picture of these influences on students' motivation to learn science.

## The Laboratory in Science Education

In the United States, the laboratory has been a central component of science education for over 200 years (Lunetta et al., 2007). For example, in 1893 the Committee of Ten strongly advocated for the use of the science laboratory by recommending “double periods for laboratory instruction, Saturday morning laboratory exercises, and one afternoon per week to be set aside for out-of-door instruction in geography, botany, zoology, and geology” (DeBoer, 1991, p. 49). Many educators argue that the science laboratory is where students make meaningful connections to the science content taught in the classroom and encourages scientific habits of mind (Hofstein & Lunetta, 1982; Lunetta et al., 2007). This is evident in the prominent role of science laboratory exercises and activities in science education benchmarks and standards (National Research Council, 1996, 2007; NGSS Lead States, 2013). However, not all educators agree that all students in all science courses should be required to engage in laboratory activities (Bradley, 1968; Jenkins, 2007). Moreover, research results have not shown conclusive evidence of positive impacts of science laboratory exercises on student learning, but they may influence student attitudes and assist in the development of collaboration and communication skills (Hofstein & Lunetta, 1982, 2003).

While the nature of this debate over the purpose and benefits of science laboratory instruction has not changed, technological advances have made additions to the landscape of possible laboratory environments. The science laboratory moved into the realm of distance education with the advent of at home science kits where students are mailed or purchase simple laboratory materials to complete activities in their in own home (Hallyburton & Lunsford, 2013;

Johnson, 2002). Today, advances in technology have allowed computer simulations and virtual laboratories to rapidly become a regular component of the landscape of science laboratories.

### Virtual Laboratories in Science Education

Virtual laboratories are a relatively new phenomenon in the realm of science education, and as such, warrant a thorough examination for their value to the teaching and learning of science. Earlier reviews on this topic have noted the benefits and potential drawbacks of physical and virtual labs (de Jong, Linn, & Zacharia, 2013) or limited their review to a specific population (Scalise et al., 2011). This review will demonstrate the existence of two gaps in the literature on virtual laboratories. First, the primary method of investigation has been quantitative comparisons of an outcome measure between a virtual lab activity and a similar face-to-face lab activity with little research into understanding students' experiences in the virtual environment. Second, a majority of the research to date has focused on the cognitive domain with little investigation into constructs within the affective domain. Thus, this literature review will provide a synthesis on the current state of research on virtual laboratories in these areas with critiques and arguments for areas that warrant further research.

#### Methods of research on virtual laboratories

The purpose of this review of the literature is to identify the range of ways that researchers have approached the investigation of virtual laboratories in the sciences. The primary tactic to investigating virtual laboratories was a quantitative comparison of an outcome measure between a virtual laboratory activity and a similar face-to-face laboratory activity. The outcomes most often compared between face-to-face and virtual lab groups were post-lab quizzes (e.g.

Gilman, 2006), lab practicals (e.g. Cobb et al., 2009), and pre-posttests (e.g. Toth et al., 2009). Studies comparing student conceptual understanding in virtual and face-to-face environments were the most common in the literature and will be reviewed in a later section of this chapter.

Quantitative surveys were also prevalent in the research on virtual laboratories and most were created by the researchers specifically for their course. Cobb et al. (2009) created a survey with scales of ease of use of the virtual laboratory, satisfaction with the virtual laboratory, and technology competence and aptitude. Akpan and Strayer (2010) employed an attitudinal assessment with scales of attitude toward dissection, attitude toward school/ science, and attitude towards computers. Pyatt and Sims (2012) created the Virtual and Physical Experimentation Questionnaire (VPEQ) with scales of usefulness of computers, anxiety towards computers, equipment usability, open-endedness, and usefulness of lab. Swan and O'Donnell (2009) created a post-survey with scales of positive attitudes toward the virtual laboratory, self-efficacy, motivation and effort, and preference for traditional form of laboratory instruction. These studies demonstrate that most researchers are concerned with students' acceptance of virtual laboratory activities within their courses and their attitudes toward the use of computers. Only one study (Akpan & Strayer, 2010) investigated the impact of virtual experiences on students' attitudes toward science and found that students in the traditional lab experience had a significant drop in attitude scores compared to the virtual lab group. This study demonstrates the need for further research into the specific aspects that contribute to differences in students' attitudes in traditional and virtual laboratory environments.

Few studies were found to have employed a true qualitative methodological approach, but instead utilized open-ended survey questions to triangulate quantitative data. For example,

students' written reflections on the benefits and drawbacks of working with a virtual and a physical DNA gel electrophoresis experiment suggest that students prefer the virtual experience to occur prior to the physical experience (Toth et al., 2009). Gilman (2006) was able to classify 33 written responses about the use of a virtual cell division lab into 12 positive, 15 negative, and six mixed. Positive comments noted the convenience of virtual laboratories and going at your own pace while the negative comments remarked on the lack of collaboration and hands-on experience. Similarly, students in an introductory biology course enjoyed the opportunities for immediate feedback from instructors, collaborative capabilities, and hands-on experiences found in face-to-face laboratories (Stuckey-Mickell & Stuckey-Danner, 2007). These studies exemplify the types of data collected through the use of open-ended survey questions where researchers seek to determine students' preferences or attitudes towards the use of virtual laboratory activities.

Chini (2010) conducted a mixed methods research study with physical and virtual manipulatives within a face-to-face laboratory environment by investigating three research questions: (1) what did students learn, (2) how do students learn, and (3) what do students think about their learning. These questions were addressed through student performance data, survey data, and interview data. The combination of a phenomenographic approach and quantitative research methods provided evidence that students valued data from the virtual laboratory activities more than the physical activities and that students who completed the virtual activities first had a better understanding of the physics concepts than those who completed the physical activities first. Thus, the combination of qualitative and quantitative methods provided a much greater understanding into students' learning during the laboratory exercises.

A study of pre-service teachers was conducted using a mixed methods research approach in order to discover their conceptions of moon phases before and after an instructional intervention on virtual moon observations (Bell & Trundle, 2008). The data collection included drawings, structured interviews, and a lunar shapes card sort and was analyzed using the constant comparative method. While the students were shown to have gained scientific understandings of lunar concepts, all of the sources of data focused on students' conceptual understanding with no information on their experiences or any constructs within the affective domain. Follow-up studies could determine how the intervention and increases in conceptual understanding impacted students' science self-efficacy and motivation and identify the aspects of the virtual learning environment that were most effective for the students.

There were also a variety of methods of employment of virtual laboratories in the literature. Some scholars implemented virtual laboratories within a face-to-face laboratory environment where students may work together to complete the virtual activities, but no hands-on work is done (e.g. Cobb et al., 2009; Finkelstein et al., 2005). In contrast, blending of virtual and face-to-face laboratories combines virtual and hands-on learning in the face-to-face laboratory (e.g. Toth et al., 2009; Zacharia & de Jong, 2014). For example, students studying light and color in an undergraduate physics course worked in groups of three with concrete and abstract objects (blended) or only abstract objects (virtual only) (Olympiou, Zacharia, & DeJong, 2012). Another method of implementation of virtual laboratories is the asynchronous virtual laboratory where students work remotely, and often independently, to complete their virtual laboratory activities (e.g. Gilman, 2006). Virtual laboratories have also been utilized as pre-

laboratory activities to increase student' pre-knowledge on the lab topic and help prepare them for the face-to-face laboratory exercise (e.g. Winberg & Berg, 2007).

### Research within the cognitive domain on virtual laboratories

The broad categories that researchers have studied within the cognitive domain on virtual laboratories include conceptual change (e.g. Dega, Kriek, & Mogese, 2013; Zacharia & de Jong, 2014), student performance/ achievement (e.g. Finkelstein et al., 2005; Toth et al., 2009), and process skills (e.g. Cobb et al., 2009; Huppert et al., 2002). Many of these studies found that students in the virtual lab group outperformed their counterparts in the face-to-face lab group (e.g. Akpan & Strayer, 2010; Finkelstein et al., 2005; Gilman, 2006; Huppert et al., 2002) while others have shown no differences between the groups (Darrah, Humbert, Finstein, Simon, & Hopkins, 2014; Pyatt & Sims, 2012). More definitively, the literature review by Scalise et al. (2011) reported that 71% of the studies on virtual laboratories and simulations reviewed showed some kind of gains in student learning outcomes, 25% showed mixed results, and 4% showed no gain with use. Thus, there is a lack of evidence showing students in face-to-face lab groups outperform students in virtual lab groups.

Research on student performance has also investigated the impact of combining physical and virtual experimentation. Zacharia and Constantinou (2008) found that students who completed both a physical and a virtual laboratory on heat and temperature outperformed students who only completed the physical laboratory. Similarly, Olympiou and Zacharia (2012) showed that students who learned about optics in a combined virtual and physical setting outperformed those in the virtual only and physical only environments. Several authors have

shown that students learn physics concepts better when virtual and physical environments were combined as compared to only a virtual environment (Jaakkola, Nurmi, & Veermans, 2011) or only a face-to-face environment (Zacharia, Olympiou, & Papaevripidou, 2008)

Other scholars have examined the impact of the order of the virtual and face-to-face experiences on student performance. Akpan and Andre (2000) provided evidence that students who completed only a virtual frog dissection and those who completed the virtual dissection before the physical dissection significantly outperformed students who completed the physical dissection before the virtual dissection and those who only performed the physical dissection. In contrast, Toth et al. (2009) documented no significant effect of sequence of virtual and face-to-face activities on student performance on DNA gel electrophoresis concepts. Likewise, Chini et al. (2012) found no difference in students' understanding of physics concepts based on the effect of order of face-to-face and virtual experimentation. These studies clearly demonstrate the effectiveness of combining physical and virtual experimentation on student learning and that order of the experience may matter in some settings.

This review of the research literature on the cognitive domain within virtual laboratories demonstrates a consensus that participation in virtual laboratories can increase student learning of science concepts. Notable is the lack of studies that document significant increases in student learning in face-to-face laboratories when compared to virtual laboratories. The research conducted within this topic has covered a multitude of areas with increasingly sophisticated studies that examine topics such as the combination and order of virtual and physical experimentation on student learning.



## Research within the affective domain on virtual laboratories

The majority of the research on virtual laboratories has focused on topics that lie within the cognitive domain. A review of the literature on virtual laboratories and science simulations in grades 6-12 found that only 4% of the 79 studies examined student engagement/ attitudes (Scalise et al., 2011). A later review of the literature by de Jong et al. (2013) noted “studies comparing virtual and physical experiments have primarily measured impacts on conceptual understanding of scientific phenomena and inquiry practices, but other outcomes, such as interest in science as a career, are worthy of investigation” (p. 308). The affective domain can be loosely defined as “the realm of values and feelings” (Lederman, 2007) and Koballa and Glynn (2007) state “attitude and motivation are indeed the most critically important constructs of the affective domain in science education” (Chapter 4). Scholars have noted that it is equally important to understand the impact of new instructional methods and learning environments, such as virtual laboratories, on students’ attitudes, interests, and motivation because of their potential impact on student learning (Fraser, 2007; Koballa & Glynn, 2007; Scott, Asoko, & Leach, 2007). Therefore, this review will provide insight into the types of research that have been conducted on the affective domain within virtual laboratories and their main findings.

Gilman (2006) used a virtual laboratory activity on cell division in a college-level biology course. The virtual lab group scored significantly higher on the lab quiz than the traditional lab group, but attitudes towards the online activities and the possible inclusion of additional online labs in the course were mixed. Thus, it can be interpreted that students’ satisfaction with their learning experiences in virtual labs may not correlate with their actual performance.

In contrast, Pyatt and Sims (2012) demonstrated that high school chemistry students possessed positive attitudes toward the use of virtual labs and equal numbers of students viewed the virtual and physical labs as useful to learning their course topics. No significant preferences were found towards one environment over the other. However, students found the virtual labs allowed exploration and manipulation of experimental variables as compared to the face-to-face labs and allowed more time for problem solving, data analysis, interpretation of results, were easier to use, and worked better than the physical labs. These results indicate that students valued the ease of manipulation and experimentation within the virtual environment more than the manual operation of equipment that many science educators assert is the integral component of a laboratory experience.

Similarly, a study of a virtual polymerase chain reaction experiment with undergraduate and masters students in a biotechnology course demonstrated that student satisfaction with the virtual lab was high (Cobb et al., 2009). Interestingly, younger students were more satisfied with the virtual lab than older students and a correlation between ease of use and overall satisfaction was found. These results point out the need for thoughtful planning of virtual experiences and their impact on non-traditional groups of students.

Students in an introductory biology course had the option to use virtual labs in addition to the traditional labs and virtual lab “users” were significantly more positive about the virtual labs than “non-users” on the post-survey (Swan & O’Donnell, 2009). However, the researchers had mixed results between the initial and replication studies on students’ motivation and effort and self-efficacy ratings after using the virtual labs. Conflicting results such as these show the need

for further clarity in this area and the importance of establishing a baseline for the measured constructs in order to ascertain change pre and post treatment.

Akpan and Strayer (2010) used a pre/ post-survey with subscales of attitude toward computers, attitude toward dissection, and attitude toward science/ school and found that students in the face-to-face laboratory group had a significant decrease in mean attitude score for all subscales while no differences were detected in the virtual frog dissection group. Also, the physical dissection group had significantly higher pre-survey scores than the virtual group while the opposite was true of the post-survey. A complete reversal in attitudes between the groups indicates that the dissection experience may not have met the expectations of the students in the physical lab group or they had less than positive experiences during the dissection.

Few studies were found to have investigated constructs within the affective domain such as students' attitudes and motivation. The studies reviewed here show a lack of agreement on students' attitudes toward virtual laboratories. While virtual laboratories may have affordances such as the ability to easily manipulate and experiment with different variables and the production of clean data for analysis, students also value the collaborative nature and immediate feedback provided in face-to-face laboratory experiences.

### Critique of the research on virtual laboratories

This review of the literature on research on virtual laboratories has covered three main areas. First, a review was conducted on the methodological approaches utilized in this field. Second, a review of investigations on the cognitive domain within virtual laboratories was

provided. Third, an evaluation of the research findings on the affective domain within virtual laboratories was provided.

The prevailing methodological approach was found to be a comparison of a quantitative outcome between students engaged in a face-to-face laboratory activity and a similar virtual laboratory activity. A single study was found to have employed a qualitative methodology, the constant comparative method, in determining college students' conceptual understanding of lunar phases through virtual activities (Bell & Trundle, 2008). The majority of qualitative data available on virtual laboratories is from open-ended survey questions used to triangulate findings from quantitative data. While this approach provides practical information, a notable gap in the literature exists on research using qualitative methodologies such as ethnography, phenomenography, or grounded theory.

The majority of research on virtual laboratories occurred within the cognitive domain and the most common topics investigated were conceptual change and student performance. There is a range of research documenting that virtual laboratories can positively impact students' understanding of science concepts. The use of reliable and validated concept inventories, when possible and appropriate, would further enable comparisons across studies and allow for a more general consensus to be drawn. However, there is a notable lack of concept inventories for many science concepts.

In this review of the literature few studies were found to have examined students' attitudes towards science. Instead, scholars investigated students' preferences for or attitudes towards the implementation of virtual labs in their course, a much narrower construct within the affective domain. While this provides some practical insight into the use of virtual labs in some

science courses, the absence of consensus of research results and design issues such as lack of baseline data (Swan & O'Donnell, 2009), indicates a need for further research that can be generalized to other populations. Furthermore, all of the scholars referenced in this review (Akpan & Strayer, 2010; Cobb et al., 2009; Gilman, 2006; Pyatt & Sims, 2012; Swan & O'Donnell, 2009) created their own survey or survey items to assess students' attitudes as opposed to utilizing previously validated surveys that could allow for comparison across studies. While this can be attributed to the fact that these studies focused on the use of virtual labs within a certain course, it also limits the ability to extrapolate these data to future use of virtual laboratories in other courses and the creation of general conclusions on their usage. The use of a previously validated survey such as the Science Motivation Questionnaire (Glynn et al., 2011) would allow researchers and educators to make conclusions and judgments on the impact of virtual labs on students' motivation to learn science.

Furthermore, no studies on virtual labs were found to have investigated motivational constructs previously identified and described by scholars within the field of motivational research. For example, a survey by Swan and O'Donnell (2009) queried students on their "motivation and effort" (p. 413) in face-to-face and virtual labs, but did not define the constructs underlying this scale in their research. For this reason, other scholars have advocated for the use of "extant conceptualizations" (Schunk, 2000, p. 116) in identifying and describing motivational constructs. Use of common terminology and descriptions by researchers would make interpretation and application of research results across studies simpler. The absence of comparable research on students' motivation to learn science could have implications for long-term outcomes such as students' interest in science as a career or beliefs in the value of science.

Last, there is an abundant body of research showing associations between student perceptions of their learning environment and both affective and cognitive outcomes (Fraser, 2007, 2012). Furthermore, there are numerous assessment instruments that could provide useful information in evaluating new approaches to laboratory instruction such as the implementation of virtual labs. Yet, no studies were found to have examined factors of the learning environment in virtual laboratories through the use of a previously validated instrument to determine their influence on students' attitudes, motivation, or conceptual understanding. This information is necessary for understanding the specific aspects of virtual environments that are most influential on these important constructs and lead to positive experiences and student success.

#### Links between Previous Research and this Research Study

This review of the literature on social cognitive theory, motivation to learn science, and virtual laboratories has informed the conceptual framework and design of this research study by identifying the findings that are agreed upon and the gaps in the current research. As with most topics, it is easier to identify what is not known than what is agreed upon within the field.

Bandura's (1986, 2001) social cognitive theory combines factors of the learning environment such as observational modeling and learning with personal factors such as self-efficacy in examination of behaviors such as motivation to learn science. Most scholars would agree that there is a body of evidence supporting the claim that students' motivation to learn science is relatively high in elementary school, but declines through middle and high school (Meece, Anderman, et al., 2006). However, there is a gap in the literature on research on college students and motivation to learn science, and much discord on the effect of gender. Also,

motivational constructs are often confused or lumped together with attitudinal constructs (Osborne et al., 2003). Thus, this research study will contribute to the body of knowledge on college students' motivation to learn science by utilizing motivational factors that have been previously described by scholars, with the collected data differentiated by gender where appropriate.

Research in the cognitive domain has shown that virtual laboratories can have positive effects on students' learning of science concepts due to their ability to stimulate conceptual knowledge and serve as another mode for inquiry experimentation (de Jong et al., 2013; Scalise et al., 2011). In contrast, little research has been conducted within the affective domain, and most of it focused on students' attitudes toward the use of virtual labs. Therefore, there is a need for research on other constructs within the affective domain, such as motivation. Researchers should use clear definitions of the motivational constructs under examination and be encouraged to employ previously validated survey instruments. These points have greatly influenced this research study to include a previously validated instrument, the *Biology Motivation Questionnaire II* (BMQ-II), with clearly defined constructs of self-efficacy, extrinsic motivation, intrinsic motivation, and self-determination (Glynn et al., 2011).

The most common methodological approach within the research on motivation to learn science was a quantitative comparison through self-report instruments. However, Velayutham and Aldridge (2012) state that qualitative methods such as "case studies, classroom observations, and in-depth interviews could lead towards a more comprehensive understanding of the learning environment's influence on student motivation in science learning" (p. 1364). Therefore, this study paired a quantitative instrument, the *Biology Motivation Questionnaire*, with a qualitative

approach, phenomenology, to provide richer insights into students' experiences in face-to-face and virtual labs.

Last, the learning environment has been shown to be very impactful on students' motivation to learn science (Meece, Anderman, et al., 2006). Therefore, any significant changes in this variable, such as the implementation of virtual laboratories, should be thoroughly investigated. This research study included the *Distance Education Learning Environment Survey* (Walker & Fraser, 2005) to elucidate the factors that influence students' motivation to learn science within virtual laboratories in a college introductory biology course.

### Conclusions

This chapter is a review of the literature on motivation to learn science and virtual laboratories in science. The virtual learning environment is a new feature of science teaching and learning and, as such, deserves thorough investigation on a multitude of factors, such as student performance, attitudes, motivation, and experiences. Thus far, the research has predominately focused on student performance and attitudes, with little to no attention on motivational factors or descriptions of student experiences.

Understanding students' motivation to learn science is imperative for building a diverse STEM workforce and creating a scientifically literate citizenry. It is rarely assessed using qualitative methods, which is an important component of assessing the impacts of pedagogy on motivation. Researchers have shown that motivation steadily declines from elementary to high school, but is rarely assessed at the college level. Learning environments in college are critically important to ensuring retention of students. While there have been many theoretical approaches



utilized in researching students' motivation to learn science, the social cognitive framework proposed by Albert Bandura (1986, 1991b) incorporates aspects of both the learning environment and student characteristics, providing researchers multiple facets from which to examine constructs such as motivation.

Laboratory instruction is critical to science education, and virtual laboratory instruction is becoming an increasingly popular tool for reducing the costs of laboratory activities. Virtual labs are typically assessed relative to face-to-face labs through idiosyncratic quantitative assessments, leaving a need for standardization and qualitative assessments. Even these assessments focus on the cognitive domain and too often ignore the possible affective impacts of virtual labs.

Scientific knowledge is growing at an exponential pace and all citizens will need to be able to make public policy decisions about complex issues. Yet there is no compulsion for students to take science while in college. Understanding students' motivation to learn biology in an introductory biology course could be an integral component of creating a scientifically literate citizenry. Furthermore, alterations to the typical lecture and laboratory format of an introductory biology course warrant research using varied methodologies. In this research study, quantitative and qualitative methods were used to begin to understand and describe college students' motivation to learn biology in face-to-face and virtual laboratories in a large introductory biology course.

## **CHAPTER THREE: RESEARCH METHODS AND METHODOLOGY**

A mixed methods design was selected for this research study. Mixed methods research utilizes methodologies from both the quantitative and qualitative research paradigms to provide richer insights into the phenomenon of interest (Gall, Gall, & Borg, 2006; Teddlie & Tashakkori, 2011). This was a fixed mixed methods design where “the use of quantitative and qualitative methods is predetermined and planned at the start of the research process, and the procedures are implemented as planned” (Creswell & Plano-Clark, 2010, p. 54). In this chapter the setting for the research study is described, the overall mixed methods design is defined, and the quantitative and qualitative methods employed are explained.

