THE EFFECTS OF BIOLOGY LAB DELIVERY MODE ON ACADEMIC ACHIEVEMENT IN COLLEGE BIOLOGY

A Dissertation

by

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ABSTRACT

Many researchers have investigated the comparative effects of virtual lab and physical lab environments with mixed results that can be explained by the variability of lab features. Therefore, there is a need for better understanding of the affordances of instructor presence and learner control in virtual lab environments as compared to physical lab environments. Guided by a framework of instructor presence and learner control, this mixed methods study investigated the effects that the affordances of instructor presence and learner control have on laboratory-based learning across four different treatments in an undergraduate biology course for non-majors during the fall 2016 semester. The quantitative phase of the study tested the hypothesis that there were statistically significant differences in student achievement, as measured by immediate and delayed recall post-test scores, across four different modes of biology lab treatments. The second phase of this study sought to more deeply understand quantitative findings by qualitatively exploring how non-majors college biology students described their experiences of instructor presence and learner control of pace and repetition in each of the four lab treatments. Findings will inform institutions of higher learning, curriculum publishers, and those interested in the utility of virtual laboratories.

DEDICATION

This dissertation is dedicated to my grandmother Yvonne Kenneth, you taught me to be an independent woman, and to always be proud of my "brains"; you instilled upon me a lifelong passion for knowledge, having fun, and interest in advanced science and mathematics. I still remember that time growing up in Las Vegas when we had to eat all the Klondike bars before they melted.

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INTRODUCTION

Virtual laboratory investigations offer a wide variety of potential benefits to students, educators, and educational institutions when employed in college and university level science, technology, engineering, and mathematics (STEM) courses. Physical labs (PLs) employ a traditional physical based format where students have hands-on interaction with laboratory equipment and materials (Alkhaldi, Pranata, & Athauda, 2016) whereas Virtual labs (VLs) are defined as delivering all of the components of the laboratory experiment through a computer interface (Ma & Nickerson, 2006). VLs save time (Bell, 1999; Parker & Loudon, 2012), serve as viable economic alternatives to costly laboratory equipment and chemicals (Brinson, 2015; Ma & Nickerson, 2006; Muhamad, Zaman, & Ahmad, 2012), and help to conserve laboratory resources (Brinson, 2015; Cooper, Vik, & Waltemath, 2015; Hallyburton & Lunsford, 2013; Muhamad et al., 2012; Pyatt & Sims, 2012; Zacharia et al., 2015). VLs can ease the large demand for PL sections that accompany STEM lecture courses (Parker & Loudon, 2012; Swan & O'Donnell, 2009), the unavailability of lab sections can negatively impact science achievement (Swan & O'Donnell, 2009).Virtual labs support understanding of abstract concepts that are hard to visualize (Akpan, 2001; Dede, 1995; Zacharia, 2015) and facilitate student engagement and achievement (Johnson, 2002). This can be helpful for non-majors students who may not possess the background knowledge, interest, experience, or time required for adequate physically lab completion (Swan & O'Donnell, 2009). Often, laboratory instructors must balance their time between setting up equipment, maintaining the lab, monitoring safety, and assisting the whole class during the laboratory section (Parker & Loudon, 2012). Virtual STEM labs allow students the freedom to repeat experiments without the time constraints of traditional labs, which often require extensive set up of equipment (Bell, 1999); students are able to review content at their own pace, without the need to remain in the physical lab (Swan & O'Donnell, 2009).Virtual labs reinforce lecture concepts, are an additional representation of course content, promote learning through inquiry, and allow students to gain critical science skills and synthesize information (Bell, 1999; Chen et al., 2016).

Comparative Effects and Affordances of Physical and Virtual Labs

In spite of the numerous benefits of VLs, many educators, educational agencies, and institutions of learning still prefer PLs (ACS [American Chemical Society], 2014; NRC [National Research Council], 2006; NSTA [National Science Teachers Association], 2007). One major benefit of PLs is that they afford instructor presence, where students can directly communicate and receive guidance from a physically present instructor or teaching assistant (TA) (De Jong, Linn, & Zacharia, 2013; Stang & Roll, 2014). Studies show that instructor presence offered by PL can positively impact student achievement (De Jong et al., 2013; Klahr & Nigam, 2004; Picciano, 2002; Stuckey-Mickell & Stuckey-Danner, 2007). Additionally, students often have positive experiences communicating and interacting with instructors in PL environments (Bhargava, Antonakakis, Cunningham, & Zehnder, 2006; Gilman, 2006). Another reason for the preference toward PLs is that educators believe they teach foundational laboratory skills, including the use of chemicals and laboratory equipment (Carnevale, 2003). Students are also positive of the hands-on experiences PLs afford (Toth, Morrow, & Ludvico, 2009).

VLs can also provide instructor presence (Lim, Kim, Chen, & Ryder, 2008; Zacharia et al., 2015) and have been shown to positively impact student learning, in some cases, more so than PLs (Finkelstein et al., 2005; Gilman, 2006; Zacharia, 2007; Zacharia, Olympiou, & Papaevripidou, 2008). Research shows that students can also have positive experiences of instructor presence and guidance in VLs (Johnson, 2002; Lim et al., 2008). Additionally, the amount of learner control in VLs provides a distinct learning advantage over PLs (Finkelstein et al., 2005; Gilman, 2006; Zacharia, 2007). Studies by Lee, Wong, & Fung (2010), Parker and Loudon (2012), and Thompson, Nelson, Marbach-Ad, Keller, & Fagan (2010) show that students' learning experiences in VLs are positive, often because they have greater direction over their own learning.