### Setting

This research study occurred in the “Principles of Biology I” course (BSC 2010) at the University of Central Florida, a large metropolitan research university, during the spring semester of 2014. This introductory biology course is a foundational course required for over 15 majors and five minors including athletic training, biology/ biomedical sciences/ biotechnology, computer science, forensic science, psychology and science education (I. Castro, personal communication, January 21, 2015). Enrollment for the course is almost always at capacity. Three sections of BSC 2010 lecture were offered in spring 2014 with a student enrollment of 454 in each section (maximum capacity). The two lecture sections chosen for this study had the same instructor, an effort to increase internal validity by controlling variables extraneous to the experiment (Gall et al., 2006). The UCF Biology Department chose one of the two lecture sections and its affiliated laboratory sections as the treatment group- virtual labs, while the other

lecture section and its students served as the comparison group- face-to-face labs. Students had no prior knowledge of the implementation of virtual labs in one of the lecture sections prior to registration, and because both sections were filled to capacity during the add/ drop period, little to no switching between the sections occurred once the students were informed of the research study.

Table 1

*Comparison of face-to-face and virtual laboratory environments*

Characteristic	Face-to-Face Laboratory	Virtual Laboratory
Collaboration	All lab activities are designed for group work	Not possible <i>within</i> the virtual environment
Instructional assistance	Graduate teaching assistants are available for assistance	Automated teaching assistant in the virtual environment provides limited help
Ability to redo lab activities	No	Yes
Convenience	Must attend scheduled class section; students who come to class late may not be allowed to attend the lab	Seven day window to complete the assigned lab activities
Time allowance for lab activities	1 hour 50 minutes	Unlimited
Preparation required for lab activities	Students should read lab handout before class	Students have to successfully complete a question and answer session before beginning the lab simulations
Hardware required	Students need to print out and bring lab handout to class and must wear closed-toe shoes to lab	Students must have access to a computer
Software required	None	None
Formative assessment	None	Students are quizzed throughout the virtual lab activities
Summative assessment	Students take four in-lab quizzes during the semester	Students take four in-lab quizzes during the semester

The independent variable in this research study was the assigned laboratory environment: face-to-face or virtual. The students were provided with a lab schedule during their first week of

the Biology I labs, January 15 – 17, 2014, which identified the lab topic and instructional mode, face-to-face or virtual (Appendix A). After the first week of lab, the students assigned to the face-to-face lab group attended the physical lab each week of the semester, while the virtual lab group attended the physical lab for course assessments, such as exams and quizzes, and two lab exercises at the end of the semester. The remaining labs were conducted in the virtual environment. Each virtual laboratory exercise was available to the students for one week, Monday to Sunday. Further description of these environments is provided in Table 1.

#### Face-to-Face Laboratory Environment

The face-to-face labs met once a week for one hour and fifty minutes. This is considered a reduced meeting time from the two hour and fifty minute pattern that is typical of most introductory biology laboratory courses. The maximum class size was 48 students. Each lab section was led by two graduate teaching assistants (GTAs) who began each lab class with a brief introduction to the subject matter and pertinent instructions, usually via PowerPoint. Typically, students worked together in groups of two to four to complete the lab exercise for that week. The instructions for the lab activities were provided in a weekly handout that the students accessed from the class Webcourses page. Students were not graded on their completion of the lab activities or the lab handout; instead a lab quiz was given every two to three weeks over the material covered. The GTAs circulated the lab room to provide feedback and assistance to students as needed during the lab class.

A typical laboratory classroom had four lab benches that each seats twelve students (Figure 2). A taller bench at the front of the room served as the teaching podium for the GTAs. A

projection screen and whiteboard were located behind the teaching bench. One wall of the room had cabinets with microscopes and a sink. The opposite wall had another sink and storage cabinets. A fume hood was located in the back of the room.

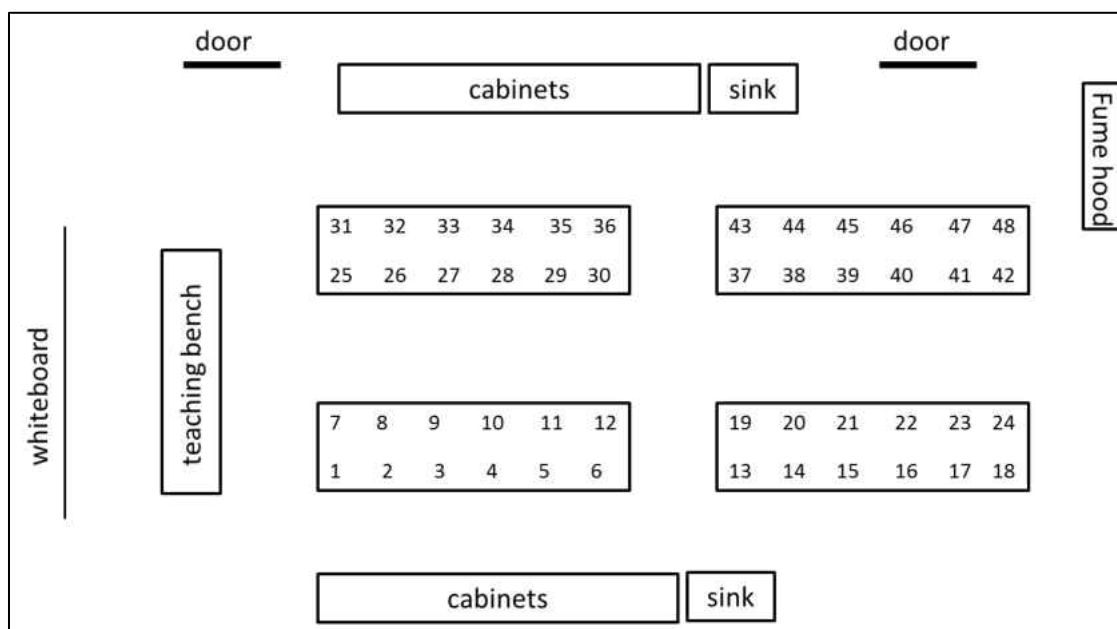


Figure 2. Diagram of a typical biology teaching laboratory.

### Virtual Laboratory Environment

The lab sections assigned as the virtual labs met the second week of the semester to review the class schedule and syllabus and then met in person only on weeks there was a quiz or exam (Appendix A). Students were instructed to complete the appropriate virtual lab topic(s) during the week noted on the lab schedule. Students were able to work on the virtual labs independently or with other students at their convenience during the seven day period each assignment was available. Students could also complete the virtual labs as many times as they chose, unlike the face-to-face lab group. While the virtual lab program provided students with a

mastery score for each lab topic, this did not impact their lab grade. Virtual lab students were only assessed through the lab quizzes, just as the face-to-face lab students, thus, the only incentive for both groups of students to complete their lab exercises were the quiz grades.

The face-to-face laboratory environment in this study can be described as a fairly typical college level laboratory setting (lab benches, groups of students working together, teaching assistants, etc.) However, it is warranted to describe the novel learning environment of the virtual labs in depth. LearnSmart by McGraw Hill Higher Education (McGraw Hill Higher Education, New York, NY) is an adaptive learning system that includes LearnSmart Labs. Before beginning a lab simulation, students must master pertinent concepts through a series of virtual question and answer sessions. The questions come in multiple formats: multiple choice, true/ false, fill in the blank, multiple answer, etc. (Figure 3).

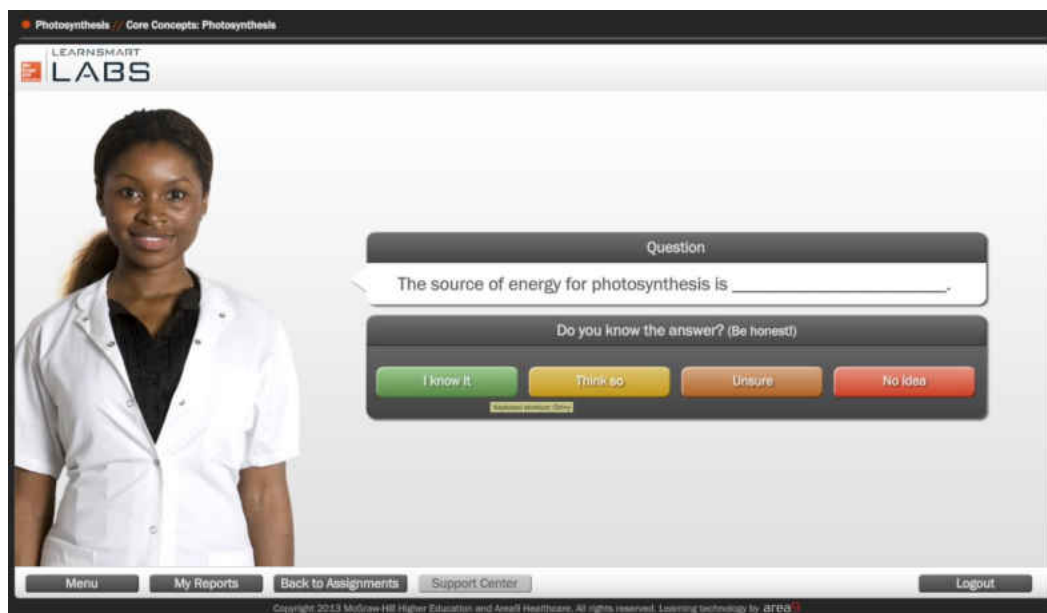
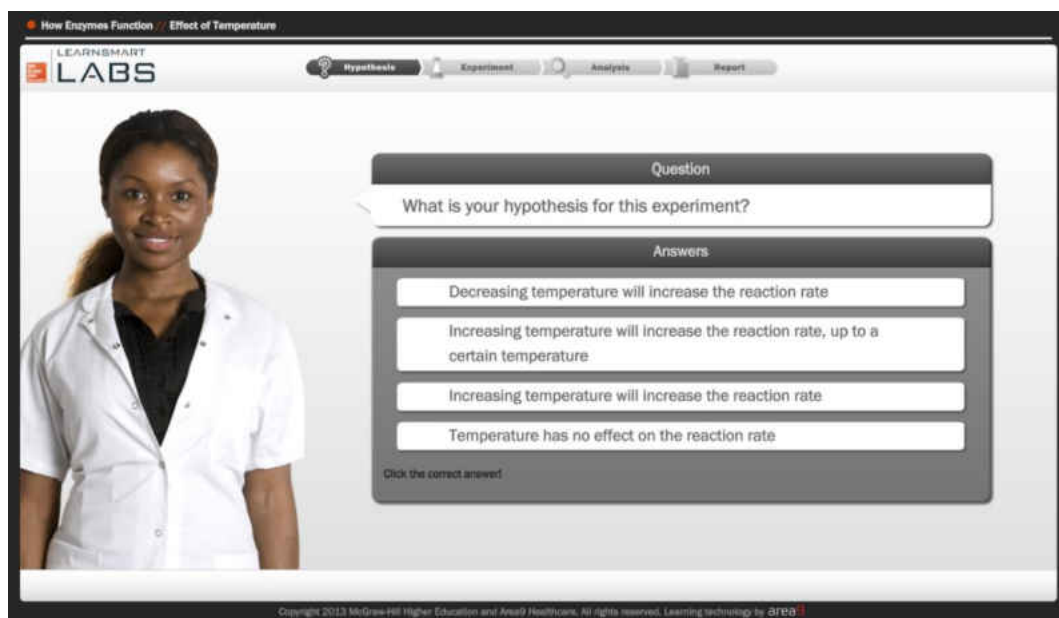


Figure 3. Example virtual laboratory question.

If students choose an incorrect answer they are directed to remediation material such as a text passage, video, or diagram. For each question, students are asked to gauge their confidence level with their answer, from “I know it”, “Think so”, “Unsure”, and “No idea.” The adaptive learning software chooses subsequent questions based on the student’s mastery of the previous question and confidence in the answer chosen.

Once a student has mastered the lab related material, he or she can proceed to the lab simulation. Oftentimes, the students are asked to make a hypothesis before beginning the simulation (Figure 4).



*Figure 4.* Example virtual laboratory hypothesis question.

Within the virtual environment, students can manipulate virtual laboratory equipment such as respirometers, pH meters, and microscopes, record data in a lab notebook, and follow written procedures similar to a lab handout (Figure 5). A virtual, automated GTA provides instructions on how to complete the lab, points out the lab equipment, and at the end of the simulation,

informs students whether their data collection was correct. However, it is important to note that students do not have the ability to ask for real-time help or collaborate with other students within this virtual laboratory environment.

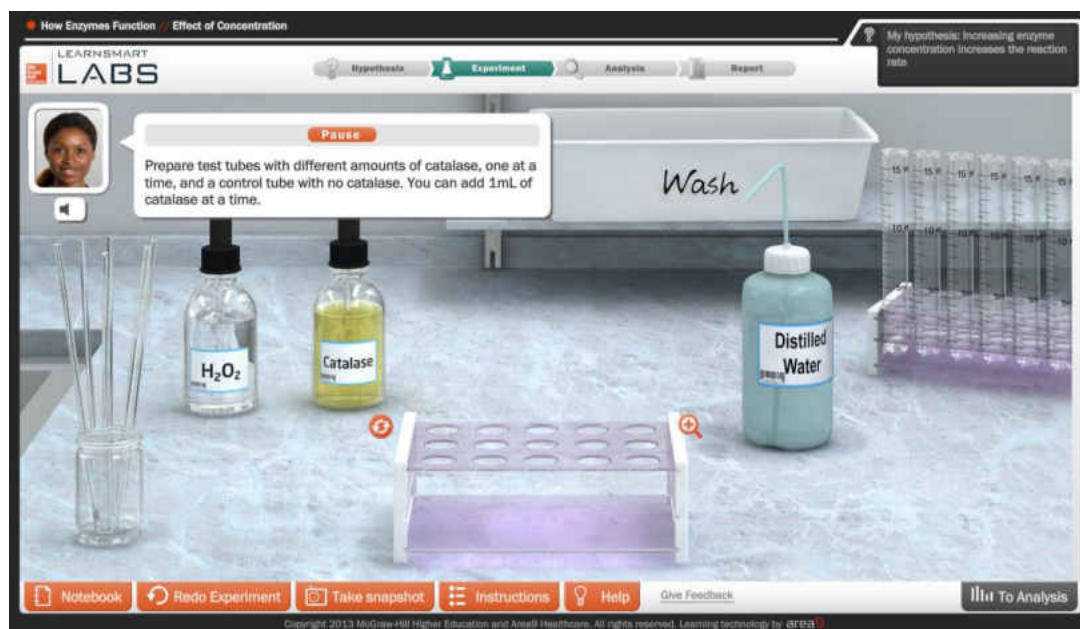


Figure 5. Example of a virtual laboratory simulation with a lab bench, supplies, equipment, and assistance from the automated teaching assistant.

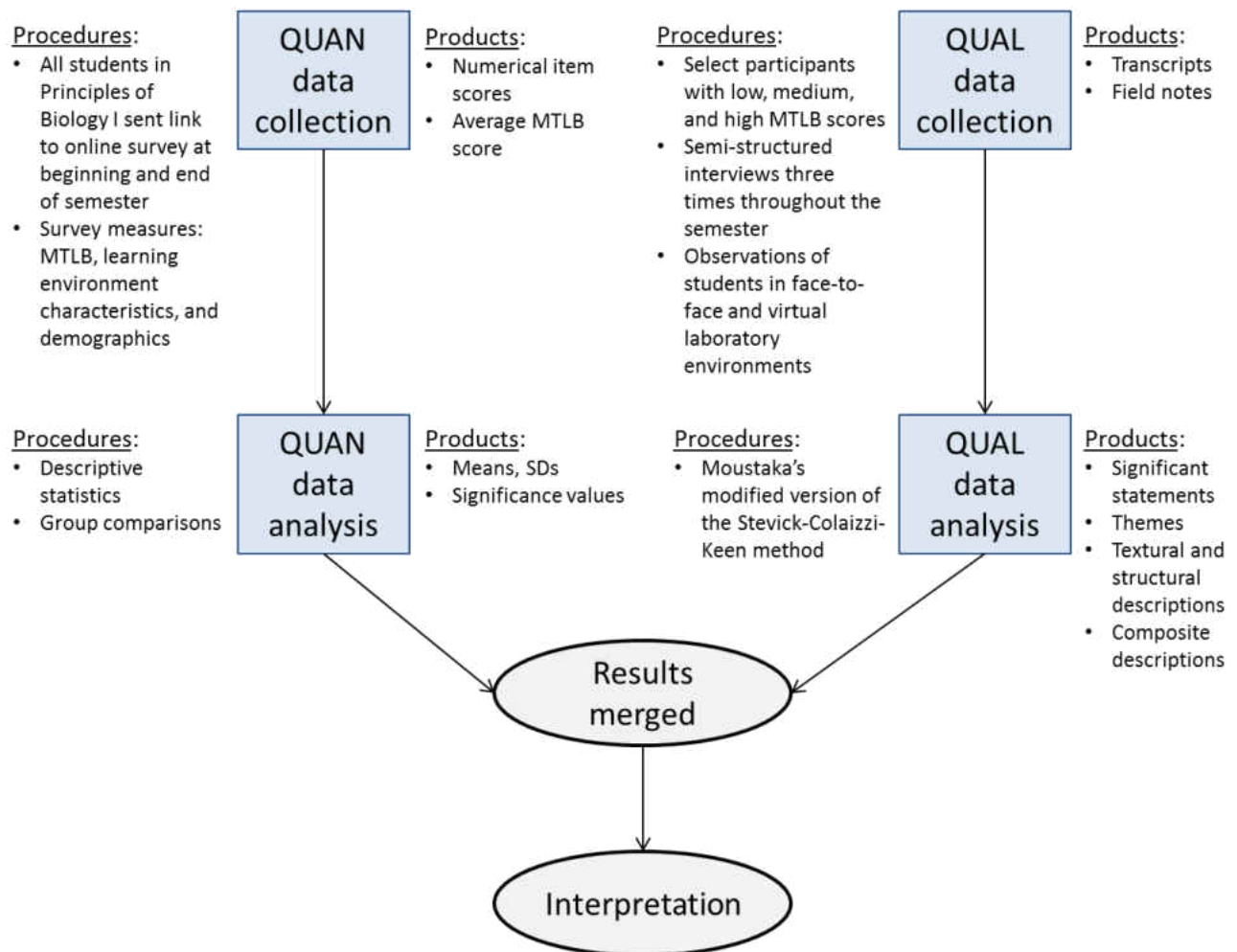
### Mixed Methods Convergent Parallel Design

The mixed methods convergent parallel design uses quantitative and qualitative methods to produce complementary data on a single topic (Creswell & Plano-Clark, 2010). This design brings together the strengths of both quantitative and qualitative methods. For this study, the quantitative methods allowed for data collection on a large sample to discover trends and make generalizations. The qualitative methods were used to collect in-depth details that are not inherent in quantitative data. A strength of the convergent parallel design is the ability for “direct



comparison and contrast of quantitative statistical results and qualitative findings for corroboration and validation purposes” (Creswell & Plano-Clark, 2010, p. 77).

There are four characteristics to consider in mixed methods research: priority, the level of interaction, timing, and mixing (Creswell & Plano-Clark, 2010). The quantitative and qualitative strands were given equal priority in addressing the research problem. The survey data provided information on motivation to learn biology and the learning environments for a large sample ( $n = 512$ ) of the students enrolled in the course. The interview and observation data gave insight into the experiences of a smaller number of students ( $n = 12$ ), but provided greater detail and a more nuanced understanding than the survey data alone. The two strands were semi-independent of each other in this research study and data were collected concurrently. The research questions, the majority of the data collection, and the data analysis were conducted independently of each other. However, the sample for the qualitative strand was chosen based on the first collection of quantitative data. The quantitative and qualitative strands were mixed after data analysis when conclusions were drawn during the data interpretation phase. Therefore, these strands of data were not completely independent even though they were distinct and separate in nature. Figure 6 depicts the order of the procedures in this research study (adapted from Creswell & Plano-Clark, 2010 p. 117).



Note: MTLB = motivation to learn biology; SDs = standard deviations

Figure 6. Description of mixed methods convergent parallel design used in this research study.

### Quantitative Methods

#### Participants

The population for this research study included students enrolled in the three sections of the Principles of Biology I course during the spring 2014 semester. Purposive sampling was used to select the two lecture sections that had the same instructor ( $N = 762$ ). The sub-sample for the

quantitative study included students enrolled in the Principles of Biology I course who completed both the beginning and end of semester surveys ( $n = 512$ ). This sub-sample was 67% of the total sample possible in the two lecture sections of the course and was fairly evenly split between the face-to-face (49%) and virtual (51%) lab groups.

The 512 participants were 63% female and 37% male. Self-report data indicate that the participants were “White/ Caucasian” (52%), “Hispanic/ Latino” (16%), “Black/ African American” (14%), “Asian” (10%) and “Other” (9%). The majority of participants were between the ages of 18-22 (92%). For most of the students (71%), this was their first college-level laboratory course. The most common major reported was biomedical sciences (36%), followed by health sciences (18%), engineering and computer science (9%), nursing (8%), social sciences (7%), and biology (6%).

### Procedure

Participation in the research study was voluntary. Quantitative data were collected through online surveys at the beginning and end of the spring 2014 semester. The students enrolled in the Principles of Biology I course were provided a link for the survey on the course website. One bonus point was given as an incentive for completion of the survey. Students could earn up to ten bonus points during the semester, with opportunities for more than ten points being offered to all students in the course.

### Informed Consent Process

The Principles of Biology Course Coordinator and the researcher informed the students in the two lecture sections about the research study on the second day of class, January 8, 2014.

The IRB approved informed consent document was presented to the students along with an overview of the project (Appendix B). The course instructor also posted the informed consent document on the class Webcourses page. Signed consent forms were not needed per IRB approval (SBE-13-09837). To opt out of participating in the research study, students were instructed to contact the Principle Investigator by email. Student age was a self-reported demographic variable collected on the questionnaire at the beginning of the semester and students who indicated they were under the age of 18 were excluded from the data analyses and all associated data were removed due to lack of parental consent. Only two students under the age of 18 completed both surveys.

### Instruments

A questionnaire was distributed to the students at two points during the semester. The first questionnaire was disseminated during the second week of the semester, the first week of the lab class. The beginning-of-semester survey collected participants' demographic information (Appendix C) and assessed their initial motivation to learn biology.

The Biology Motivation Questionnaire II © (BMQ-II; Glynn et al., 2011) was used to measure participants' motivation to learn biology at the beginning and end of the semester (Appendix D). This instrument consisted of 25 items on a 5-point rating scale of temporal frequency (1 = never, 5 = always). The possible score range for the instrument was 25 – 125 with higher scores indicating greater motivation to learn biology. The five subscales within the instrument and their Cronbach's alphas were: (1) intrinsic motivation (0.89), (2) self-determination (0.88), (3) self-efficacy (0.83), (4) career motivation (0.92), and (5) grade

motivation (0.81). The combined Cronbach's alpha of all 25 items was 0.92. These results indicated a high level of internal consistency or reliability of the subscales and instrument as a whole. Furthermore, Glynn et al. (2011) reported that science majors scored significantly higher on all subscales compared to the non-science majors which they interpret as another indication of construct validity. Also, each subscale was found to correlate with college science GPAs, providing evidence of criterion-related validity.

The BMQ-II instrument was validated for use in introductory courses in the general education science population with both biology majors and non-biology majors, similar to the population used in this research study. Validation of the BMQ-II for the population under consideration was performed by combining the responses to the beginning and end of semester questionnaires ( $N = 1024$ ). Using a principal component analysis with Direct Oblimin with Kaiser Normalization rotation, the instrument items loaded on five components with eigenvalues greater than 1. These five factors accounted for 73.68% of the total variance. Factor 1 contained the five items for self-efficacy with Cronbach's alpha of 0.9. Factor 2 contained the five items for career motivation with Cronbach's alpha of 0.96. Factor 3 contained the five items for grade motivation with Cronbach's alpha of 0.83. Factor 4 contained the five items for self-determination with Cronbach's alpha of 0.88. And Factor Five contained the five items for intrinsic motivation with Cronbach's alpha of 0.9. Cronbach's alpha coefficient for the entire instrument was 0.95. These data indicate the BMQ-II is highly reliable for use in this general education science population.

The second questionnaire was distributed at the end of the semester and contained the BMQ-II plus a modified version of the Distance Education Learning Environments Survey

(DELES; Appendix E; Walker & Fraser, 2005). The post-semester survey was used to reassess students' motivation to learn biology and gather information on perceptions of the assigned lab environments. The DELES was developed for use in higher education and was field tested with undergraduate ( $n = 186$ ), masters ( $n = 364$ ), and doctoral students ( $n = 130$ ) and found to be a valid instrument for assessing students' perceptions of their learning environment (Walker & Fraser, 2005). It was chosen for use in this study over other valid instruments such as the Science Laboratory Environment Inventory (Fraser, Giddings, & McRobbie, 1995) because of its applicability to both laboratory environments.

The DELES had 34 items in six subscales that are scored on a 5-point rating scale of temporal frequency (1 = never, 5 = always). The six subscales and their Cronbach's alphas were: (1) instructor support (0.87), (2) student interaction and collaboration (0.94), (3) personal relevance (0.92), (4) authentic learning (0.89), (5) active learning (0.75), and (6) student autonomy (0.79) (Walker & Fraser, 2005). These scores indicated a high level of internal consistency or reliability of the subscales and instrument as a whole.

This instrument was modified by removing two items from the subscale instructor support and adding six items from the Science Laboratory Environment Inventory (SLEI; Fraser, Giddings, & McRobbie, 1995). The two items, (1) the instructor helps me identify problem areas in my study and (2) the instructor provides me with positive and negative feedback on my work, were removed because these were neither expected of the teaching assistants in the face-to-face laboratories nor a component of the virtual laboratories. The six items added to the instrument composed the subscale open-endedness which was determined to be an important factor to compare between the two environments. Open-endedness described the level of scientific inquiry

students engaged in during their laboratory activities (Fraser & Griffiths, 1992). Many scholars and science educators believe open inquiry to be an important component of laboratory education (Hofstein & Lunetta, 1982, 2003; Lunetta et al., 2007). This sub-scale had a Cronbach's alpha of 0.71. The SLEI has been validated for assessment of science laboratory environments in high schools and universities, in the U.S. and internationally (Fraser et al., 1995; Fraser, McRobbie, & Giddings, 1993; Fraser & Griffiths, 1992).

The modified version of the DELES survey used in this research study had seven subscales, including the addition of the open-endedness subscale from the SLEI. Validation of the modified DELES was performed using responses from the end of semester questionnaire ( $N = 512$ ). Factor analysis was performed using principle component analysis with Promax rotation (Velicer & Jackson, 1990). The 39 instrument items loaded onto six factors, not the anticipated seven factors. The subscales student autonomy and active learning were combined into one factor. Items with a correlation below 0.6 were removed from the survey and factor analysis was performed again. Items OPEN1, OPEN5, and AUTHEN1 were removed using this method. The remaining 36 items loaded onto six factors and accounted for 74.54% of the total variance (Table 2). Factor 1 contained the seven items from the subscale student interaction and collaboration with reliability of 0.96. Factor 2 contained the five items from the subscale student autonomy plus the three items from the subscale active learning with reliability of 0.93. Factor 3 contained the seven items from the subscale personal relevance with reliability of 0.91. Factor 4 contained the six items from the subscale instructor support with reliability of 0.95. Factor 5 contained four of the six items from the subscale open-endedness with reliability of 0.87. And Factor 6 contained four of the five items from the subscale authentic learning with reliability of 0.91.

Cronbach's alpha for these 36 items was 0.95, indicating a high level of reliability for its use in this population.

Table 2

*Factor analysis of modified Distance Education Learning Environment Survey*

Scale	Items	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
COLLAB4	I discuss my ideas with other students.	0.95					
COLLAB5	I collaborate with other students in the class.	0.94					
COLLAB3	I share information with other students.	0.94					
COLLAB1	I work with others.	0.91					
COLLAB6	Group work is part of the class activities.	0.86					
COLLAB2	I relate my work to others' work.	0.81					
COLLAB7	Students work cooperatively in lab sessions.	0.71					
AUTON1	I make decisions about my learning.		0.88				
ACTIVE3	I solve my own problems.		0.87				
AUTON5	I approach learning in my own way.		0.85				
ACTIVE2	I seek my own answers.		0.83				
AUTON2	I work during times that I find convenient.		0.81				
AUTON3	I am in control of my learning.		0.79				
AUTON4	I play an important role in my learning.		0.76				
ACTIVE1	I explore my own strategies for learning.		0.68				
RELEV3	I can connect my studies to my activities outside of the lab class.			0.88			
RELEV5	I link lab work to my life outside of university.			0.85			
RELEV4	I apply my everyday experiences in this lab class.			0.85			
RELEV7	I apply my out-of-class experience.			0.82			
RELEV2	I am able to pursue topics that interest me.			0.8			
RELEV6	I learn things about the world outside of university.			0.62			
RELEV1	I can relate what I learn to my life outside of university.			0.62			
INSTR4	The instructor adequately addresses my				0.96		



Scale	Items	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
	questions.						
INSTR2	The instructor responds promptly to my questions.				0.9		
INSTR1	If I have a question, the instructor finds time to respond.				0.9		
INSTR3	The instructor gives me valuable feedback on my assignments.				0.88		
INSTR6	It is easy to contact the instructor.				0.86		
INSTR5	The instructor encourages my participation.				0.78		
OPEN3	In the lab sessions, different students do different experiments.					0.88	
OPEN2	In this lab class, we are required to design our own experiments to solve a given problem.					0.85	
OPEN4	Students are allowed to go beyond the regular lab exercise and do some experimenting on their own.					0.85	
OPEN6	Students decide the best way to proceed during lab experiments.					0.82	
AUTHEN4	I work with real examples.						0.89
AUTHEN3	I work on assignments that deal with real-world information.						0.85
AUTHEN2	I use real facts in lab activities.						0.7
AUTHEN5	I enter the real world of the topic of study.						0.67

### Data Analysis

The four research questions driving this study were answered by several forms of data (Table 3). The quantitative survey data collected in this study were analyzed using the *Statistical Package for the Social Sciences 20*. Participant responses to the beginning and end of course surveys were combined through the use of a student provided identifier, their NID (Network Identification). Data of participants who did not complete both the beginning- and end-of-semester surveys were excluded in further statistical analyses. Data screening was performed

prior to statistical comparisons (Gall et al., 2006). First, missing values were searched for throughout the dataset. If a participant failed to answer more than 10% of the items on the combined surveys, the student's data were removed from further analyses. Randomly scattered missing values were replaced with the mean value for that survey item.

Table 3

*Primary and secondary data sources of data for each research question*

Research Question	Primary Data Source	Secondary Data Source
1 – Change in motivation to learn biology	Biology Motivation Questionnaire II	Interview data
2 – Differences between the learning environments	Distance Education Learning Environment Survey	Interview data and observation data
3 – Influence of the laboratory environment on motivation to learn biology	Biology Motivation Questionnaire II and Distance Education Learning Environment Survey	
4 – Students' experiences in the laboratories	Interview data	Observation data

Descriptive statistics for the beginning and end of semester BMQ-II and the DELES questionnaires were calculated along with tests of normality. The total scores for each instrument and their respective subscales were checked for outliers through boxplots and Q-Q plots. Outliers were identified and examined for potential random responding by a participant. No outliers were removed from the data set. The group comparisons for Research Questions 1 and 2 were calculated using independent *t*-tests, paired samples *t*-tests, Welch's *t*' tests, or one-way Analysis of Variance (ANOVA), where appropriate. Bonferroni corrections were made where multiple comparisons were performed within a family of hypotheses. Non-parametric statistical analyses

were also performed to ensure the probability distributions of the variables assessed did not affect the significance of the findings. Stepwise multiple regression analyses were conducted for Research Question 3. Research Question 4 was addressed through qualitative methods which are described in the following section.

### Qualitative Methods

#### Phenomenological Methodology

Phenomenological research is “one in which it is important to understand several individuals’ common or shared experiences of a phenomenon” (Creswell, 2007, p. 60).

Moustakas (1994) states

The aim of phenomenological research is to determine what an experience means for the persons who have had the experience and are able to provide a comprehensive description of it. From the individual descriptions general or universal meanings are derived, in other words the essences or structures of the experience (p. 13).

The main goal of this research study was to understand students’ experiences in face-to-face and virtual biology labs and the effect these experiences had on their motivation to learn biology. The phenomena of interest were the face-to-face and virtual biology labs and the experiences of several students in those labs.

#### Researcher as the Instrument

“In phenomenological studies the investigator abstains from making suppositions, focuses on a specific topic freshly and naively” (Moustakas, 1994, p. 47). Therefore, it is

important that the researcher suspend her past knowledge and experience on the topic under examination in order to understand the phenomenon at a deeper level. To do this, bracketing is used to identify and set aside one's beliefs, feelings, and perceptions to better understand the phenomenon through the experiences of the participants (Creswell, 2007). Before beginning data collection, I attempted to fully bracket my experiences that related to this project and acknowledged my preconceptions in this crucial part of the research process. The bracketing interview and resulting themes are further described in Appendix F.

### Procedure

The online survey conducted at the beginning of the semester was a recruitment tool for participants for the qualitative portion of this study. Students were asked to provide an email address if they were interested in participating in interviews and/ or observations about their experiences in the biology labs throughout the semester. Over 450 students provided an email address to indicate their willingness to participate in the research project. The participants selected for the phenomenological study were offered ten points of extra credit to encourage them to complete all three interviews. Over the course of the semester, all students were provided many opportunities for extra credit, but no student could receive more than ten points of extra credit total.

### Participants

Twelve students participated in the qualitative portion of this study (Table 4). Pseudonyms were used to ensure confidentiality of the data. These participants were selected based on their initial motivation to learn biology score (high, medium, or low) and demographic

factors such as gender, age, ethnicity, and major. One student withdrew from the course mid-way through the semester and another student only completed two of the three interviews, therefore, the data of these two students were not used in this study.

Table 4

*Characteristics of participants in the phenomenological study*

Participant <sup>a</sup>	Group <sup>b</sup>	Gender	Ethnicity	Major	MTLB <sup>c</sup>
Lance	VL	Male	White	Computer Science	Low
Leon	VL	Male	Hispanic	Sports and Exercise Science	Low
Lexi	F2F	Female	African American	Health Science	Low
Mia	F2F	Female	Hispanic	Mathematics	Medium
Melanie	VL	Female	Hispanic	Science Education	Medium
Madge	VL	Female	Asian	Biomedical Science	Medium
Hugh	VL	Male	White	Sports and Exercise Science	High
Heidi	F2F	Female	White	Biomedical Science	High
Holly	F2F	Female	White	Health Science – Pre Dental	High
Hank	F2F	Male	Asian	Computer Science	High
Hannah	VL	Female	White	Biomedical Science	High
Heather	VL	Female	Multi-racial	Biomedical Science	High

*Note.* <sup>a</sup>Participants are identified by pseudonyms to ensure confidentiality of data. <sup>b</sup>F2F is the face-to-face lab group while VL is the virtual lab group. <sup>c</sup>MTLB is motivation to learn biology.

#### Data Collection

In keeping with the traditions of phenomenological research, the main sources of data collection were interviews with the selected participants. Individual semi-structured interviews were conducted at the beginning, middle, and end of the semester and audio-recorded. The first interview allowed the researcher to gain rapport with the participant, assess their initial

motivation to learn biology, and describe their prior experiences in science courses. The second interview focused on the participant's experiences in their assigned lab environment and the meaning made of these experiences. The final interview was similar to the second interview, but also asked the participant to describe any changes to their motivation to learn biology over the course of the semester. An outline of the interview questions for each group can be found in Appendix G.

Observational data of students' activities in the face-to-face and virtual labs were collected twice throughout the semester to triangulate and increase the trustworthiness of the survey and interview data (Creswell & Plano-Clark, 2010; Creswell, 2007). Four students participating in the phenomenological study were observed completing one lab exercise in their assigned lab environment (face-to-face or virtual). Observations about the environment, activities students engaged in during the lab, and conversations between students were collected into field notes (Creswell, 2007). The students were asked about these experiences in the following interview. These data provided insight into students' experiences in their laboratory environment (Research Question #4), while also providing triangulation for the quantitative comparisons between the environments (Research Question #2).

### Data Analysis

Two sources of data were collected in the qualitative portion of this study: interviews and observations. The interviews were transcribed verbatim while descriptive and reflective notes were created from the observational field notes (Creswell, 2007). These sources formed the raw data for analysis.

Moustakas' (1994) modified version of the Stevick-Colaizzi-Keen method was used to organize and analyze the qualitative data obtained in this study. These sequential steps were followed:

1. The researcher's experiences with biology labs were fully described.
2. A list of significant statements about students' experiences in the biology labs and their motivation to learn biology were derived from the transcript data. A list of "non-repetitive, non-overlapping statements" was created in the process of "horizontalization" of the data (Moustakas, 1994, p. 122).
3. These significant statements were grouped into "meaning units or themes" (Creswell, 2007, p. 159; Moustakas, 1994, p. 122).
4. "Textural descriptions" (Moustakas, 1994, p. 122) of the experiences, including verbatim examples, were constructed from the list of themes. Creswell (2007) explains this as describing "what" (p. 159) the participants experienced.
5. A description of "how" the experiences occurred created the "structural descriptions" including "reflecting on the setting and context of the phenomenon" (Creswell, 2007, p. 159; Moustakas, 1994, p. 122). The data derived from the observations were employed here.
6. A "composite textural-structural description of the meanings and essences of the experience" were created (Moustakas, 1994, p. 122).

The qualitative data were divided into two main sections: the first round of interview data and the combined second and third rounds of interview data. The first round of interview data covered the topics of prior science experiences, students' initial motivation to learn biology, and

reactions of the participants assigned to the virtual laboratory group. In the second and third set of interviews the participants described their experiences in the biology labs and the impact these experiences had on their continuing motivation to learn biology. Observation data were used to triangulate the participants' accounts and to provide depictions of the laboratory environment and activities.

### Summary

This mixed-methods study was conducted in the laboratory portion of the Principles of Biology I course at the University of Central Florida. The researcher's experiences with biology labs, as a student, graduate teaching assistant, and laboratory coordinator, were bracketed. A questionnaire was sent out at the beginning of the semester to collect demographic data and gauge students' initial motivation to learn biology. An end of semester questionnaire gauged students' final motivation to learn biology and their perception of their laboratory learning environment. Participants who completed both the beginning and end of semester questionnaires comprised the sub-sample of 512 participants. Fourteen participants were recruited from the beginning of the semester questionnaire and participated in interviews throughout the semester, with data from 12 of these participants included in the data analysis. The interview data were transcribed verbatim; significant statements were culled, and merged into themes. These themes were used to write textural and structural descriptions that culminated in a composite description. Observational data were used for triangulation of both the survey and interview data.



## CHAPTER FOUR: QUANTITATIVE RESULTS

The purpose of this research project was twofold: (1) to compare the impact of face-to-face and virtual laboratories on students' motivation to learn biology and (2) to describe the experiences of students in the face-to-face and virtual laboratories. The first objective was addressed by three quantitative research questions; the results of which are presented in this chapter. The second objective was qualitative in nature and those results are presented in the following chapter (Chapter 5).

### Research Question One

Research question 1: How does motivation to learn biology differ over the course of the semester between the face-to-face and virtual laboratory groups?

This question was answered by examining the participants' responses to the Biology Motivation Questionnaire II© (BMQ-II; Glynn, Brickman, Armstrong, & Taasobshirazi, 2011) at the beginning and end of the semester. Table 5 provides a summary and range of the subscales of the BMQ-II. This instrument consists of 25 items on a 5-point rating scale of temporal frequency (1 = never, 5 = always). The possible score range for the instrument is 25 – 125 with higher scores indicating greater motivation to learn biology. The score range was divided into three groups: highly motivated students (125-101), moderately motivated students (100-75), and low motivated students (75<).

Over half ( $n = 269$ ) of the 512 students scored in the highly motivated range, while 43.2% ( $n = 221$ ) were moderately motivated, and 4.3% ( $n = 22$ ) had low motivation to learn biology. The face-to-face laboratory group ( $n = 249$ ) was 46% highly motivated learners, 50%

moderately motivated learners, and 4% low motivated learners. The virtual laboratory group ( $n = 263$ ) was 58.5% highly motivated learners, 36.5% moderately motivated learners, and 5% low motivated learners.

Table 5

*Descriptions and ranges of the subscales of the Biology Motivation Questionnaire II ©*

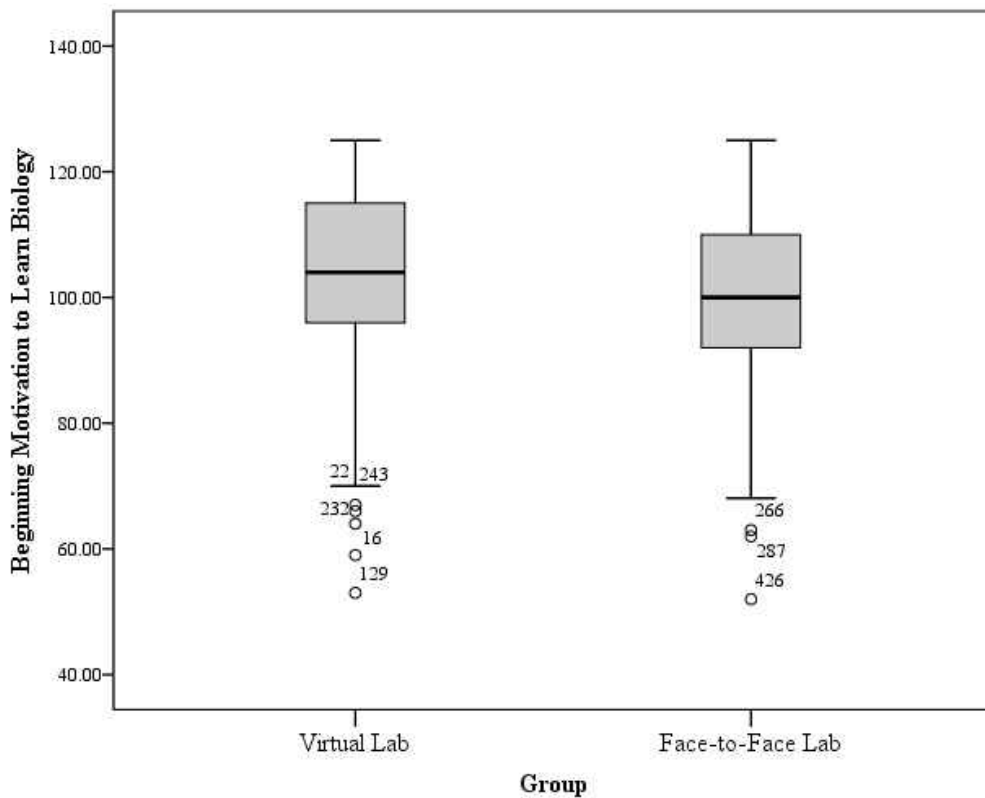
Subscale	Description	Range
Intrinsic Motivation	Performance of a task for one's own enjoyment	5-25
Grade Motivation	Performance of a task for a grade; short-term form of extrinsic motivation	5-25
Self-determination	One's perception of control over his or her learning	5-25
Career Motivation	Performance of a task with a future career in mind; long-term form of extrinsic motivation	5-25
Self-efficacy	Belief in one's ability to perform a task	5-25

#### Motivation to Learn Biology at the Beginning of the Semester

Statistically significant differences in motivation to learn biology were found between the face-to-face and virtual lab groups on the beginning-of-semester questionnaire. An independent  $t$ -test revealed that overall motivation to learn biology was significantly higher ( $t_{(510)} = 2.82, p = 0.005$ ) in the virtual lab group ( $M = 103.72, SD = 14.46$ ) than the face-to-face group ( $M = 100.23, SD = 13.59$ ). Cohen's  $d$  was calculated as 0.25, a low effect (Cohen, 1992). Review of the Shapiro-Wilk test for normality ( $SW_{(512)} = 0.97, p < 0.001$ ) indicated some non-normality of these data. A boxplot of the beginning of semester motivation to learn biology scores shows both groups had several outliers (Figure 7) and these data were negatively skewed. Skewness (-0.52) and kurtosis (0.17) were within the range of normality and Levene's test showed the

homogeneity of variance assumption was satisfied ( $F = 1.49, p = 0.22$ ). Also, the robustness of a two-tailed independent  $t$ -test is assumed to minimize the effects of Type I and Type II errors.

Due to some departures from normality in the beginning of semester motivation to learn biology data, a non-parametric test equivalent to the independent  $t$ -test was also conducted. The Mann-Whitney U test indicated a statistically significant difference in the beginning of semester motivation scores ( $U = 27458, p = 0.002$ ). These results support the findings from the independent  $t$ -test.



*Figure 7.* The median beginning of semester motivation score for the virtual laboratory group was higher than the face-to-face laboratory group. The box represents the middle 50% of the distribution of the scores while the whiskers represent the range of scores with outliers displayed as circles.

Further examination of the beginning of semester data revealed significant differences between the face-to-face and virtual lab groups in the BMQ-II subscales Self-determination ( $t_{(510)} = 3.24, p = 0.001$ ), and Self-efficacy ( $t_{(510)} = 2.9, p = 0.004$ ), but not Intrinsic Motivation ( $t_{(510)} = 2.36, p = 0.019$ ), Grade Motivation ( $t_{(510)} = 2.0, p = 0.046$ ), or Career Motivation ( $t_{(510)} = 1.14, p = 0.254$ ) when using a Bonferroni adjusted alpha level of 0.0083. However, Cohen's  $d$  showed the magnitude of these differences to be small ( $d < 0.3$ ) for each comparison (Cohen, 1992). The mean scores for the two laboratory environments on these subscales can be seen in Table 6.

Table 6

*Mean scores for the subscales of the BMQ-II for the face-to-face and virtual lab groups*

Time	Group <sup>a</sup>	Intrinsic Motivation (25)	Grade Motivation (25)	Self-determination (25)	Career Motivation (25)	Self-efficacy (25)
Beginning	F2F	18.14 (3.94)	22.5 (2.35)	19.28 (3.23)	20.02 (4.79)	20.29 (3.27)
	VL	18.95* (3.85)	22.93* (2.5)	20.21* (3.26)	20.52 (5.15)	21.12* (3.19)
End	F2F	17.19 (4.31)	21.49 (3.14)	18.57 (3.77)	18.46 (5.68)	18.66 (4.13)
	VL	17.9 (4.22)	21.67 (3.22)	19.18 (3.76)	18.97 (5.58)	18.89 (4.33)
Change	F2F	-1.06 (3.1)	-1.26 (2.77)	-1.03 (3.5)	-1.55 (3.69)	-2.23 (3.88)
	VL	-0.95 (3.09)	-1.01 (2.74)	-0.71 (3.11)	-1.55 (3.79)	-1.63 (3.64)

*Note.* Standard deviations are in parentheses.

<sup>a</sup>F2F = face-to-face lab group ( $n = 249$ ); VL = virtual lab group ( $n = 263$ ).

\*  $p < 0.05$

#### Motivation to Learn Biology at the End of the Semester

In contrast, an independent  $t$ -test revealed that no statistically significant difference in total motivation to learn biology ( $t_{(510)} = 1.5, p = 0.133$ ) existed between the face-to-face ( $M = 94.37, SD = 16.42$ ) and virtual lab groups ( $M = 96.6, SD = 17.06$ ) on the end-of-semester questionnaire. The mean scores for the two lab groups on the BMQ-II subscales are shown in

Table 6. The Shapiro-Wilk test ( $SW_{(512)} = 0.98, p < 0.001$ ) suggests the distribution of these data deviated from normality, but skewness (-0.34) and kurtosis (-0.03) were within the range of normality. The negative skew of these data is depicted by the boxplot in Figure 8 where several outliers for the virtual lab group can also be seen. Levene's test indicated the homogeneity of variance assumption was satisfied ( $F = 0.16, p = 0.687$ ).

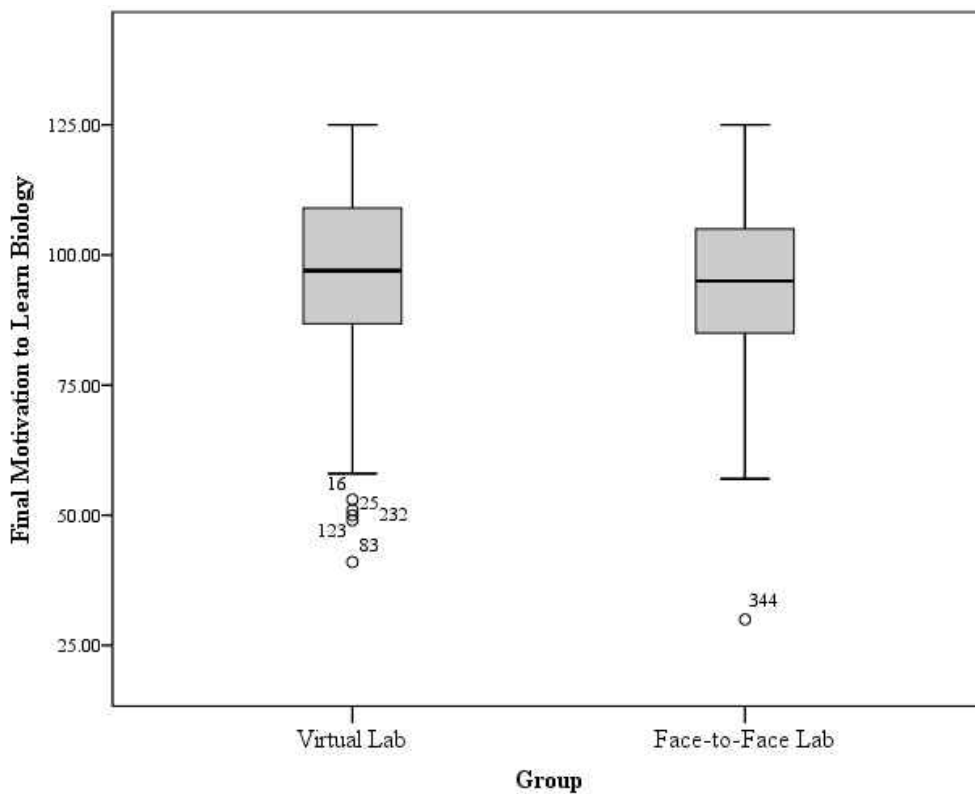


Figure 8. The median score was higher for the virtual laboratory group than the face-to-face laboratory group. The box represents the middle 50% of the distribution of the scores while the whiskers represent the range of scores. Outliers are shown as circles.

To test whether there was a mean difference in the end of semester motivation to learn biology scores based on the laboratory group (face-to-face or virtual) while controlling for the

beginning of semester scores, an Analysis of Covariance (ANCOVA) test was performed using the beginning of the semester motivation to learn biology scores as the covariate and the end of semester motivation scores as the dependent variable (Lomax & Hahs-Vaughn, 2012). The results suggest a statistically significant effect of the covariate, beginning of semester motivation, on the dependent variable, end of semester motivation ( $F = 459.99, p < 0.001$ ). However, no statistically significant effect for the laboratory group was found ( $F = 0.36, p = 0.548$ ). These results indicate that no differences in end of semester motivation were found between the face-to-face and virtual laboratory groups when the beginning of semester motivation scores were held constant.

#### Change in Motivation to Learn Biology

Change in motivation to learn biology was calculated as a participant's end-of-semester motivation to learn biology score minus the beginning-of-semester motivation to learn biology score. These data were examined for differences in the overall Biology I sample, laboratory groups, and motivation groups.

A dependent *t*-test revealed the Biology I participants experienced a significant decline ( $M = -6.51, SD = 12.4, t_{(511)} = 11.87, p < 0.001$ ) in overall motivation from beginning to end of the semester. Significant differences were found in each of the subscales as well, even with a Bonferroni adjusted alpha level of 0.0083. A small effect size ( $d < 0.5$ ) was found for most of these comparisons, except for the change in total motivation ( $d = 0.52$ ) and self-efficacy ( $d = 0.51$ ). These data are shown in Table 7.

Table 7

*Mean motivation to learn biology scores for the Biology I participants*

	Beginning of the Semester		End of the Semester	
	<i>Mean</i>	<i>SD</i>	<i>Mean</i>	<i>SD</i>
BMQ-II Total (125)	102.02	14.14	<b>95.51*</b>	16.78
Intrinsic Motivation (25)	18.56	3.92	17.55*	4.27
Grade Motivation (25)	22.72	2.41	21.58*	3.18
Self-determination (25)	19.75	3.28	18.88*	3.77
Career Motivation (25)	20.27	4.98	18.72*	5.63
Self-efficacy (25)	20.72	3.25	<b>18.78*</b>	4.23

Note. *SD* = standard deviations; boldface indicates Cohen's *d* above 0.5.

\*  $p < 0.001$

An Analysis of Covariance (ANCOVA) test was performed using the beginning of the semester motivation to learn biology scores as the covariate and the change in motivation scores as the dependent variable. No differences in the change in motivation ( $F_{(1)} = 0.36, p = 0.55$ ) were found between the face-to-face ( $M = -5.85, SD = 11.69$ ) and virtual laboratory ( $M = -7.13, SD = 13.03$ ) groups when the beginning of semester motivation scores were held constant. The mean change in motivation to learn biology for the two laboratory groups on each of the subscales of the BMQ-II can be seen in Table 6. These data were not normally distributed ( $SW_{(512)} = 0.98, p < 0.001$ ), but skewness (-0.62) and kurtosis (1.49) were within the range of normality, and the homogeneity of variance assumption was satisfied ( $F = 3.45, p = 0.064$ ). An ANCOVA test was applied to the change in motivation data by grouping the beginning-of-semester motivation to learn biology scores into high (125-101), medium (100-76), and low ( $75 <$ ) groups by using the beginning of semester motivation data as the covariate. These groupings were determined by an

examination of the beginning of semester motivation data and suggestions by scholars who have used the Science Motivation Questionnaire (e.g. Glynn et al., 2007; Obrentz, 2012). Over the course of the semester, the highly motivated group experienced a decrease in motivation ( $M = -8.06$ ,  $SD = 12.29$ ) as did the medium motivated group ( $M = -5.4$ ,  $SD = 12.41$ ). The mean motivation for the low motivated group increased over the semester ( $M = 1.37$ ,  $SD = 9.67$ ). The ANCOVA test showed no significant differences ( $F_{(2)} = 0.84$ ,  $p = 0.435$ ) between the three groups in their change in motivation from the beginning to the end of the semester. Levene's test of equality of error variances indicated the assumption of homogeneity of variance was met for this analysis ( $F = 1.09$ ,  $p = 0.337$ ),

Table 8

*Mean change in motivation to learn biology for each motivation group by laboratory group*

	High Motivated Learners (125-100)	Medium Motivated Learners (100-76)	Low Motivated Learners (75<)
Face-to-Face Labs	-7.08 (10.46)	-5.33 (12.71)	2.55 (8.35)
Virtual Labs	-8.8 (13.49)	-5.48 (12.07)	0.56 (10.74)

*Note.* Standard deviations are in parentheses.

The motivation groups were then compared by learning environment. The mean changes in motivation by group and laboratory environment are shown in Table 8. Independent  $t$ -tests indicated that no significant differences in the change in motivation to learn biology were found between the face-to-face and virtual lab groups with high ( $t_{(267)} = -1.137$ ,  $p = 0.257$ ), medium ( $t_{(219)} = -0.088$ ,  $p = 0.93$ ), and low ( $t_{(20)} = -0.464$ ,  $p = 0.647$ ) motivation at the beginning of the



semester. Because some non-normality and non-homogeneity of variance existed for these data, Welch  $t'$  test were also conducted. These results were the same as the independent  $t$ -tests. Thus, any deviation from normality and homogeneity of variance did not affect the results of this comparison.

### Motivation to Learn Biology by Gender

The motivation to learn biology data were also disaggregated by gender. The 512 Biology I course sample was 63.28% (324) female and 36.72% (188) male. Females had significantly higher total motivation at the beginning ( $t_{(510)} = 5.11, p < 0.001$ ) and end of the semester ( $t_{(510)} = 4.92, p < 0.001$ ) compared to the males ( $d < 0.5$ ). However, no difference was found in their change in motivation ( $t_{(510)} = 0.82, p = 0.413$ ). The 263 virtual laboratory sample was 63.88% (168) female and 36.12% (95) male. In the virtual laboratory group, the females began ( $t_{(261)} = 3.47, p = 0.001$ ) and ended ( $t_{(261)} = 3.74, p < 0.001$ ) the semester with significantly higher motivation to learn biology than the males ( $d < 0.5$ ), but no significant difference in their change in motivation was found ( $t_{(261)} = 1.00, p = 0.318$ ). The mean scores for the virtual laboratory group and overall Biology I course are shown in Table 9.

Further examination of the change in motivation data by subscale was performed with the entire Biology I course sample. The mean scores for females and males on the BMQ-II subscales can be seen in Table 10. Using a Bonferroni adjusted alpha of 0.0083, significant differences were found between the genders on the beginning of semester questionnaire on the subscales of Grade Motivation ( $t_{(510)} = 4.56, p < 0.001$ ), Self-determination ( $t_{(510)} = 4.62, p < 0.001$ ), and Career Motivation ( $t_{(510)} = 7.88, p < 0.001$ ), but not Intrinsic Motivation ( $t_{(510)} = 2.32, p = 0.021$ )

or Self-efficacy ( $t_{(510)} = -0.36, p = 0.722$ ). Cohen's  $d$  was calculated for each of the comparisons with a statistical difference and only Career Motivation was determined to have a moderate effect,  $d = 0.68$ .

Table 9

*Motivation to learn biology by gender in the overall Biology I course and the virtual laboratory group*

Time	Virtual Laboratory Group		Biology I Course	
	Females ( $n = 168$ )	Males ( $n = 95$ )	Females ( $n = 324$ )	Males ( $n = 188$ )
Beginning of Semester	106* (12.9)	99.69 (16.17)	104.4* (12.22)	97.93 (16.49)
End of Semester	99.48* (15.21)	91.49 (18.96)	98.23* (15.06)	90.83 (18.51)
Change	-6.52 (12.49)	-8.19 (13.94)	-6.16 (12.21)	-7.1 (12.75)

*Note.* Standard deviations are in parentheses.

\*  $p < 0.05$

There were significant differences between the genders on the end of semester questionnaire on the same three subscales: Grade Motivation ( $t_{(510)} = 4.79, p < 0.001$ ), Self-determination ( $t_{(510)} = 4.91, p < 0.001$ ), and Career Motivation ( $t_{(510)} = 7.19, p < 0.001$ ), but not Intrinsic Motivation ( $t_{(510)} = 2.26, p = 0.024$ ) or Self-efficacy ( $t_{(510)} = -0.12, p = 0.91$ ). The change in each subscale by gender was not significantly different. Cohen's  $d$  for each comparison was determined to be a small effect, except for Career Motivation,  $d = 0.67$ , a moderate effect.

Table 10

*Mean scores for the subscales of the BMQ-II for all females and males*

Time	Gender	Intrinsic Motivation (25)	Grade Motivation (25)	Self-determination (25)	Career Motivation (25)	Self-efficacy (25)
Beginning	Female	18.86* (3.64)	23.09* (2.05)	20.25* (3.01)	<b>21.52*</b> (3.7)	20.68 (3.25)
	Male	18.03 (4.3)	22.1 (2.8)	18.89 (3.53)	18.12 (6.05)	20.78 (3.26)
End	Female	17.88* (3.92)	22.08* (2.67)	19.49* (3.43)	<b>20.02*</b> (4.75)	18.76 (4.3)
	Male	16.99 (4.78)	20.72 (3.76)	17.83 (4.11)	16.48 (6.29)	18.76 (4.3)
Change	Female	-0.98 (2.94)	-1.0 (2.5)	-0.76 (3.21)	-1.5 (3.83)	-1.91 (3.97)
	Male	-1.04 (3.34)	-1.38 (3.15)	-1.07 (3.5)	-1.64 (3.58)	-1.97 (3.42)

*Note.* Standard deviations are in parentheses. Boldface indicates Cohen's *d* above 0.5.

\*  $p < 0.05$

### Research Question Two

Research question 2: What differences exist between the learning environments of the face-to-face and virtual laboratories?

This question was answered using the modified Distance Education Learning Environment Survey (DELES; Walker & Fraser, 2005) that students completed at the end of the semester. This questionnaire also used a 5-point temporal rating scale (1 = never, 5 = always). Factor analysis determined there were six factors for this population. A summary of each subscale and its range is shown in Table 11. The maximum possible score on the DELES was 180.

Table 11

*Descriptions and ranges of the subscales of the Distance Education Learning Environment**Survey*

Subscale	Description	Range
Instructor Support	Engagement and interaction between students and an instructor	6-30
Student Interaction and Collaboration	Degree of contact, communication, and group work among students	7-35
Personal Relevance	Significance and applicability of class activities	7-35
Authentic Learning	Engagement in genuine and realistic class activities	4-20
Open-endedness	Extent to which activities are inquiry based	4-20
Active Learning/ Student Autonomy	Ability to self-direct learning	8-40

Significant differences were found between the face-to-face and virtual lab groups on the total score for the modified DELES questionnaire. An independent *t*-test indicates that the total DELES score was significantly higher ( $t_{(510)} = -5.91, p < 0.001$ ) in the face-to-face lab group ( $M = 132.36, SD = 18.89$ ) than the virtual lab group ( $M = 120.9, SD = 24.44$ ). Cohen's *d* was calculated as  $d = 0.52$ , a moderate effect size. The Shapiro-Wilk test for normality showed some non-normality to these data ( $SW_{(512)} = 0.99, p < 0.001$ ), but skewness (-0.28) and kurtosis (0.78) were within normal limits. Levene's test indicates the homogeneity of variance assumption was not satisfied ( $F = 9.11, p = 0.003$ ), but the results of a Welch *t*' test were the same as the independent *t*-test. Thus, any deviation from homogeneity of variance did not affect these results.

Table 12

Mean scores for the subscales of the DELES for the face-to-face and virtual lab groups

Group	Instructor Support (30)	Student Interaction and Collaboration (35)	Personal Relevance (35)	Authentic Learning (20)	Open-endedness (20)	Active Learning/ Student Autonomy (40)
Face-to-Face Lab	25.36* (4.53)	<b>28.57*</b> (5.59)	23.1* (5.24)	13.87* (3.4)	10 (4.33)	31.59 (4.9)
Virtual Lab	23.05 (5.98)	21.21 (8.14)	21.46 (6.4)	12.84 (3.71)	9.87 (4.15)	32.35 (5.84)

Note. Standard deviations are in parentheses. Boldface indicates Cohen's  $d$  above 0.5.

\*  $p < 0.05$

Further analysis indicates that significant differences exist between the face-to-face and virtual laboratory groups in the subscales of Instructor Support ( $t_{(510)} = -4.92, p = 0.001$ ), Student Interaction and Collaboration ( $t_{(510)} = -11.86, p < 0.001$ ), Personal Relevance ( $t_{(510)} = -3.16, p = 0.002$ ), and Authentic Learning ( $t_{(510)} = -3.26, p = 0.001$ ). No significant differences were found between the two groups in the subscales of Open-endedness ( $t_{(510)} = 0.33, p = 0.74$ ) and Active Learning/ Student Autonomy ( $t_{(510)} = 1.59, p = 0.113$ ). The subscale Student Interaction and Collaboration had a large effect size ( $d = 1.05$ ) while the others were determined to be below 0.5, a small effect size. The mean scores for each of these subscales can be seen in Table 12.

### Research Question Three

Research question 3: Which factors of the laboratory environments are most influential on students' motivation to learn biology?

First, the relationship between the variables was assessed through Pearson's correlations. The correlation matrix in Table 13 shows a majority of the factors had a significant, but weak ( $<$

0.5) correlation. Personal Relevance was the only factor of the learning environment to have a strong and significant correlation with motivational factors: beginning Intrinsic Motivation (0.5), final Intrinsic Motivation (0.62), and final Motivation to Learn Biology (0.55).

Stepwise multiple regression analyses were conducted for each laboratory group to investigate the relationships among students' motivation to learn biology and characteristics of their assigned learning environment. The predictors were the six subscales of the DELES survey (Instructor Support, Student Interaction and Collaboration, Personal Relevance, Authentic Learning, Open-endedness, Active Learning/ Student Autonomy) while the response variable was students' motivation to learn biology at the end of the semester.

For the face-to-face laboratory group four models were produced. The first model included the subscale Personal Relevance ( $F_{(1, 247)} = 175.57, p < 0.001$ ) and explained 41.5% of the variance in students' end of semester motivation to learn biology. The subscale Active Learning/ Student Autonomy was included in the second model ( $F_{(1, 246)} = 105.08, p < 0.001$ ) and explained an additional 4.5% of the variance in students' end of semester motivation to learn biology. Model three added the subscale Open-endedness ( $F_{(1, 245)} = 74.71, p = 0.005$ ) and explained an additional 1.7% of the variation in students' end of semester motivation to learn biology. The final model included the subscale Instructor Support ( $F_{(1, 244)} = 4.29, p = 0.039$ ) and explained an additional 1% of the variation in students' end of semester motivation to learn biology.

Two regression models were produced for the virtual laboratory group. The first model included the subscale Personal Relevance ( $F_{(1, 261)} = 95.77, p < 0.001$ ) and explained 27% of the variance in students' end of semester motivation to learn biology. The subscale Open-endedness

was included in the second model ( $F_{(1, 260)} = 50.54, p = 0.043$ ) and explained an additional 1% of the variance in students' end of semester motivation to learn biology.

The variables of lab group (face-to-face and virtual) and gender (female and male) were dummy coded for multiple regression analysis with end of semester motivation to learn biology. Being a female was the only factor with a significant probability and explained 4% of the variance in final motivation to learn biology ( $F_{(1, 510)} = 24.23, p < 0.001$ ) and had a positive correlation with motivation to learn biology ( $b = 0.21, p < 0.001$ ).

Table 13

*Correlations of the subscales of the BMQ-II at the beginning and end of the semester and the subscales of the DELES*

	Motivation to Learn Biology													Learning Environment						
	BMTLB	BIM	BGM	BSD	BCM	BSE	FMTLB	FIM	FGM	FSD	FCM	FSE	CMTLB	DELES	COLLAB	AUTACT	RELEV	INSTR	OPEN	
BIM	<b>.84*</b>																			
BGM	<b>.67*</b>	.38*																		
BSD	<b>.84*</b>	<b>.64*</b>	<b>.55*</b>																	
BCM	<b>.82*</b>	<b>.59*</b>	.47*	<b>.56*</b>																
BSE	<b>.75*</b>	<b>.6*</b>	.42*	<b>.62*</b>	.40*															
FMTLB	<b>.69*</b>	<b>.61*</b>	.41*	<b>.56*</b>	<b>.61*</b>	.47*														
FIM	<b>.66*</b>	<b>.72*</b>	.3*	.49*	<b>.53*</b>	.46*	<b>.86*</b>													
FGM	.45*	.28*	<b>.54*</b>	.37*	.39*	.24*	<b>.69*</b>	.40*												
FSD	.47*	.37*	.34*	<b>.56*</b>	.34*	.28*	<b>.77*</b>	<b>.56*</b>	<b>.56*</b>											
FCM	<b>.66*</b>	<b>.55*</b>	.34*	.45*	<b>.76*</b>	.34*	<b>.83*</b>	<b>.69*</b>	.48*	.49*										
FSE	.44*	.42*	.17*	.35*	.28*	<b>.52*</b>	<b>.78*</b>	<b>.68*</b>	.43*	<b>.52*</b>	.48*									
CMTLB	-.21*	-.13*	-.20*	-.20	-.11*	-.22*	<b>.57*</b>	.42*	.42*	<b>.50*</b>	.38*	<b>.56*</b>								
DELES	.35*	.38*	.18*	.30*	.27*	.22*	.46*	.46*	.27*	.34*	.36*	.39*	.23*							
COLLAB	.15*	.16*	.09	.13*	.12	.07*	.22*	.19*	.17*	.18*	.17*	.18*	.13*	<b>.77*</b>						
ACTAUT	.32*	.27*	.24*	.30*	.23*	.26*	.35*	.3*	.32*	.26*	.23*	.32*	.11	<b>.59*</b>	.21*					
RELEV	.42*	<b>.5*</b>	.15*	.31*	.36*	.28*	<b>.55*</b>	<b>.62*</b>	.21*	.36*	.47*	.44*	.26*	<b>.79*</b>	.46*	.37*				
INSTR	.16*	.16*	.12*	.17	.10	.10*	.29*	.25*	.22*	.27*	.18*	.26*	.21*	<b>.72*</b>	<b>.58*</b>	.34*	.41*			
OPEN	.10	.16*	-.01	.09	.10	.05	.08*	.15*	-.04	.07	.09	.03	-.01	.47*	.23*	.17*	.34*	.14*		
AUTH	.33*	.39*	.14*	.27*	.25*	.22*	.46*	.48*	.21*	.29*	.37*	.41*	.24*	<b>.76*</b>	.43*	.42*	<b>.74*</b>	.43*	.27*	

*Note.* Correlations  $\geq 0.5$  are in boldface. BMTLB = beginning motivation to learn biology; BIM = beginning intrinsic motivation; BGM = beginning grade motivation; BSD = beginning self-determination; BCM = beginning career motivation; BSE = beginning self-efficacy; FMTLB = final motivation to learn biology; FIM = final intrinsic motivation; FGM = final grade motivation; FSD = final self-determination; FCM = final career motivation; FSE = final self-efficacy; CMTLB = change in motivation to learn biology; DELES = Distance Education Learning Environment Survey; COLLAB = student interaction and collaboration; ACTAUT = student autonomy/ active learning; RELEV = personal relevance; INSTR = instructor support; OPEN = open-endedness; AUTH = authentic learning. \*  $p < 0.01$



## Summary

The quantitative results to three research questions were presented in this chapter. The first research question investigated changes in motivation to learn biology during the semester in a college-level introductory biology course. The majority of the Biology I students experienced a decline in motivation from the beginning to the end of the semester, regardless of laboratory group, gender, or motivation group. The laboratory groups did not statistically differ at the end of the semester or in their change in motivation. However, females began and ended the semester with significantly higher total motivation than males. Research question two examined the learning environments of the two laboratory groups. The face-to-face laboratory group had significantly higher scores on four of the six environmental subscales, but only Student Interaction and Collaboration had a significant effect size. The third research question looked for variables of the learning environment that predicted students' motivation to learn biology. For the face-to-face laboratory group, four regression models were produced. The final model contained the variables Personal Relevance, Active Learning/ Student Autonomy, Open-endedness, and Instructor Support and accounted for 48% of the variation in motivation. The final model for the virtual laboratory group contained two variables, Personal Relevance and Open-endedness, and accounted for 28% of the variation in motivation. These data show some significant differences in motivation and the learning environment. The next chapter, Chapter 5, will present qualitative results on these same topics to provide a more well-rounded understanding of students' experiences in the face-to-face and virtual laboratories and the effects of these learning environments on their motivation to learn biology.

## CHAPTER FIVE: QUALITATIVE RESULTS

This chapter begins with an overview of the participants recruited for this project. The body of the chapter is then divided into two main sections: first round of interview data and the combined second and third rounds of interview data. A summary of the themes and trends from these sections is presented at the end of the chapter.

### The Participants

The participants were grouped based on their scores on the Biology Motivation Questionnaire II © (BMQ-II; Glynn, Brickman, Armstrong, & Taasobshirazi, 2011) at the beginning of the semester. In order to keep straight the motivation group each participant belongs to, students with low motivation were given pseudonyms beginning with “L,” moderately motivated learners all have pseudonyms that begin with “M” and highly motivated participants begin with “H.” Table 14 shows the total motivation score and sub-scale scores for each participant. The average motivation score for the face-to-face lab group ( $M = 103$ ,  $SD = 21.74$ ) was slightly higher than the average score for the virtual lab group ( $M = 97.71$ ,  $SD = 22.49$ ) at the beginning of the semester.

There were originally 14 participants in this research project, but only 12 completed all three interviews conducted during the semester. One highly motivated student withdrew from the course midway through the semester and completed only two interviews. The other student from the moderately motivated group never responded to multiple emails requesting a meeting for the third interview at the end of the semester. Therefore, only the information from the remaining 12 participants is presented here.

Table 14

*Profiles of the student participants from the Biology Motivation Questionnaire© at the beginning of the semester organized from lowest to highest motivation score*

Participant	Group <sup>a</sup>	Beginning Motivation to Learn Biology (125)	Intrinsic Motivation (25)	Grade Motivation (25)	Self-determination (25)	Career Motivation (25)	Self-efficacy (25)
Lance	VL	66	11	15	15	5	20
Leon	VL	72	10	24	15	8	15
Lexi	F2F	73	7	25	14	19	8
Mia	F2F	87	11	24	18	16	18
Melanie	VL	94	20	19	16	20	19
Madge	VL	100	20	20	20	20	20
Hugh	VL	106	19	23	20	23	21
Heidi	F2F	114	22	25	21	24	22
Holly	F2F	120	23	24	24	25	24
Hank	F2F	121	25	24	22	25	25
Hannah	VL	123	23	25	25	25	25
Heather	VL	123	25	25	25	24	24

<sup>a</sup>F2F = face-to-face laboratory group; VL = virtual laboratory group.

It was difficult to recruit students with low motivation to learn biology for this research project. I sent out emails to many students who had indicated they would be interested in participating in the project, but only three students responded. Two of the students, Leon and Lexi, indicated they were participating for the extra credit offered while Lance really wanted to share his opinions on the virtual laboratories. The three students with medium motivation to learn biology VL who responded to the email request for interview participants were all females.

This was not surprising because the demographic makeup of the course was nearly two thirds female.

### Results from the First Set of Interviews

During the first round of interviews, I asked the participants to describe their prior experiences in science classes. This allowed me to gain background information on the kinds of courses they had previously taken, whether in high school or college, their laboratory experiences, and the impact of these on the student. I also asked the students to describe their motivation to learn biology at that time. Specifically, I asked them to describe how motivated they were to learn biology and what motivated them. Students in the virtual laboratory group were also asked to describe their initial reaction to being assigned to the virtual environment.

### Participants' Prior Science Experiences

All of the participants took a biology course in high school and most took some combination of chemistry, physical science, anatomy and physiology, environmental science, or marine biology. A few of the students took Advanced Placement science courses as well. The descriptions of their experiences were coded as positive or negative and grouped together to look for patterns within the data.

Science teachers were described as both positive and negative influences by the students. Lexi recalled that her favorite science class in high school was anatomy and physiology because she had a “really good teacher” who “explained everything really well.” The teacher was a labor and delivery nurse whom she described as “really hands-on.” In contrast, she described her 10<sup>th</sup> grade chemistry teacher in a negative light:

She did not have a teaching degree. She had a chemistry degree so she did not know how to teach us. She knew all the information and was really smart, but she didn't know how to relate it to us students.

Heidi described one of her high school teachers as “pretty passionate about it, but when you are dealing with a class of students who just don't care, it makes it frustrating, but I found it interesting.”

Several of the participants related negative experiences with their high school science courses. A trend seen across the motivation groups was the emphasis on bookwork and learning vocabulary terms in biology classes. Lexi described her high school biology class this way: “I feel like biology was a vocabulary class. All I can remember from my ninth grade biology class is going through vocab words. I don't remember learning material, just taking so many vocabulary tests.” In a similar vein, Heidi disliked that much of the classwork was “questions based off of material in the textbook and I felt that was kind of pointless. What is the point of me memorizing something verbatim? It's not helping me understand the concept.”

Hands-on activities were recalled as positive experiences by several of the participants. Heidi liked hands-on activities because she perceived herself as a visual learner. “If I'm listening to a lecture I'll write down notes, but I'm not really going to understand it until I see it in front of me. That's why I really appreciate the laboratory aspect of Bio.” Similarly, Hugh attributed his enjoyment of high school science to his ability to learn through hands-on activities. “I found that whenever I could conduct an experiment or dissect something, I was able to learn, see it, touch it.”

In fact, dissections were the most often mentioned and best remembered activity among the high school laboratory experiences. Students fondly recalled dissecting fetal pigs, cats,

earthworms, frogs, and sheep brains. Some of the dissections occurred in biology courses, but the majority were in an anatomy and physiology course. Several of the participants enjoyed anatomy and physiology more than their other high school science courses. Both Heidi and Lexi professed enjoying learning about the human body, possibly due to the personal relevance of the material.

When describing their prior laboratory experiences, the participants were asked if these were open-ended or teacher-directed activities. With the exception of Advanced Placement (AP) courses, nearly every student experienced teacher-directed laboratory activities in their high school science courses. Mia described her laboratory experiences as, “A set of rules that you follow. They tell us what to do and what is going to happen. So, you do it because you have to for the class, but I don’t recall learning much from that.” Several students recalled following handouts. Lance said, “It was almost always a handout. I’ve never had anything that wasn’t, like, do this step. Write that down. Do this step. Write that down.” In contrast, Hank had science teachers who emphasized self-guided learning, “We designed our own experiments and gave reports on what we wanted to [do] and what materials we would need and he would provide it for us.”

#### Participants’ Motivation to Learn Biology at the Beginning of the Semester

There are several themes evident from the participants’ descriptions of their motivation to learn biology at the beginning of the semester. First, the participants’ explanations of their motivation to learn biology correspond with their scores on the Biology Motivation Questionnaire II. This consistency provides another level of validation to the use of the BMQ-II with this population.

Grade, intrinsic, and career motivation were repeatedly described by the participants. Interestingly, grade motivation was cited most often among participants with low motivation

whereas intrinsic and career motivation were more common among the highly motivated participants (Table 15). In fact, earning a good grade was the top motivator for all three participants with low motivation. For example, Lance, a senior, did not want to take biology at all, but it was required for his major, Computer Science. He described being motivated by his grade point average (GPA), “I want a good GPA and I am not one of those people who will just try and get a C. If I am going to do this, then I am at least going to shoot for an A.” Similarly, Leon reported being motivated by earning a good grade in the class, which coincides with his score on that subscale (24/25). When asked if he sees any relevance of the course content to his future career, his reply was fairly ambiguous, matching his low score on that subscale (8/25).

Most likely not. Actually, a little bit because as a coach I do have to tell my athletes why oxygen is important or why water is important and the reason behind biomechanics and stuff, so that is relative to the science, but not a whole lot.

Lexi is taking the class for a second time because she earned a “D” in it the previous semester. Getting into chiropractic school is her motivation for learning biology which is reflected in her moderate Career (19/25) and high Grade Motivation (25/25) scores. She claimed to be “really motivated because I don’t want to take the class again”, but her overall motivation score was fairly low (72/125) due to her low scores on the subscales of Intrinsic Motivation (7/25) and Self-efficacy (8/25).

The participants in the medium range of motivation to learn biology show a shift from being motivated solely by earning a good grade to showing motivation toward an appreciation for the relevance of biology to their future career. Melanie, Hugh, and Hannah each spoke about their future career in relation to their motivation. For example, Melanie’s descriptions of

motivating factors included her future as a science educator, “It’s about learning the concepts and being able to come up with lessons that will help my students.”

Table 15

*Participant descriptions of their motivation to learn biology*

Participant	Group <sup>a</sup>	Major	Description of Motivation to Learn Biology
Lance	VL	Computer Science	Grade
Leon	VL	Sports and Exercise Science	Grade
Lexi	F2F	Health Science	Grade/ Career
Mia	F2F	Mathematics	Grade
Melanie	VL	Science Education	Career
Madge	VL	Biomedical Science	Career
Hugh	VL	Sports and Exercise Science	Intrinsic/ Career
Heidi	F2F	Biomedical Science	Intrinsic
Holly	F2F	Health Science – Pre-Dental	Career
Hank	F2F	Computer Science	Intrinsic
Hannah	VL	Biomedical Science	Intrinsic/ Career
Heather	VL	Biomedical Science	Intrinsic

<sup>a</sup>F2F = face-to-face laboratory group; VL = virtual laboratory group.

The highly motivated participants more often described intrinsic reasons for learning biology. For example, Hugh found personal relevance in much of the course material.

I am really intrigued into the body and how the body works. I love working out. I love learning about what makes the human body perform better. So anytime I am learning biology I try to apply it to myself and how like if I am eating this or I am doing this, how is it going to help me with protein synthesis or something like that.



However, Holly did not fit the described pattern. She outright stated, “It’s not something that I specifically am interested in, but I know it makes sense as to why I have to take the course.”

### Reactions of Participants in the Virtual Laboratory Group

During the first interview, the students participating in the virtual laboratories were asked about their reactions to being assigned to this novel environment. An inverse relationship between motivation to learn biology and initial satisfaction with assignment to the virtual laboratories was found. In other words, students with low motivation had positive reactions while the highly motivated students were more likely to have a negative initial reaction to the virtual laboratories (Table 16).

Table 16

*Initial reactions of participants assigned to the virtual laboratory group*

Positive	Mixed	Negative
Lance	Hannah	Madge
Leon		Hugh
Melanie		Heather

The convenience afforded by the virtual laboratories and positive prior experiences with virtual laboratories shaped low motivated students’ positive views of their assignment to the virtual laboratory group. For instance, Lance and Leon were pleased they did not have to attend a weekly laboratory class and could complete the virtual laboratories at their leisure. Lance had taken several online courses in his degree program at UCF while Melanie had encountered virtual laboratories in high school. She anticipated the virtual labs would have more detailed information and better support than the face-to-face laboratories:

In the face-to-face lab you have someone stand in the front and vaguely explain it and then you are on your own to figure out how the experiment is going to go. In the virtual lab it will be step-by-step interactions and if you get lost you can click help.

In contrast, Madge, Hugh, and Heather were disappointed to be in the virtual lab group.

The negative reactions were attributed to the lack of hands-on work and a feeling of inadequate computer skills. Hugh simply felt that his experiences in the virtual labs would be different from the face-to-face labs. He listed pros and cons to the face-to-face labs such as having a partner who doesn't participate fully and the benefit of hands-on experiences as opposed to "the virtual lab where it is kinda just clicking a mouse." Heather was unhappy being in the virtual labs this semester because she viewed herself as "not tech savvy at all so when you put me in front of a computer I get flustered and just don't do well..." And Hannah's mixed reaction was a perfect conglomeration of the positive (convenience) and negative (lack of hands-on work) factors cited by the other students.

### Results from the Second and Third Set of Interviews

I asked the participants to describe their experiences in their laboratory environment during the interviews at the middle and end of the semester so I could begin to understand and compare their experiences. I also observed students completing the face-to-face and virtual laboratories for triangulation of the interview data. During the final interview of the semester, I asked the participants what they learned in their Biology I labs this semester and how they knew they learned it. They were also asked to describe the impact their biology lab experiences had on their motivation over the course of the semester.

## Experiences in a Face-to-Face Laboratory Class

There were similarities and differences in the experiences students had in the two laboratory environments. Mia outlined a face-to-face laboratory class this way:

Basically, my TAs switch on and off who teaches the lab. Usually as soon as we get in its lights out, PowerPoint on, and they lecture. They tell us to take pictures of their slides or take notes, because they are not available anywhere else. Then they tell us to start our lab using those slides and our packet. We then look over the packet and do the lab on our own. Sometimes we have time to go over it [together as a class], other times the labs are so long we don't have time to go over it.

A typical face-to-face class began with students finding their assigned seat and waiting for the TAs to pass the sign-in sheet. During one observation, several students left the lab class once the sign-in sheet was collected and they had determined there was no extra credit for completing the lab handout. As Heidi remarked, "Since they didn't collect anything in the labs, my partner would sign her name and just leave. It was kind of annoying. So I would work with someone else."

While the sign-in sheet was making its way around the room, the TAs started their mini-lecture on that week's topic. Many of the students were paying attention, taking notes or photos of the PowerPoint slides, but there was always some low level chatter among those who were not following along, prompting a TA to hush the students. The presentation generally lasted about 15 minutes and contained background information on the lab topic and some overview of the lab procedures. Following the presentation, the students paired up into groups of two to four students, depending on the lab and begin to read through their lab packet. The students were responsible for downloading the lab packet from Webcourses, printing it, and bringing it to lab.

As such, probably one-third of the students did not actually have the packet with them for lab. This resulted in some bargaining among students so that each pair or group ended up with one handout.

There were two main types of lab exercises: experimental and non-experimental. An experimental lab required the students to follow procedures to set-up an experiment with an end goal of recording some type of data. A non-experimental lab often involved modeling a process such as DNA transcription and translation using foam pieces.

In one observation I witnessed students engaged in a human genetics lab exercise where they matched chromosome pairs to determine various genotypes and phenotypes of their “offspring.” The students worked in pairs to follow the procedures in the lab guide. The pair I observed frequently consulted each other about the answers to the questions and when they were unable to figure it out together would raise their hand for assistance from a TA. At the end of the lab the TAs reviewed the questions in the lab handout with the class and ended the class by saying, “That’s pretty much it for today.” Except for signing in for attendance, nothing was collected or graded for that lab class. The lack of incentive for completion of the lab handout could have negative consequences for encouraging students to learn biology. As Mia stated, “Once I saw it didn’t really matter if you participated or not, I didn’t learn as much as I could have or should have.”

In another observation I watched students solve a crime scene whodunit by comparing evidence to known samples. The goal of the exercise was for the students to learn how to use compound and dissecting microscopes. Whenever a student had difficulty finding an image under the microscope, a TA found it for them, leaving the student with no better understanding of how to work the device. However, none of the students seemed to mind this, probably because

there were no skills tests or lab practicals to test students' ability to use the equipment. For this particular lab, the TAs offered extra credit to the groups who determined the perpetrator of the crime scene which motivated the students to work through all of the steps in the handout. Once students determined the perpetrator of the crime, they left the lab.

### Experiences in a Virtual Laboratory Class

Leon provided a succinct description of the process followed in a typical virtual lab exercise:

There were always questions at the beginning. Then they would go over the steps and procedure and review it. Then you actually tried it. You had a notebook on the side to record the data as you went along. There was making a chart, usually a bar graph or line graph. More questions at the end to see how your results fit with your hypothesis.

This description demonstrates the strict process that the majority of virtual lab exercises followed. Each virtual lab exercise began with a short introduction to the topic by the virtual TA and then moved to "Core Concepts" where the students read a series of passages on the lab topic. Often there were figures, graphics, and/ or videos embedded in the material. And the "Next Page" button did not appear right away to prevent students from automatically clicking through this introductory section. However, I observed Lance rapidly move through many of the introductory pages without paying much attention to the content presented.

Once the student reviewed the relevant introductory material, a question and answer session began. While observing Melanie work through a human genetics virtual lab exercise, there were multiple choice, true/ false, fill in the blank, select all, and matching questions. Each question also asked the learner, "Do you know the answer? Be honest!" with choices of "I know it", "Think so", "Unsure", and "No idea." Whenever Melanie missed a question, it would

eventually appear again, usually in a different format from the original question. Once, after missing the same question twice, Melanie resorted to searching the Internet for assistance and was rewarded by selecting the correct answer the next time it appeared. Other students described writing down the answers to the questions they missed and using trial and error to determine the solution. Often, supplemental material appeared for the student to review the pertinent concepts of the missed question. When Lance got a question wrong and was re-directed to the supplemental material, he remarked, “This is cool. Better than the notes from class.” He was able to select the correct answer the next time the question appeared. At the end of the question and answer sessions, the students received a grade for their efforts. Interestingly, several of the virtual lab participants remarked on their efforts to always achieve 100% on these quizzes, even though these grades did not impact their Biology Lab grade in any way. Receiving a grade, whether it was counted or not, may have influenced students’ to perform their best on the virtual lab quizzes, thereby increasing their likelihood of understanding and retaining the lab content, achieving higher scores on the in-lab quizzes that do count, and increasing their feelings of self-efficacy and self-determination.

After completing the question and answer session, the virtual TA gave a brief description of the lab simulation. As in the face-to-face labs, there were experimental and non-experimental virtual labs. In comparison to a non-experimental lab, an experimental lab simulation began by asking the student to select a hypothesis from a list of four to five choices. Madge noted, “Usually they just keep switching the variables [between the choices] so you can kind of guess.” In a non-experimental lab simulation, Lance had to match the phases of mitosis and meiosis with images from a microscope. He made several mistakes during the matching process which

prompted me to ask him during the follow-up interview whether he ever reviewed the relevant material before starting a lab exercise. He replied:

No, because there is no penalty for me re-doing it. If it were a really long process, like, if I had to re-do a thousand questions if I messed up, then yeah, I would review, but it's not a problem to guess and have them tell me.

Lance also had to restart the lab simulation at several different points when he got confused as to what his next step should be or when he missed a step in the procedure. Hugh once explained, "Some of the directions in the labs were not helpful and I felt like I had to do it over and over again until I got it figured out." Yet, several of the participants cited the ability to restart the lab simulations as a beneficial aspect of the virtual labs.

The virtual labs were plagued with glitches. During Melanie's observation, the sound for the virtual TA abruptly quit in the middle of providing instructions on how to complete the lab simulation. Madge reported similar difficulties with the virtual lab system at the beginning of the semester, "At first, it was hard because I think my computer didn't really interact with the lab thing so pictures wouldn't show up and the lady would stop speaking." Other students recounted having to restart their virtual lab exercises when the system would freeze. As Madge stated, "It wasn't difficult [to complete the lab]. I think it was frustrating. Like, some of it, the instructions were kinda off and I just had to get the hang of it." As with any new activity, there was a learning curve to the virtual labs. It would be easy to see how the students could become frustrated with the virtual labs and have diminishing motivation to complete them.

### Comparison of the Laboratory Environments

The environment in which the participants completed their laboratory exercises is an important component of understanding their experiences. Unsurprisingly, there were few

similarities between the face-to-face and virtual lab environments. Major differences were found between these environments in the themes of: 1) instructional support, 2) collaboration, and 3) the physical environment. Each of these environmental characteristics had the possibility to influence students' motivation to learn biology.

### Instructional Support

Most of the face-to-face lab participants remarked on the helpfulness of the TAs in answering their questions during the lab exercises. For Lexi, the TAs were more than just guides during the labs. She frequently emailed her TAs with questions about lecture content and would stay after lab or go to their office hours for help with subjects that were part of the lecture and the lab course. As she stated, "Having the resources there is so easy to access." Even though Lexi began the semester with low motivation to learn biology, she was determined to pass the Biology I course this time and, as such, made use of many different resources.

During my observations, I saw TAs who walked around the lab room checking on students during their lab exercises, but there were also TAs who stood by the podium at the front of the lab room chatting together until a student approached them for help. Holly noted similar differences when she had to attend a different lab section:

When my TAs gave us the slide show they just read off of it and just told us how to go about the experiment. We worked in our groups to do it all. If we had questions they would answer them, but they were iffy about things. The TAs in the other section were a lot more interactive and I feel like that was the difference. They are there to help you to another level.

Regardless of their level of interactivity, the TAs were a positive influence for the face-to-face students. In one lab observation, the TAs made a genetic pedigree for Harry Potter and the trait



magical ability. The students were very engaged in the example, raising their hands to volunteer answers and asking about problem-solving techniques. This example also illustrates the fact that many of the TAs are only a few years older than their students, providing a unique role model for students learning biology.

Thus, the smaller lab classes allowed for more personal attention between the instructors and the students which could impact their continuing motivation to learn biology in ways that the large lecture classes could not. Even so, Heidi reported, “It would be nice if the labs were smaller. There are a lot of students and most of them don’t even want to be there. Sometimes it is hard to concentrate on the lab and get everything done.”

The lack of instructional support in the virtual environment was a common theme in participants’ descriptions of their laboratory experiences. As Heather said, “There is a TA person on the virtual lab, but she doesn’t answer your questions.” She also noted other differences between the virtual and real-life TAs, “The TAs use verbal, visual, and one-on-one forms of teaching with the students. So you see all types of teaching in one environment compared to the computer where you don’t see all those types of teaching.” I observed the automated, virtual TA delivering information and instructions throughout the virtual lab exercises, but she was not capable of addressing student concerns or questions. As Hannah said, “Every lab was different, so it was I figuring out every time a different thing that was going wrong. Measuring something or putting numbers in correctly. Every time there was something like that.” Many students had similar difficulties with the learning curve inherent in the virtual environment, but few sought help from other students or their instructors.

## Collaboration

Collaboration among students was another theme found throughout participants' responses. The face-to-face laboratory environment provided opportunities for students to engage in small group discussions about course material which could be vital for the students who are not highly motivated to learn biology. For example, Mia felt working with a partner was helpful "especially in ... biology where it is not my strongest subject." And Holly felt that "working with others" enhanced her learning of the course material:

Sometimes I don't think of things and then you hear someone else say it and you're like, oh yeah, that's the most obvious thing. So it's good to have other people to discuss these things with, because not everyone can do study groups.

Although the majority of the collaborative experiences of the face-to-face lab participants were positive, Mia noted some downfalls of group work, "You have that one person that does the entire lab and then everyone just fills out their packet as they go." and "A lot of the time there are two parts to the lab so we'll split it and exchange answers." And Lexi described her group as "pretty dedicated", but then noted their motivation to complete the lab activities was "if you finish early, then you can leave." Holly felt motivated by working with other students "because science is a difficult course. I can't just sit there and read the textbook and make study guides. I need more than that. That is why I liked going into the lab." The weekly peer-to-peer interactions in the face-to-face lab class may have sustained and, possibly, boosted students' motivation to learn biology.

Peer collaboration was commonly cited by the participants as both a positive and negative aspect of the virtual labs. Heather lamented the lack of collaboration within the virtual environment even though she completed many of the virtual labs with a group of other students.

We worked together in the dorm. But in the virtual labs you are only going to get what you put in and most of the people just clicked their way through it...I found that when we worked together on the virtual labs, people who wanted to understand the concepts were often pressured by the other students to just keep going.

In contrast, Leon had a positive response to the lack of collaboration within the virtual lab environment, "I feel like I work better at my own pace. Sometimes I feel working with others kind of holds me back. I'm kind of an independent person so I don't really miss it." This feeling was echoed by several of the virtual lab students. And as Lance put it, "I like it [the virtual labs] more than having to go waste my time with a bunch of other people." This extreme viewpoint may be due to the fact that Lance had low motivation to learn biology and as a fifth year computer science student he "has friends outside of it [biology class]." However, for first year students who are majoring in the sciences, the lack of collaborative opportunities could have an isolating effect and negative consequences for their ongoing motivation.

### Physical Environment

While observing students completing a human genetics lab exercise, I noted how noisy the room had become. Students were walking around comparing genetic traits such as the shape of their thumbs and earlobes and exclaiming over the color-blindness charts around the room. The two students I observed worked well together to quietly and quickly complete the lab activities, but were frequently interrupted by another pair that were having difficulty understanding the lab procedures. This seemed to cause the first pair to lose their train of thought and momentum in completing the lab. In another observation, the group of four students was seated at the back of the room near a fume hood that was quite loud. I could barely hear the

presentation by the TAs and the students seemed to quickly lose focus on the presentation and explanation of the lab directions.

The students in the virtual labs tended to complete their lab exercises in either an on-campus computer lab or their own home. The two virtual lab students I observed during the semester behaved very differently from students in the face-to-face lab environment. Lance wore headphones while working in one of the University's computer labs and seemed practically unaware of his surroundings. And Melanie completed a virtual lab on her personal laptop computer in a common area at the University. Instead of using headphones, she had the volume turned down low so it would not bother students working nearby.

#### Comparison of Laboratory Activities

In addition to the environment, the participants were asked to describe the types of activities they did during lab exercises. Largely, participants from both learning environments described engaging in similar laboratory activities with some key differences. The majority of these activities were categorized as setting up experiments, measuring, modeling, and answering questions. Example descriptions of these common lab activities are shown in Table 17. The participants' descriptions diverged on three laboratory activities: 1) hypothesis testing, 2) recording data, and 3) graphing.

Hypothesis testing was an activity the virtual lab students engaged in frequently. They described selecting a hypothesis from a list of choices before beginning a lab simulation. However, the students in the face-to-face group never mentioned this activity and when probed about it, Mia responded, "I believe if you do read the directions sometimes it asks you to make a hypothesis. My group usually does not." In comparison, Hannah stated, "I learned how to set-up

hypotheses. How you would do it before and then corrected yourself afterwards. Or you went back and did it again.”

Table 17

*Examples of participant descriptions of activities in common between the face-to-face and virtual laboratories*

Activity	Face-to-Face Laboratories	Virtual Laboratories
Setting up experiments	“You had to use a de-coring thing to get a little potato core piece and then we put it into a solution with different percent of salt to see how the cells of the potato will take in water or release water depending if it was normal water, H <sub>2</sub> O, or NaCl and H <sub>2</sub> O.” - Heidi	“You have to fill each [test tube] with a different sugar and with a reactant. Get a stirring rod and stir them all up. And you have to put them in a heating thing and you can fast forward the time and watch how the bubbles react differently.” - Madge
Measuring	“We’ve measured gas consumption, changes in volume of gases, weight of things, distance, liquids for preparing solutions, temperature.” - Hank	“You take temperature, pH, gas, how many or how high the level raises, or how the temperature increase or decrease with the catalyst or something.” - Hugh
Modeling	“We had these beads that we connected and took apart for crossing over. There was a little magnet in the middle and that was like sticking the chromatids together.” - Lexi	“We did a mix and match mitosis and meiosis with sorting of phases, like matching a picture to the names.” - Madge
Answering questions	“There were questions in the lab manual and the data helped us understand the questions and answer them.” - Heidi	“It will ask you a question and if you answer it wrong it will explain it and then you say I understand or I don’t understand and then it will ask you again later the same question.” - Melanie

Both groups recalled recording data, but the virtual lab students reported it more often and gave much more detailed accounts of the process. This may be attributed to the fact that the virtual lab software would not allow students to progress to the end of a simulation without the

correct data entered in their table. In fact, I observed students become increasingly frustrated with this step in the lab simulations. As Leon described:

One of them gave me a hard time and I didn't learn much because it was so difficult to complete. The data was never accurate so I just gave up on it. But the others where I got the right results immediately, I definitely learned.

Another difference between the two lab groups was the frequency of creating a graph with their data. The participants in the virtual labs described creating graphs with their data at the end of most of the lab exercises. These students were given the option of creating a line, scatter plot or bar graph and had to decide how to plot their data on the X and Y axes. The face-to-face students described graph-making in conjunction with a single lab exercise. As Lexi stated, "When we had the cellular respiration graph we plugged all the information into the computer and the computer graphed it all." At the end of a lab exercise, both groups would use their data for answering questions on that week's lab topic.

### Reactions to the Laboratory Activities

The participants were also asked what they thought of the activities they completed in their assigned lab environment. Three of the five students in the face-to-face group made comments indicating they had some preconceived ideas about what the Biology labs would be like. For instance, Lexi said:

I would have expected more, not just hands-on, because we had a lot of hands-on labs, but more stuff. We didn't dissect or anything. I was expecting lab to be so messy and gross, but it wasn't bad. It was more bookwork than anything.

And Heidi thought it would be “like you need a lab coat and goggles and there would be these scary experiments that we had to follow step-by-step procedures and if we messed up you could burn a hole in your shoe or something.”

Several of the students in the virtual labs remarked on the lack of hands-on work in their environment. Madge felt, “It wasn’t a lot of actual doing anything. It was mostly seeing what happens.” And Heather thought that the Biology labs would be all about hands-on work and making observations, but the virtual labs were more about memorization of concepts. So, students in both groups found their lab activities generally helpful for learning the Biology I course content, but underwhelming in their execution.

#### Evidence of Student Learning in the Laboratories

Both groups of students felt the repetition of information from the lecture class helped them learn the concepts covered. For the virtual lab students, the question and answer sessions that are a part of the adaptive learning software made the greatest impact. Hugh described it as:

It was a lot of reiterating and going back and seeing the same concepts over and over again. I knew that I was learning because you would see something earlier in a lab and then you would remember it next time. After you would see it and know, you would have to take the posttest and realize you know it. It was a continuous seeing of the concepts. I felt like I was learning better that way.

The TAs were integral in the learning process for the face-to-face students. Heidi noted: Usually I would wait until after the lab to review the material because the lab helped me understand it without having to go through my notes so much. The TAs would talk about something and I would be like, I remember hearing that in class. It helped to refresh what you learned and then you understand it without having to reread it.

However, two students did not think the lab portion of the course helped them learn the concepts presented in lecture. Mia was the only student from the face-to-face group who had this issue:

I was never able to correlate the two [lecture and lab]. I don't know if that was my issue, but I felt like they were two completely different classes. I just didn't see that the lab helped me with the actual bio class when it came to exams and things like that.

And from the virtual lab group, Heather was the only student who expressed a similar sentiment:

I feel like a lab should enhance on the information you already knew from lecture. And it didn't do that for me. It mixed up information in my head. For instance, in lecture we learned about DNA and RNA and pedigrees. The lab, well it could just be me, but I had a mental block to understanding the information in the virtual labs.

It should be noted that Mia did not want to take the Biology I course and did not appreciate how the material was relevant to her statistics major. On the other hand, Heather really enjoyed learning about biology, but was upset about being assigned to the virtual lab group.

### End of Semester Motivation to Learn Biology

The goal of this project was to determine the impact of virtual laboratories on students' motivation to learn biology and to describe their experiences in the face-to-face and virtual environments. To this end, the participants were asked to complete the Biology Motivation Questionnaire II (BMQ-II) again at the end of the semester. The summary statistics for the two groups are shown in Table 18 while Table 19 displays each participant's change on the subscales of the BMQ-II. These data are compared with the participants' descriptions of their motivation at the end of the semester.



The end of semester quantitative data shows that motivation to learn biology changed drastically over the course of the semester for most of the participants. Seven of the twelve students experienced a decrease in their motivation, one had no change, and four increased. Overall, the change in motivation to learn biology ranged from 26% increase to 34% decrease. The subscales Grade Motivation and Self-efficacy accounted for most of the drop in motivation. Most noteworthy, the seven students in the virtual lab group had a combined increase in motivation of seven points while the five students in the face-to-face group had a collective decrease of 58 points.

Table 18

*Summary statistics of the change in motivation by laboratory group*

	Face-to-Face Laboratory Group (n = 5)	Virtual Laboratory Group (n = 7)
Total change in motivation	-58	+7
Average change in motivation	-11.6	+1
Standard deviation	16.83	11.72
Maximum increase	16	17
Minimum decrease	30	17

Of the six highly motivated students, Hugh was the only one whose score increased from the beginning of the semester. In the final interview, he explained that while he was initially unhappy with being assigned to the virtual laboratories, “As time progressed, I was happy that I was chosen to be part of it.” For Hugh, the convenience of working independently combined with the adaptive learning system of the virtual labs made him “feel like every lab was important and went right along with what we were doing [in lecture].”

Table 19

*Change in participants' Biology Motivation Questionnaire© scores arranged from greatest decrease to greatest increase*

Participant	Group <sup>a</sup>	Motivation to Learn Biology (125)		Intrinsic Motivation (25)		Grade Motivation (25)		Self-determination (25)		Career Motivation (25)		Self-efficacy (25)	
		Beginning	Change	Beginning	Change	Beginning	Change	Beginning	Change	Beginning	Change	Beginning	Change
Mia	F2F	87	-30 (34%)	11	-4	24	-5	18	-3	16	-10	18	-8
Hannah	VL	123	-17 (14%)	23	-2	25	0	25	-4	25	0	25	-11
Heidi	F2F	114	-15 (13%)	22	-4	25	-2	21	-4	24	-4	22	-1
Hank	F2F	121	-16 (13%)	25	-1	24	-5	22	-6	25	-4	25	0
Holly	F2F	120	-13 (11%)	23	-3	24	-1	24	-2	25	-3	24	-4
Leon	VL	72	-7 (10%)	10	3	24	-8	15	-2	8	+4	15	-4
Heather	VL	123	-2 (2%)	25	-1	25	0	25	0	24	0	24	-1
Madge	VL	100	0	20	0	20	+1	20	-1	20	0	20	0
Melanie	VL	94	+2 (2%)	20	0	19	-2	16	+4	20	0	19	0
Hugh	VL	106	+14 (13%)	19	+5	23	+2	20	+3	23	+1	21	+3
Lexi	F2F	73	+16 (22%)	7	+6	25	-1	14	+4	19	+2	8	+5
Lance	VL	66	+17 (26%)	11	+3	15	+6	15	+1	5	+5	20	+2

<sup>a</sup>F2F = face-to-face laboratory group; VL = virtual laboratory group.

Lexi began the semester with low scores in Intrinsic Motivation and Self-efficacy after having failed the course the previous semester. At the end of the semester, her motivation score increased by 22%, with large gains in the aforementioned subscales. When asked how her experiences in the face-to-face labs impacted her motivation, she replied:

I'd say it increased my willingness to want to learn biology. Just being in the labs with other people who have the same goals as me. The end goal of knowing the same stuff and motivating you to want know the same things. Having the TAs. The TAs are really good and if you have questions they can help you.

These positive experiences plus her passing grade likely boosted her self-confidence and general interest in biology.

Three students described their change in motivation differently from their scores on the BMQ-II. Mia's motivation to learn biology score dropped by 30 points, a 34% decrease, yet when asked about her motivation at the end of the semester, she claimed, "It stayed the same." Conversely, Heather described a stark decline in her motivation, yet her BMQ-II score only decreased by 2%:

It [the virtual labs] really messed up my motivation. Sometimes I would feel hopeless even though I had an excellent grade in lecture. You can see in my grades that I felt this. I was really disappointed because I felt like I learned more in high school biology than in college. I thought it would be the opposite. I thought I got the baby concepts in high school and in college I am supposed to have more information.

Lance had the greatest increase in motivation of all twelve participants. However, he reported, "The virtual labs have not changed it [my motivation] at all. The course has not changed it either. It was cool learning about evolution, but the rest of it was not that interesting."

Perhaps Lance's low expectations for the course gave him more room for positive experiences compared to the students who began the semester with high motivation and large expectations.

### Summary

The qualitative results from this research study were divided into two main sections from the first round of interviews and the combined second and third round of interviews. Four major themes emerged from the first round of interviews.

First, the participants had similar experiences in their prior science courses. Teachers were cited as both positive and negative influences on students' enjoyment of science courses. Several participants felt their science teacher's emphasized bookwork and learning vocabulary terms. Hands-on activities, especially dissections, were positive experiences for the participants. Yet, the majority of laboratory exercises were teacher-directed with step-by-step procedures on a handout. No obvious trends were found in correlation with these data and participants motivation to learn biology, but the prior experiences of the participants can influence their expectations of the current biology course.

Second, the face-to-face laboratory group had a slightly higher average motivation to learn biology score at the beginning of the semester compared to the virtual laboratory group. Furthermore, participants' descriptions of their motivation generally matched their scores on the Biology Motivation Questionnaire II.

Third, the three motivation groups (low, medium, and high) described their initial motivation to learn biology differently. Most of the highly motivated learners tended to enjoy learning about biology and had an inherent appreciation for the subject while the learners with low motivation would not have chosen to take the course in the first place and were more concerned with its impact on their GPA. The moderately motivated participants fell between

these extremes; almost as if there was a continuum from intrinsic motivation to grade motivation with career motivation as the midpoint.

Fourth, a correlation can be seen between a participant's motivation to learn biology and their reaction to assignment in the virtual laboratory group. Students with low motivation to learn biology had positive reactions to working in the virtual laboratories, mostly due to the easy availability of virtual classes. Highly motivated students were more likely to be disappointed with their assignment to the virtual labs because of the perceived lack of hands-on work. The student with a mixed reaction cited the same reasons given by those with positive and negative reactions.

The second and third interviews during the semester were focused on detailing the two learning environments, the activities the participants' engaged in, and their ongoing motivation to learn biology.

The descriptions of the face-to-face and virtual laboratory environments provided by the participants differed in three major ways: 1) the level of instructional support available, 2) the ability for collaboration among students, and 3) characteristics of the physical environment. Each of these environmental features has the possibility to influence students' motivation to learn biology.

Teaching assistants (TAs) were described as a key element of the face-to-face laboratory environment. The ability for immediate feedback in the labs and support outside of the classroom, combined with a narrow age difference from their students, suggest the TAs were positive motivators. In comparison, a lack of instructional support was found in the virtual environment. This was particularly a problem when the students encountered unclear directions

or glitches in the virtual system. These were often cited as learning detractors by the virtual lab students and could have negative consequences for persistence of motivation to learn biology.

Collaboration among students was the second theme found in common between the laboratory environments. In the face-to-face labs, students worked in groups on laboratory exercises which facilitated discussion of the course content. However, group work also allowed some students to sit idle while their partner did the majority of the work. Only one virtual lab participant collaborated with other students in completing the virtual lab exercises and she reported negative emotions about the benefits of this type of interaction. The majority of the virtual lab students enjoyed the convenience of working independently. While working independently may not have harmed these students' motivation to learn biology, it probably did not sustain, or boost it, as students in the face-to-face labs described.

The physical environment in which the participants completed their laboratory exercises was vastly different. The face-to-face labs were often full of chatter and environmental noises. One participant felt the lab classes should be smaller to facilitate in-depth collaborative experiences, but the general sentiment was very positive. The virtual lab participants tended to complete their labs in quiet environments such as their own home or a university computer lab. They were focused and "locked in" while working in the virtual environment until a glitch would occur. The lack of peripheral disturbances may be a benefit of the virtual environment, but is unlikely to have much impact on students' motivation while frustration about having to restart the labs due to malfunctions could be a negative influence.

There were several common activities between the lab groups: following procedures to set-up experiments, measuring, modeling, and answering questions. Yet, the virtual lab students described hypothesis testing and graph making while the face-to-face students seldom, if ever,

mentioned engaging in these activities. Also, differences existed between the groups in how they recorded data. These differences suggest that the virtual lab exercises followed a highly structured process similar to the stereotypical “scientific method.”

Lab exercises were not graded in either environment. Some students in the face-to-face labs took advantage of this by leaving after attendance was taken. Some students felt the lack of incentive for completion of the lab exercises decreased their motivation to learn biology. Students in the virtual environment received scores on their lab simulations and virtual lab quizzes, but these scores had no impact on their Biology I grade. Yet, several students mentioned redoing the virtual lab exercises until they had achieved a perfect score on the material. Receiving a grade, whether it was counted or not, may influence students to perform their best on the virtual lab quizzes, thereby increasing their likelihood of understanding and retaining the lab content, achieving higher scores on the in-lab quizzes that do count, and increasing their sense of self-efficacy and self-determination.

The majority of students in both lab groups felt they learned course concepts from their lab exercises. The virtual lab participants believed they had less of a hands-on experience than they would have had in a face-to-face lab, yet several of the face-to-face participants felt their hands-on experiences did not meet their expectations. They seemed to anticipate collegiate lab exercises would be different from their teacher-directed high school experiences and would instead be very involved, intense, and, perhaps, borderline dangerous.

Last, most of the participants experienced a change in their motivation to learn biology over the course of the semester. Seven of the twelve students experienced a decrease in their motivation, one had no change, and four increased. Furthermore, the virtual laboratory group had

a slight positive change in motivation while the face-to-face group experienced a severe decline in motivation.

In conclusion, the participants in this study had many similar experiences, regardless of their assigned laboratory environment. However, the virtual labs were viewed as being more convenient and followed a structured process that emphasized hypothesis testing similar to the stereotypical scientific method. The face-to-face laboratories were seen as being more hands-on, facilitated peer collaboration, and offered instructor support. Even in light of these differences, the end of semester data shows the face-to-face laboratories had a negative impact on these participants' motivation to learn biology compared to the virtual laboratories.



## CHAPTER SIX: DISCUSSION

In this chapter, the implications of the quantitative (Chapter 4) and qualitative (Chapter 5) results are discussed. First, the main quantitative and qualitative findings on motivation to learn biology are integrated and examined for convergence and divergence with each other and previous literature. This process is repeated for the results on the two learning environments- face-to-face laboratory and virtual laboratory. A brief discussion of the associations between motivation to learn biology and the learning environments follows. Next, theoretical, practical, and research implications of this study are discussed. Finally, limitations of the study are reviewed and suggestions for future research within science education are made.

### Motivation to Learn Biology

The first goal of this study was to document students' motivation to learn biology in face-to-face and virtual laboratories in an introductory biology course. No differential effects of the laboratory group were found on students' motivation to learn biology. More specifically, the majority of the Biology I students, regardless of laboratory group, motivation group, or gender, reported a decline in their motivation over the course of the semester.

No studies documenting motivation at multiple points during a semester in biology courses were found. However, studies of introductory chemistry courses have shown smaller degrees of declining motivation (Obrentz, 2012; Zusho, Pintrich, & Coppola, 2003). One potential explanation for the decline in motivation in my study could be that students began the semester with high aspirations and ended with a sense of apathy and exam fatigue. This is consistent with research showing decreases during the first year of college in students' motivation to learn, a shift in their focus from mastering material to concentrating on grades, and

an increasing tendency to do the minimum amount of work necessary (Kowalski, 2007). For example, a low grade on the first exam of a semester has been shown to negatively influence students' continuing motivation in an introductory psychology course (Jagacinski, Kumar, Boe, Lam, & Miller, 2010). And a longitudinal study of Chinese college students found that the greatest decline in motivation occurred during the first year, with science majors experiencing a more rapid decline than liberal arts majors (Pan & Gauvain, 2012); however, these findings may not translate across cultural and national differences to apply to the population in my study. Thus, existing research offers some potential explanations for the decrease in motivation observed here; however, my study was unique in incorporating aspects of the learning environment into an assessment of motivation to learn science.

### Laboratory Group

The students in the face-to-face and virtual biology laboratory groups had similar motivation to learn biology at the end of the semester and for the change in motivation from the beginning to the end of the semester. However, the students in the qualitative study showed a different trend. The virtual lab group had a slight increase in motivation while the face-to-face group had a steep decrease in motivation. The differences between the quantitative and qualitative results are most likely due to the small sample size and non-random sampling in the qualitative study (Gall et al., 2006).

While no published research was found comparing well-defined motivational constructs between face-to-face and virtual laboratories, it is possible to extrapolate from other studies. For example, Akpan and Strayer (2010) found that students in a face-to-face frog dissection began with more positive attitudes than the virtual dissection group, but this was reversed at the end of the dissection. Contrastingly, the students in my study experienced a decrease in their motivation

to learn biology, regardless of their laboratory group. Raes and Schellens (2012) investigated secondary science students' motivation to learn science in web-based collaborative inquiry learning experiences. They discovered that the motivational profiles of the majority of the students did not change, but nearly 50% of the students who began with good motivation shifted to low motivation, similar to the findings in this research study. These authors concluded that more research is needed to explore how innovative learning approaches support students' motivation.

### Motivation Group

Students who began the semester with high or moderate motivation to learn biology experienced a decline over the semester, but the low motivated group experienced a slight increase. This trend was true for both the overall Biology I and virtual laboratory samples. In the qualitative sample, five of the six highly motivated students reported a decline in their motivation to learn biology, the three moderately motivated participants told of no change, and the three low motivated learners described no change or a slight increase in their motivation. Interview data indicate the highly motivated students initially had a negative reaction to assignment to the virtual laboratory group because of a perceived lack of hands-on work and a feeling of inadequate computer skills among the participants. Those with low motivation had positive reactions and cited the convenience afforded by the virtual labs and positive prior experiences with virtual labs as their main reasons. At the end of the semester, only one student (highly motivated) described the virtual laboratories as having a negative impact on her motivation to learn biology.

Other scholars have focused on the relations of student achievement with motivation to learn science and grouped students by their achievement level (e.g. Obrentz, 2012; Zusho et al.,

2003). Grouping students by their beginning of semester motivation score was a unique approach utilized in my study. These findings provide evidence that the face-to-face and virtual laboratories had similar effects on students' motivation to learn biology when examined by the beginning of the semester motivation level (high, medium, and low).

### Gender

Females began and ended the semester with higher motivation to learn biology than the males in both the Biology I course as a whole and the virtual laboratory group. However, there were no differences between the genders in their change in motivation from the beginning to the end of the semester. In comparison, several studies utilizing the Science Motivation Questionnaire© found no difference in total motivation to learn science between males and females in high school (Bryan et al., 2011), non-science majors (Glynn et al., 2007, 2009), and science majors (Glynn et al., 2011). And Obrentz (2012) found that males had higher total motivation to learn chemistry at the beginning, middle, and end of the semester. Thus, the results from my study are unique. One possibility for the gender difference in total motivation for the participants in this study could be the presence of a female instructor for the course. The presence of female role models, especially female professors, has been shown to increase the science self-confidence of female students (Cotner, Ballen, Brooks, & Moore, 2011).

When the motivation to learn biology survey data were examined at the subscale level, it is evident that females began and ended the semester with higher *grade motivation, self-determination, and career motivation* than the males. Of these differences, only career motivation was found to have a moderate effect size, and thus, a meaningful difference between the genders. Similar differences between the genders in career motivation were previously not found in non-science (Glynn et al., 2011, 2009) or science majors (Glynn et al., 2011). However,

females have been found to believe that science was more relevant to their careers than men do (Glynn et al., 2007). The results of the my study are not surprising given that females have outnumbered males in degree obtainment in the biological sciences every year from 2000 – 2011 and are almost equal (48%) in employment in a life sciences field (National Center for Science and Engineering Statistics, 2014). Thus, the biological sciences are not considered a field in which a dire gender gap is present.

Remarkably, no difference was found between females and males in their feelings of self-efficacy at the beginning or end of the semester. This contradicts several previous studies where scholars have shown that females possess lower feelings of science self-efficacy compared to males in introductory biology courses for non-science and science majors (Glynn et al., 2011, 2009) and introductory chemistry courses (Obrentz, 2012; Yu, 1999) at the collegiate level. The lack of difference between the genders in my study is important to note because females have been found to possess inaccurately low self-evaluations of their performance and confidence compared to males (Beyer & Bowden, 1997) even when their science achievement is equal to, or better than, their male counterparts (e.g. Anderman & Young, 1994; Britner, 2008).

### The Learning Environment

The central outcome of the quantitative and qualitative data regarding the two laboratory groups indicated the students in the face-to-face laboratory group held a more positive view of their learning environment than those in the virtual laboratory group. Several differences, both quantitative and qualitative, were found between the learning environments of the face-to-face and virtual laboratories. The students in the face-to-face laboratories rated the environmental characteristics of *instructor support, student interaction and collaboration, personal relevance, and authentic learning experiences* significantly higher than the students in the virtual

laboratories. Of these, only the subscale *student interaction and collaboration* was found to have a meaningfully large effect size between the groups. The students in the face-to-face labs often described collaboration with their peers as a major, positive influence on their continuing motivation. There is a body of research demonstrating that collaborative learning “can significantly improve the acquisition of course content over learning on one’s own” because “knowledge is more a socially held or socially based phenomenon than it is a body of information and concepts transmitted from expert to novice” (as reviewed in Pascarella & Terenzini, 2005, p. 103). Furthermore, collaborative learning in introductory science courses has been shown to improve learning outcomes such as asking higher level questions (Marbach-Ad & Sokolove, 2000) and performance on projects, course exams, and semester grades (Chace, 2010). Research supports the conclusion that the science laboratory “offers unique opportunities for students and their teacher to engage in collaborative inquiry and to function as a classroom community of scientists” (Hofstein & Lunetta, 2003 p. 36).

Other researchers investigating the use of virtual labs have shown similar results linked to these facets of the learning environment. For example, Gilman (2006) found that students’ written responses about the use of a virtual cell division lab noted the convenience of virtual laboratories and going at your own pace while the negative comments remarked on the lack of collaboration and hands-on experience. And Stuckey-Mickell and Stuckey-Danner (2007) reported that introductory biology students enjoyed the opportunities for immediate feedback from instructors, collaborative capabilities, and hands-on experiences found in the face-to-face laboratories.

The results from the interview data demonstrated that the teaching assistants (TAs) in the face-to-face environment provided greater instructional support than the automated TA in the

virtual lab environment. The TAs reiterated course concepts through their mini-lectures at the beginning of each lab class and answered students' questions on not only the lab exercises, but they were also available as a source of one-on-one instruction for students who sought it out. Frequent student-teacher interactions such as these are known to increase motivation (Kowalski, 2007), academic achievement, and retention (Pascarella & Terenzini, 2005; Pascarella & Terenzini, 1979). The majority of students in large introductory science courses, such as Principles of Biology I, often have much more contact with their TAs than their course instructor (Seymour et al., 2005). A large-scale survey of undergraduate science majors revealed the TAs in introductory STEM courses influenced retention factors such as course climate, grades, and knowledge of science careers (O'Neal, Wright, Cook, Perorazio, & Purkiss, 2007). Therefore, the TAs share an important role in these gateway courses and the lack of interactions with lab TAs due to implementation of virtual labs could have negative ramifications for student achievement and retention.

The difference in the subscale authentic learning experiences between the face-to-face and virtual lab students may be explained by participants' expectations of their lab experiences. Students in the face-to-face labs expected their biology labs to offer more technical lab activities than they experienced in high school science courses. Instead, they felt the labs were akin to Supplemental Instruction (SI) sessions with an emphasis on repetition of the concepts presented in the lecture portion of the course and limited focus on learning advanced laboratory techniques and concepts. In comparison, the virtual lab students did not think their lab activities qualified as hands-on work and their lack of hands-on experience would negatively impact those students going into more advanced science courses. In other words, the students in both groups had expectations of "minds-on as well as hands-on" (Hofstein & Lunetta, 2003 p. 32) laboratory

activities with the possibility for authentic research experiences (Brownell & Kloser, 2011). These results contrast with research by Pyatt and Sims (2012) where students valued the ease of manipulation and experimentation within the virtual environment more than the manual operation of equipment in the face-to-face labs.

### Associations between Motivation to Learn Biology and the Learning Environment

Multiple regression analyses identified separate models of what determines motivation for the face-to-face and virtual laboratory groups. The four environmental factors *personal relevance, active learning/student autonomy, open-endedness, and instructor support* were included in the face-to-face laboratory model of motivation, while a smaller subset of those same factors, *personal relevance and open-endedness*, were part of the virtual laboratory model. The difference between the environments on the factor *active learning/student autonomy* is interesting because the interview and observational data did not provide evidence of inquiry-based opportunities in either the face-to-face or virtual laboratories. The students in both laboratory groups described engaging in many of the same types of activities, but perhaps the stringent procedural aspects of the virtual labs were viewed as more limiting than the face-to-face labs. For example, students in the virtual labs had to complete each and every step of a lab exercise (e.g. answering questions, choosing a hypothesis, experimental procedures, etc.) in the order specified to progress through the virtual lab. In the face-to-face labs, students rarely, if ever, turned in their lab handouts and, therefore, may have had a greater sense of independence in completion of their exercises.

The other factor that differed between the learning environments of the two lab groups was instructor support, which was discussed in depth in the previous section. The abundance of



positive descriptions of the TAs in the face-to-face labs and negative comments about the virtual TA elucidate the differences between these learning environments on this factor.

For the variables lab group (face-to-face and virtual) and gender (female and male), being female was found to have a significant influence on motivation to learn biology. This finding is in-line with the motivation data previously reported, adding further support to the conclusion that females in this course possessed higher motivation to learn biology than the males.

### Theory of Social Cognitive Motivation to Learn Biology

This research study was based on a social cognitive framework of motivation to learn biology. The findings were generally consistent with the proposed model. Students' motivations to learn biology were found to be influenced by factors of the learning environment such as instructor support, as well as characteristics of the individual such as gender. Bandura's (1986, 2001) social cognitive theory posits that people learn through social interactions such as observing others completing tasks or the discussion of concepts. The results from this study demonstrate that students perceived face-to-face laboratories as having more instructor support and student interaction and collaboration, which, as posed by social cognitive theory, would increase their motivation to learn biology. Yet, no significant differences in motivation were found between the lab groups. One in four students in this study was a non-science major, and because students may vary in the value they place on interactions with their instructors and peers by major, the diversity of majors in this population may explain why motivation was not impacted by the lack of interaction within the virtual laboratories. Qualitative data provided evidence that non-science students often feel less of a need for a connection with their peers compared to students who have peers majoring in the same science field and will be taking

several more science courses together and could benefit from creating peer connections early on in their degree program.

### Implications

The results of this study have practical implications for college biology and other introductory science instructors in three areas. First, the Biology Motivation Questionnaire II© was found to be a valid and reliable tool in assessing students' motivation in two different laboratory settings. This finding should encourage instructors to consider assessment of motivation along with the more typical achievement measurements when implementing novel teaching techniques. Second, the virtual laboratories used in this study did not have a negative impact on students' motivation to learn biology compared to the face-to-face laboratories, even when the data were examined for different motivation levels (high, medium, low) and gender (female and male). These results combined with the extant literature on virtual laboratories should provide instructors with confidence in the integration of virtual labs into their courses. Third, developers of virtual laboratory curricula will now have a better sense of environmental factors that are important to students. This study has shown that students value opportunities for interaction and collaboration with their peers and instructors. Thus, virtual learning environments should provide opportunities for students to feel a sense of connection with their instructors and peers even while working remotely. For instance, incorporation of virtual office hours has been shown to increase student satisfaction compared to classes that offered only face-to-face office hours (Pitts & Li, 2009). And social media tools can be effective at facilitating student communication in virtual learning environments (S. Hazari & Thompson, 2014). However, the large number of students in introductory biology courses could make implementation of these tools cumbersome.

The results of this study also have implications for the science education research community. Previous scholars have focused on examining conceptual learning in virtual laboratories (e.g. Finkelstein et al., 2005; Huppert et al., 2002; Olympiou & Zacharia, 2012), whereas this study identified well-defined motivation constructs. Thus, this study helps to fill a gap in the literature base on undergraduate biology education and laboratory learning environments. In addition, the incorporation of a qualitative methodology provided a voice to the student participants and their experiences in the face-to-face and virtual laboratories, giving a more nuanced understanding to the quantitative comparisons. These results also extend the literature in science education at the post-secondary level where a dearth of research exists on motivational constructs.

#### Limitations of the Study

There were several limitations with this research study. First, students received extra credit for their participation and there is potential for motivational differences between those who participated and those who did not. Second, the generalizability of these findings is limited due to the sample (introductory biology course at a large research university) and the specific intervention (McGraw Hill LearnSmart Labs). This sample was somewhat unique in that the biology laboratory course had a shorter than typical meeting time. Generally, introductory biology laboratory courses meet for two hours and fifty minutes per week while this course met for one hour and fifty minutes. Third, despite my efforts to recognize and identify my previous experiences with and beliefs about biology laboratories, it is still possible that those experiences could have had some influence on the qualitative portion of this study.

### Further Research

Further research on students' motivation to learn biology and virtual laboratories could take many different directions. For example, the inclusion of science achievement measures such as exam grades and lab grades would allow for a more holistic understanding of the impacts of virtual laboratories on students when combined with the motivation data. Further group comparisons such as major and ethnicity would also provide additional insight. Another line of research could include a longitudinal, multi-semester study of students' motivation to learn biology as they transition from virtual laboratories to face-to-face laboratories in their upper division biology courses. This study would provide information on the cumulative influences of the virtual learning environment. Future research could also attempt to identify why the majority of students experienced a decrease in motivation to learn biology. Similar investigations into the impacts of face-to-face and virtual laboratories on students' motivation to learn could be carried out in other science disciplines such as physics and chemistry. All of these types of studies would contribute greatly to the existing literature base on motivation and virtual laboratories.

### Conclusion

The laboratory component of large enrollment introductory biology courses are often seen as the critical juncture between the large-scale efficiency of science education at the university level and small group, hands-on learning. While virtual laboratories may be a less resource intensive alternative to the traditional face-to-face laboratories, little is known about their impact on students. Previous research has shown that achievement does not differ between these environments (Akpan & Strayer, 2010; Finkelstein et al., 2005; Huppert et al., 2002), but it

was unclear how virtual laboratories might affect student motivation to learn biology, an important factor in sustaining student engagement and interest in science learning.

Thus, in this research project the impacts of face-to-face and virtual laboratory environments on students' motivation to learn biology were examined through quantitative and qualitative methods. Statistical analyses provided quantifiable evidence that the novel virtual laboratory environment did not have a differential effect on students' motivation to learn biology, with this finding being supported by the qualitative results. Comparison of the laboratory environments showed that students in the face-to-face labs reported greater instructional support, student interaction and collaboration, relevance of the lab activities, and authentic learning experiences than the students in the virtual labs. Qualitative results provided evidence that the teaching assistants in the face-to-face labs were an influential factor in sustaining students' motivation by providing immediate feedback and instructional support in and out of the laboratory environment. In comparison, the virtual laboratory students often had to redo their lab exercises multiple times because of unclear directions and system glitches, potential barriers to persistence of motivation. The face-to-face students also described the importance of collaborative experiences and hands-on activities, factors that have been recommended for improving undergraduate biology education (American Association for the Advancement of Science, 2009). The virtual laboratory students appreciated the convenience of working at their own pace, location, and time.

According to social cognitive theory (Bandura, 1986, 2001), the differences in the learning environments reported by the students should have had ramifications for their motivation to learn biology, yet this did not hold true for the students in this study. Therefore, while these laboratory environments are demonstrably different, the virtual laboratories did not

negatively impact students' motivation to learn biology and could be an acceptable replacement for face-to-face laboratories in an introductory biology course.

**APPENDIX A:  
SPRING 2014 PRINCIPLES OF BIOLOGY I (BSC 2010)  
LABORATORY SCHEDULE**

	Dates (2014)	Topic	Virtual Lab or Physical Lab
Week 1	1/8 – 1/10	No Labs	No Labs
Week 2	1/15 – 1/17	Introduction and Pre-Test	Physical Lab
Week 3	1/22 – 1/24	Exam #1	Physical Lab
Week 4	1/29 – 1/31	Osmosis and Diffusion	Virtual Lab
Week 5	2/5 – 2/7	Enzymes	Virtual Lab
Week 6	2/12 – 2/14	Exam #2 and Lab Quiz #1: Osmosis, Diffusion, Enzymes	Physical Lab
Week 7	2/19 – 2/21	Cellular Respiration	Virtual Lab
Week 8	2/26 – 2/28	Exam #3 and Lab Quiz #2: Cellular Respiration	Physical Lab
Week 9	3/5 – 3/7	No Labs: Spring Break	No Labs
Week 10	3/12 – 3/14	Mitosis and Meiosis	Virtual Lab
Week 11	3/19 – 3/21	Human Genetics	Virtual Lab
Week 12	3/26 – 3/28	Exam #4 and Lab Quiz #3: Mitosis, Meiosis, Human Genetics	Physical Lab
Week 13	4/2 – 4/4	DNA Synthesis/ Transcription/ Translation	Physical Lab
Week 14	4/9 – 4/11	Exam #5 and Lab Quiz #4: DNA Synthesis/ Transcription/ Translation	Physical Lab
Week 15	4/16 – 4/18	Microscopes and Post-Test	Physical Lab



**APPENDIX B:  
INSTITUTIONAL REVIEW BOARD APPROVAL LETTER**



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

### Approval of Exempt Human Research

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

To: **Amber Jean Reece**

Date: **December 19, 2013**

Dear Researcher:

On 12/19/2013, the IRB approved the following activity as human participant research that is exempt from regulation:

Type of Review: Exempt Determination  
Project Title: Evaluating the Impact of Virtual Labs in an Introductory Biology Course on Students' Performance, Attitudes, and Motivation to Learn Science  
Investigator: Amber Jean Reece  
IRB Number: SBE-13-09837  
Funding Agency:  
Grant Title:  
Research ID: N/A

This determination applies only to the activities described in the IRB submission and does not apply should any changes be made. If changes are made and there are questions about whether these changes affect the exempt status of the human research, please contact the IRB. When you have completed your research, please submit a Study Closure request in iRIS so that IRB records will be accurate.

In the conduct of this research, you are responsible to follow the requirements of the Investigator Manual.

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

Signature applied by Joanne Muratori on 12/19/2013 02:48:43 PM EST

IRB Coordinator

**APPENDIX C:  
BEGINNING-OF-SEMESTER SURVEY**

Provide your complete name as it appears on the course roster.

First Name:

Last Name:

Please record your NID in the box provided. Your NID typically begins with the first two letters of your first name, followed by six numbers. For example: Alan's NID is AL123456

Select your lecture section from the list below:

- Mrs. Thomas: MWF 8:30-9:20am
- Dr. Diercksen: MWF 10:30-11:20am
- Dr. Diercksen: MWF 12:30-1:20pm

Which best describes you?

- Female
- Male

Which best describes you? (check all that apply)

- Asian
- Black/ African American
- Hispanic/ Latino
- White/ Caucasian
- Other, please explain \_\_\_\_\_

Which best describes you?

- Under 18
- Age 18-22
- Age 23-29
- Age 30+

Is this your first college-level science laboratory class? (Do not include college-level courses taken while in high school.)

- Yes
- No

Please identify your major.

- Arts & Humanities
- Biology
- Biomedical Sciences
- Chemistry
- Forensic Science
- Physics
- Mathematics/ Statistics
- Education
- Nursing
- Business
- Health & Public Affairs
- Social Sciences: Psychology, Sociology, etc.
- Engineering & Computer Science
- Other, please identify \_\_\_\_\_

Do you intend to take a science course next semester (summer or fall)?

- Yes
- No

Which type(s) of course are you going to take? Please select all that apply.

- biology

- chemistry
- physics
- other \_\_\_\_\_

Would you be willing to be interviewed as a part of this research project? Students who consent to being observed in the lab and interviewed will receive extra credit. However, all students in the lab classes have opportunities to receive extra credit. If you are interested in this opportunity, please choose yes below and provide an email address so we may contact you.

- Yes, I am interested in being observed and/ or interviewed for this research project.  
My contact information is: \_\_\_\_\_
- No, I am not interested in being observed or interviewed for this research project.

**APPENDIX D:  
BIOLOGY MOTIVATION QUESTIONNAIRE II ©**

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In order to better understand what you think and how you feel about your biology courses, please respond to each of the following statements from the perspective of "When I am in a biology course..."

Never      Rarely      Sometimes      Often      Always

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- The biology I learn is relevant to my life.
  - I like to do better than other students on biology tests.
  - Learning biology is interesting.
  - Getting a good biology grade is important to me.
  - I put enough effort into learning biology.
  - I use strategies to learn biology well.
  - Learning biology will help me get a good job.
  - It is important that I get an "A" in biology.
  - I am confident that I will do well on biology tests.
  - Knowing biology will give me a career advantage.
  - I spend a lot of time learning biology.
  - Learning biology makes my life more meaningful.
  - Understanding biology will benefit me in my career.
  - I am confident that I will do well on biology labs and projects.
  - I believe I can master biology knowledge and skills.
  - I prepare well for biology tests and labs.
  - I am curious about discoveries in biology.
  - I believe I can earn a grade of "A" in science.
  - I enjoy learning biology.
  - I think about the grade I will get in biology.
  - I am sure I can understand biology.
  - I study hard to learn biology.
  - My career will involve biology.
  - Scoring high on biology tests and labs matters to me.
  - I will use biology problem-solving skills in my career.
-



**APPENDIX E:  
MODIFIED DISTANCE EDUCATION  
LEARNING ENVIRONMENT SURVEY**

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The following questions are about the laboratory portion of the Biology I class. Think about your experiences this semester in the lab class when answering these questions. In the biology labs...

Never  
Rarely  
Sometimes  
Most of the Time  
Always

---

If I have a question, the instructor finds time to respond.  
The instructor responds promptly to my questions.  
The instructor gives me valuable feedback on my assignments.  
The instructor adequately addresses my questions.  
The instructor encourages my participation.  
It is easy to contact the instructor.  
I work with others.  
I relate my work to others' work.  
I share information with other students.  
I discuss my ideas with other students.  
I collaborate with other students in the class.  
Group work is part of the class activities.  
Students work cooperatively in lab sessions.  
I can relate what I learn to my life outside of the lab class.  
I am able to pursue topics that interest me.  
I can connect my studies to my activities outside of the lab class.  
I apply my everyday experiences in this lab class.  
I link lab work to my life outside of university.  
I learn things about the world outside of lab.  
I apply my out-of-class experience.  
I study real cases related to the lab.  
I use real facts in lab activities.  
I work on assignments that deal with real-world information.  
I work with real examples.  
I enter the real world of the topic of study.  
I explore my own strategies for learning.  
I seek my own answers.  
I solve my own problems.  
I make decisions about my learning.  
I work during times that I find convenient.  
I am in control of my learning.  
I play an important role in my learning.  
I approach learning in my own way.  
There is opportunity for students to pursue their own science interests in this lab class.

In this lab class, we are required to design our own experiments to solve a given problem.

In the lab sessions, different students do different experiments.

Students are allowed to go beyond the regular lab exercise and do some experimenting on their own.

In our lab sessions, the teacher/ instructor decides the best way to carry out the lab experiments.

Students decide the best way to proceed during lab experiments.

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**APPENDIX F:  
BRACKETING INTERVIEW AND RESULTING THEMES**

This narrative is my attempt to identify and set aside my personal experiences that are relevant to this research project in order to focus my attention on the participants and their experiences with the phenomenon (Creswell, 2007).

## **Collegiate Experiences with Biology Laboratories**

### **Undergraduate Experiences**

My first experience with college level biology was in a General Biology course at South Florida State College. The course was a typical “old school” biology course that covered an enormous amount of information in the course of a semester with “cookbook” style laboratory exercises. For some unknown reason, I felt challenged by the course and was determined to do well. I memorized all of the class notes and earned A’s on every test. I had mediocre grades in high school so this accomplishment really bolstered my motivation to succeed in college.

After earning an A in the course I was asked to be a laboratory assistant the following semester. My duties included setting up for the lab activities, assisting during the lab classes, cleaning up after the labs, and preparing the lab practicals. This experience led me to the realization that I really enjoyed teaching. However, while I had done well in the course by memorizing the material, now I had to really understand the concepts in order to answer questions and explain them in different ways for different learners. My enjoyment of these laboratory teaching and learning experiences led me to declare a major in biology when I transferred to the University of Central Florida (UCF) after completing my Associate of Arts degree.

My first biology course at UCF was Principles of Ecology, a three credit lecture course. I decided to take the Ecology laboratory course as an elective the same semester. While I found the content presented in the lecture course interesting, it was the lab class that really captivated

my attention. The lab activities were a mix of field and lab work including visiting different ecosystems and learning common sampling techniques. The hands-on work in the lab really brought to life the theory and principles presented in the lecture course. After this experience I took as many laboratory courses as I could.

Two experiences really stand out for me from my subsequent undergraduate biology courses. The first experience was the final project in the Genetics lab course where we had to determine the inheritance pattern of an unknown trait in fruit flies. Each group of students was responsible for performing the mating crosses and counts in the “fly closet” on their own time. The scientific style report that was the culmination of the project brought me an in-depth understanding of the scientific process like no other school assignment before.

The second experience occurred in the Vertebrate Zoology course I took during my senior year. This was a field work intensive course unlike anything I had ever taken before. While I found the lecture portion of the course to be an overwhelming amount of information to memorize, the fieldwork was demanding and rewarding at the same time. Our field trips included activities such as snorkeling in freshwater springs for turtles, beach surveys for nesting sea turtles and emerging hatchlings, and early morning bird watching tours.

Common interests and shared experiences forged strong bonds between some of my classmates and me. Several of us still keep in contact today. In fact, my husband and I began dating during this class and recounted one of our class experiences at our wedding! I find it amazing that whenever I meet with some of my old classmates, we always end up revisiting some of our incredible experiences. Notably, the time many of us were snorkeling in a spring during a thunderstorm and the water was struck by lightning. And the time I jumped out of the bed of a pick-up truck to catch a baby alligator for the class.

Laboratory courses such as Ecology, Ecosystems of Florida and Vertebrate Zoology gave me the skills and knowledge for a position as a field technician during my senior year. Putting into practice skills such as ecosystem delineation and specimen identification made me feel that my coursework was very applicable to my real world experiences.

### **Graduate Experiences**

Because I enjoyed my upper-division courses so much and I had no other plans after completing my undergraduate degree, I applied for the master's degree program at UCF. During the master's program, I was a graduate teaching assistant (TA) in the Biology Department for five semesters. The first semester I taught three sections of Biology I labs. I remember marveling at how some of the students in my classes had so little motivation to do well in the course. I was also surprised that students could do well in a lab activity, but had no idea how it connected to the concepts taught in the lecture portion of the class. Working with different learners to make connections between lecture concepts and the hands-on work was a rewarding experience that taught me that not everyone possessed the aptitude and motivation to learn biology that I did.

The next semester taught one section of Biology I lab as well as serving as "head TA" for the lab portion of the course. My role was to assist TAs in teaching the lab by creating quizzes, providing background information on the lab topics, and creating PowerPoint presentations to standardize materials taught by different TAs. This is when I learned that I was an organized and effective administrator, but that I most enjoyed teaching.

During my last semester as head TA for the Biology I labs, I had the opportunity to interact with a professor whose research focused on biology education. She would attend our weekly TA meetings and make suggestions that went against everything we had been taught to do in our lab sections. One suggestion that still stands out in my memory was to replace the

introductory PowerPoint presentations with off the cuff class discussions instead. At the time I thought this was a really bad idea because of the differing levels of ability of the TAs. I was concerned that while some TAs would embrace this method and do an excellent job of leading focused, relevant class discussions, other TAs would not be as well suited for this style of teaching and their students would not receive the necessary content. We compromised by creating PowerPoint presentations that had built-in discussion questions until all TAs felt comfortable leading discussions and could work without this crutch. I still always thought it was important to provide the TAs with an outline or other supplementary material to create structure and consistency between the lab classes. While I was initially resistant to some of the professor's ideas about teaching in large, introductory courses, I realized over time that this was a field of interest for me.

After serving as head TA for three semesters, I was offered the opportunity to teach the Principles of Ecology lab; the same lab course that first piqued my interest at UCF. Teaching a field course with only upper-classmen Biology majors was a new and very different experience from teaching Biology I labs. The majority of students were there of their own volition and they wanted to learn the material for mastery, not just for a grade. I particularly enjoyed teaching these motivated students basic ecology field and laboratory techniques. This was a very positive and rewarding teaching experience for me.

### **Experiences as a Science Educator**

During my last semester in the Master's program I began a job as an ecosystem surveyor. I enjoyed many aspects of this job, but eventually the unsteady work and job hazards (heat exhaustion, being chased by wildlife such as turkeys or cows, and being yelled at by land owners and/ or developers who wanted a survey to come out on their side) made me re-think my career



path. Since I knew that I also enjoyed teaching biology, I decided to apply for teaching positions. After several interviews I was hired as an 8<sup>th</sup> grade physical sciences teacher in the Orange County Public School system. Teaching middle schoolers was a vastly different experience from teaching college students and I was totally unprepared for it. Furthermore, I found that I did not enjoy teaching physical sciences as much as life sciences. I missed sharing my knowledge of topics that I found personally relevant such genetics and human physiology as opposed to the more intangible laws of physics. Planning laboratory exercises for 8<sup>th</sup> graders with limited materials and funds was especially challenging and gave me a new perspective on my K-12 learning experiences.

After one year as an 8<sup>th</sup> grade teacher I relocated to St. Louis, Missouri where I was hired as a high school life sciences teacher in the Roman Catholic Archdiocese school system. The combination of teaching high schoolers and life sciences made this a much better fit for my respective talents and interests. One of my favorite classes of the day was Human Anatomy and Physiology because the students tended to be more intrigued and motivated to learn the content due to its personal relevance. Some of my fondest memories of teaching are of leading the class in dissections. I would point out the structures that we had previously reviewed in textbook diagrams and quiz students on their functions. It felt like a very Socratic method of teaching that was enjoyed by both the students and me. While very few of the laboratory exercises were inquiry based, most students enjoyed the hands-on aspect of the class and the applied nature of the content.

I also taught a biology Advanced Credit Course (ACC) during this time. This course was the equivalent of one semester of university level General Biology spread over a year. The students in this course could be generalized as highly motivated, over achievers. Teaching this

course really challenged my knowledge of the content. I was unprepared for how quickly they could progress through the course material which required much more preparation from me than any other course I had previously taught. The small class size and above average students made this an enjoyable teaching experience.

After two years teaching high school I moved to a position as a laboratory coordinator for a majors-level introductory biology course at Saint Louis University (SLU). This was a very challenging position. I was responsible for every aspect of the laboratory curriculum from ordering supplies, creating assignments, and training and managing the TAs. During the three years I was employed at SLU I overhauled the laboratory curriculum extensively. I worked with all of the stakeholders (faculty, administrators, graduate and undergraduate students) to create a laboratory curriculum that taught students basic lab skills and the principles of scientific writing within an inquiry framework. Many of the TAs were resentful of the changes because it meant heavier workloads for them and some of the faculty members were resistant to change, simply on principle. My strongest memories are of being challenged by a faculty and a graduate student (separately) on some of the alterations to the lab activities. Working through these challenges taught me to be more diplomatic and savvy in presenting new ideas to different groups. It also formed strong bonds between us. Those same individuals became my greatest champions once I got them on board with my ideas.

Based on my experiences as a science educator, I have several mental stereotypes of students in a post-secondary introductory biology course. The first type of student is the highly motivated student who has a type “A” personality and *must* earn an A in the course. Often, these are students majoring in the biomedical sciences who believe they are destined for medical school. Sometimes they are truly gifted students who will probably reach those lofty goals. There

are always some students in this group who have a hard time adjusting to the level of work required to earn an A in a college-level science course. These students complain of having earned As in all of their classes in high school and their expectations that college would be the same way.

On the other end of the continuum are the students with low motivation to learn biology who just want to earn a decent grade to fulfill their science requirement. These students are not majoring in a typical science field; athletic trainers and computer science majors often fall in this group. These students frequently fail to see the applications of the material to their future career. They are only concerned with learning the material that will be covered on the test.

My favorite type of student is the typical biology major. These students do not always earn the highest grades in the course, but they often possess a desire for a more in-depth understanding of the material. These students tend to be very engrossed in the laboratory activities. They are interested in the applications of the content presented and how they will build upon it in future courses.

Of course, there are students who fall all along the spectrum of motivation to learn biology and have all sorts of possible reasons for their drive or lack of drive to succeed in an introductory biology course. I have had students in class who were truly interested in biology, but could not wrap their minds around the information covered in the course. These students were more difficult to advise compared to the other students because they often had a difficult time reconciling their perceived passion for the sciences with the difficulties of learning the nuts and bolts of biological processes.

## **Experiences with Instructional Technology**

The most common type of instructional technology I have encountered as a science educator could be described as probeware or environmental sensors. I've used probes in laboratory activities to measure the output of gases such as carbon dioxide and oxygen. Students always seemed to enjoy the real-time graphing of these devices, even if they could not explain what the graph was showing.

I've also employed online virtual dissections for students who could not or would not participate in hands-on dissections. At the time it was my opinion that these activities were inferior learning experiences as compared to the hands-on activities. My expectation was that students would simply click through the online activities without actually engaging in them. Whereas in the hands-on dissections I observed students engaged in the physical actions of cutting, tweezing, and probing, I did not see the equivalent of these practices in the virtual dissections.

The downfall of technology such as probes and virtual lab activities are the technical problems. Theoretically, students should be able to plug in a probe and proceed with the lab activities. However, there are always issues such as a probe not syncing with the computer or not producing a read-out from the sensor. Now, my job has shifted from assisting students in comprehending the processes involved in the lab activity to troubleshooting the technology that was supposed to make the lesson easier and more enjoyable for the students. In the case of virtual lab activities, there are always the issues of student access to computers and internet connectivity.

I often felt that the use of technology created a sense of distance between the student and the learning activity. A student using a probe to measure carbon dioxide output would be sitting

idly by while the experiment proceeded whereas a student conducting the same experiment without a probe would be taking measurements at constant intervals. There seemed to be a difference in the level of engagement between these two practices. But, I think that students have begun to expect a certain level of use of technology in their education because they use it so often in their everyday lives. Ultimately, it is our job as educators to find meaningful ways to incorporate technology in our teaching.

### **Themes**

Several themes emerge from this narrative on my experiences with biology laboratory education. Laboratory teaching and learning have been of interest to me for a long time. I realize now that my field and laboratory courses in college were what I found to be the most rewarding of my educational experiences. However, when I think of rewarding educational experiences, I envision the upper-division labs such as Genetics and Ecology and not the uninspiring lab activities from my General Biology courses. I placed value on learning activities that were inquiry in nature as opposed to following step-by-step directions. Even at that time I realized that not all hands-on work was equal.

Motivation and engagement in lab activities is a recurring theme in this narrative. As a science educator I created lab activities to engage students in the course material in a way that cannot be accomplished through lecture alone. Some of my least motivated students would become completely engaged in activities such as dissections or field trips to the zoo. However, I note that not all students are equally motivated to learn biology or are motivated by the same factors. Personal relevance is mentioned several times throughout this narrative as a factor that motivates students to learn biology. My observations of how different students perceive the relevance of biology coursework has probably helped to form my mental stereotypes of student

motivation. While it would be easy to use my past experiences to lump students into categories of motivation, these preconceptions should be set aside as much as possible to listen to students' experiences in their laboratory environment.

My first experiences teaching in graduate school were about creating structure and standardization across the many lab sections of the Biology I course. I believe now that I was teaching the way that I was taught in those courses instead of recreating the inquiry learning environment that made such an impact on me. However, this perspective gradually changed over my course as a science educator.

Friendship was another aspect of my experiences in laboratory courses. I have very fond and vivid memories of engaging in long, late night study sessions with my classmates after a day of grueling field or lab work. The intense nature of some of the classes created strong bonds. I also developed friendships among the faculty and graduate students at SLU based on our shared experiences of the General Biology labs.

My time as laboratory coordinator at SLU gave me an appreciation for both sides of the issues in large classes. I still think there is a need for standardization of course material across lab sections, but students should also be challenged and motivated by the lab activities. I now believe that with adequate training, most TAs can effectively teach inquiry labs. However, I also realize that there must be considerable resources in place for this to occur.

Another theme seen in this account is the downfalls of the use of technology in the laboratory. I cite technical issues with physical instruments such as probeware and online activities. I also remark on students' expectations for the use of technology in lab work and my observations on the differences in student engagement in technology enriched lab activities. However, there is a notable lack of my own experiences with technology in laboratory activities

or online courses. I do not think I have avoided online courses in my educational experiences, but they were not as common during my time in school and even scarcer in the sciences. The fact that I have never taken an online course is very relevant to this research project and could influence my expectations of the outcome.

### **Conclusion**

These experiences as a student, teaching assistant, K-12 teacher, and university lab coordinator give me a unique perspective on the current changes in the Biology I course at UCF. The process of bracketing these experiences has identified their impact on my beliefs, values, and biases. Acknowledging these subjectivities will allow me to better monitor them throughout the research project.

**APPENDIX G:  
INTERVIEW QUESTIONS**



Initial student interview protocol – Virtual laboratory group

Initial Question	Follow-up Questions	Desired Information
What kinds of science classes did you have in high school?	Describe these classes. How did these impact you?	Background information on student's prior science courses.
What do you recall about your experiences in the science labs in high school?	Describe the kinds of lab activities you did in high school. How did these impact you? Did you enjoy these courses?	Background information on student's prior science lab experiences to put data in context.
Did you enjoy learning about science in high school?	Did you participate in extra-curricular activities that were related to science (science fair, botany club, etc.)? If so, please describe these experiences.	Background information on student's previous science experiences to put data in context and develop a baseline of his/ her enjoyment of science.
Describe your motivation to learn biology.	How motivated are you and why?	Initial estimation of student's motivation to learn biology.
What was your initial reaction when you found out you were assigned to the virtual labs for this course?	Why did you have this reaction?	Student perception of virtual labs.
Have you completed a virtual lab? If so, describe your first experiences in the lab environment.	Describe the process of going through the lab.	Information on what the student has done in the virtual lab, feelings about the experiences, frustrations and successes.
What do you think of your learning experience in the virtual labs so far?	Are there specific characteristics of the virtual lab that you feel detracted from or enhanced your learning?	Student perception of learning enhancements and detractors.
Ask for clarification, additions, and deletions.	Paraphrase student answers about experiences in science courses in high school, motivation to learn biology, and their reaction towards the virtual labs.	Verification of researcher interpretation.

Initial student interview protocol – Face-to-face laboratory group

Initial Question	Follow-up Questions	Desired Information
What kinds of science classes did you have in high school?	Describe these classes. How did these impact you?	Background information on student's prior science courses.
What do you recall about your experiences in the science labs in high school?	Describe the kinds of lab activities you did in high school. How did these impact you? Did you enjoy these courses?	Background information on student's prior science lab experiences to put data in context.
Did you enjoy learning about science in high school?	Did you participate in extra-curricular activities that were related to science (science fair, botany club, etc.)? If so, please describe these experiences.	Background information on student's previous science experiences to put data in context and develop a baseline of his/ her enjoyment of science.
Describe your motivation to learn biology.	How motivated are you and why?	Initial estimation of student's motivation to learn biology.
Have you completed a Biology lab? If so, describe your first experiences in the lab environment.	Describe the process of going through the lab.	Information on what the student has done in the lab, feelings about the experiences, frustrations and successes.
What do you think of your learning experience in the labs so far?	Are there specific characteristics of the lab that you feel detracted from or enhanced your learning?	Student perception of learning enhancements and detractors.
Ask for clarification, additions, and deletions.	Paraphrase student answers about experiences in science courses in high school, motivation to learn biology, and their reaction towards the labs.	Verification of researcher interpretation.

Midpoint student interview protocol – Virtual laboratory group

Initial Question	Follow-up Questions
How do you prepare for the lab?	Do you make sure you have a block of time set aside to work on it? Do you review any course materials before starting the lab?
Tell me about the environment in which you typically complete the virtual labs.	Is there a certain time of day you typically work on them? Is there a particular space/ computer that you use to complete the labs? Do you ever find working on the computer to be distracting?
Tell me about your experiences completing the virtual lab assignments.	How long did the labs typically take to complete? Do you work all the way through a lab or stop and go back to complete parts of it at another time? Have you had to ask for help in completing a lab? If so, whom did you ask? Tell me what you think about completing the labs independently. Do you use other resources to help you complete the lab?
What are your thoughts on the process of collecting and analyzing data in the virtual lab?	Describe some of the data collection you have completed in the virtual labs. What do you do with the data after having collected it (answer questions, create graphs, etc.)? Is this similar to how you remember this process being in a physical lab?
What do you think of your learning experience in the virtual labs so far?	Are there specific characteristics of the virtual lab that you feel detracted from or enhanced your learning? Has your perspective on the virtual labs changed any since you have completed several? Do you see a connection between the material covered in the labs and in the lecture course?
Ask for clarification, additions, and deletions.	Is there anything else you would like to share about your experiences in the virtual labs so far?

Midpoint student interview protocol – Face-to-face laboratory group

Initial Question	Follow-up Questions
How do you prepare for lab?	How often do you read the lab handout before lab? Do you ever highlight or make notes on the handout before going to lab?
Tell me about the lab environment.	What do you like/ dislike about it? Are there any distractions in the lab?
Describe your experiences in the lab.	How long do the labs take to complete? How does your group work together during the lab? Do you ever have to ask for help in completing in the lab? If so, whom do you ask? Do you use other resources to help you complete the lab?
Tell me about the data collection and analysis process in the labs.	Describe some of the data you have collected this semester (measurements). What do you do with the data after having collected it (answer questions, create graphs, etc.)?
What do you think of your learning experience in the labs so far?	Are there specific characteristics of the lab that you feel detracted from or enhanced your learning? Has your perspective on the face-to-face labs changed any since you have completed several? Do you see a connection between the material covered in the labs and in the lecture course?
Ask for clarification, additions, and deletions.	Is there anything else you would like to share about your experiences in the labs so far?

Final student interview protocol – Virtual laboratory group

Initial Question	Follow-up Questions	Desired Information
Describe the kinds of things you have done in the <b>virtual lab</b> this semester. Describe the kinds of things you have done in the <b>F2F lab</b> this semester.	How do you feel about ___ (activities)?	Information on what the student has done in the lab, feelings about the experiences, frustrations and successes.
What did you learn in the virtual labs? How did you learn it?	Did you learn what you expected to learn? How do you know you learned this material?	Details on how, when, and where students completed the virtual labs. Whether the class met the student's expectations, what worked, and did not work. How did they gauge their learning (quiz grades, questions in the virtual platform, test scores)?
How satisfied are you with your learning experiences in the virtual labs?	Do you prefer working independently? Would you have taken the traditional lab if you could have? Would you recommend the virtual labs to other students? What do you think about the Biology department replacing the traditional labs with virtual labs in this course? Do you plan to take any future biology courses? What characteristics are most important in a science lab? Do you think the process you followed in the labs were similar to the process a scientist would go through when doing research?	Overall impressions and final opinions of the course.
How have your experiences in the virtual labs impacted your motivation to learn biology?	Describe specific experiences that impacted you. Did the labs help you feel connected to the course? Why/ why not?	Student perceptions of how the virtual labs impacted their motivation to learn biology.
Ask for clarification, additions, and deletions.	Is there anything else you would like to share about your experiences in the virtual labs so far?	Verification of researcher interpretation.

Final student interview protocol – Face-to-face laboratory group

Initial Question	Follow-up Questions	Desired Information
Describe the kinds of things you have done in the lab this semester.	How do you feel about ___ (activities)?	Information on what the student has done in the lab, feelings about the experiences, frustrations and successes.
What did you learn in the biology labs? How did you learn it?	Did you learn what you expected to learn? How do you know you learned this material?	Details on how students completed the labs. Whether the class met the student's expectations, what worked, and did not work. How did they gauge their learning (quiz grades, test scores)?
How satisfied are you with your learning experiences in the labs?	Do you prefer working in groups? Would you have taken the virtual lab if you could have? Would you recommend this course to other students? What do you think about the Biology department replacing the traditional labs with virtual labs in this course? Do you plan to take any future biology courses? What characteristics are most important in a science lab? Do you think the process you followed in the labs were similar to the process a scientist would go through when doing research?	Overall impressions and final opinions of the course.
How have your experiences in the labs impacted your motivation to learn biology?	Describe specific experiences that impacted you. Did the labs help you feel connected to the course? Why/ why not?	Student perceptions of how the labs impacted their motivation to learn biology.
Ask for clarification, additions, and deletions.	Is there anything else you would like to share about your experiences in the virtual labs so far?	Verification of researcher interpretation.

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