However, the results remain mixed in regard to instructor presence and learner control in PL and VL environments. There is a need to investigate how the affordances of instructor presence and learner control provided by these labs impact student achievement (Picciano, 2002; Smith, 2015; Zacharia, 2007; Zacharia et al., 2015). Finally, there is limited research exploring students' experiences of instructor presence and learner control in PLs and VLs, as such, there is a need for future studies to investigate how students feel about their lab based learning (Humphries, 2007; Lee et al., 2010; NRC, 2006; Puttick, Drayton, and Cohen, 2015; Richardson et al., 2015).

Research Reported in this Dissertation

Three manuscripts comprising a mixed methods research approach are presented in this dissertation. First, a systematic literature review of instructor presence and learner control in PL and VL environments in STEM classes, second, a quantitative quasi-experimental study of the effects of mode of lab delivery on learning biology concepts in a sample of non-majors college undergraduate students, and third, a qualitative quasi-experimental study of students' learning experiences using the affordances of instructor presence and learner control in PL and VL environments.

Chapter II presents a systematic literature review of the studies conducted to: test the comparative effects of physical and virtual labs, measure the impact of the affordances of instructor presence and learner control on students' achievement in PL and VL delivery modes, and explore students' learning experiences using the affordances of instructor presence and learner control. In order to inform laboratory based teaching practices in STEM subjects, it is necessary for educators, curriculum developers, and learning institutions to understand the comparative effects of PL and VL delivery modes on student achievement. Additionally, it is important to gain insight to students' learning experiences in these environments to promote achievement and a better understanding of learners' needs. Further, the analysis of past and current literature on the affordances of instructor presence and learner control serves as the foundation to the studies presented in this dissertation. Through researching the affordances present in PLs and VLs and measuring their impact on students' achievement and learning experiences, instructional designers, curriculum developers, and educators can gain insight into the laboratory design and delivery strategies that best serve learners. Therefore, the main purpose of this section was to synthesize the recent literature of how the specific affordances of instructor presence and learner control provided within VLs and PLs quantitatively impact student achievement, and to explore qualitative studies of how student experiences of using PL and VL environments are influenced by the provision of the affordances of instructor presence and learner control.

Chapter III presents a quantitative study exploring the comparative effects of four distinct modes of biology lab delivery and how the affordances of instructor presence and learner control in each of the four modes impacts student learning outcomes. Data were collected from undergraduate students enrolled in four sections of an introductory course for non-majors, who participated in either a PL or VL activity on the topics of mitosis and meiosis. These data were then used to assess the effect that each laboratory delivery mode had on students' learning and achievement.

Chapter IV further investigates the results of the quantitative study through qualitative methods exploring students' experiences using the affordances of instructor presence and learner control in PL and VL environments. Data were collected through three focus groups and one interview where students expressed their opinions of learning using the labs, provided insight into their previous lab experiences, and offered suggestions for improving the labs.

While numerous studies have directly compared PLs and VLs, the unique affordances provided by each deserve further investigation. Further, the learning experiences students have within PL and VL environments are just as critical to learning as the content of the labs themselves. The three studies presented in this dissertation aim to provide a comprehensive foundation toward learning in PL and VL environments.

CHAPTER II: A Systematic Literature Review of Instructor Presence and Learner Control in Physical and Virtual Laboratory Environments in STEM Classes

Abstract

We examine and summarize the quantitative and qualitative studies comparing the effects and impacts of physical and virtual labs and studies of how the affordances of instructor presence and learner-control provided within physical and virtual labs impact student achievement. Literature was selected based on academic database keyword searches, sorted according to relevance of abstract, and read. Each of 126 studies was systematically coded using mixed-methods analysis software. Findings indicate mixed comparative effects of physical and virtual labs on students' academic achievement. Students benefit in physical labs from instructor presence, but are constrained by time, scheduling, and resources. Virtual labs afford more learner control of repetition, pacing, and scheduling. However, without instructor presence students in virtual labs may experience confusion, inefficient use of time, and frustration. Both affordances positively impact student achievement in each mode when they are offered. Students generally describe positive experiences of real science skills and instructor presence in physical labs, and the learner control and convenience afforded by virtual labs. Relationships have been found between students' satisfaction in physical and virtual labs and their effectiveness as learning tools. Recommendations for future study of instructor presence and learner control in both modes of laboratory delivery are discussed.

Introduction

Research on science curriculum and learning substantiate the credibility of laboratory investigations in science courses (NRC [National Research Council], 2006). Numerous studies have been done to explore how physical laboratory (PL) investigations impact student learning outcomes in science, technology, engineering, and mathematics (STEM) courses (Hofstein & Lunetta, 2004). For the past two decades, researchers have investigated virtual laboratories (VLs) as an alternative to PLs due to advances in technology, and the wide spread adoption of computers in educational environments (Finkelstein et al., 2005; Ma & Nickerson, 2006; Pyatt & Sims, 2012). However, findings regarding the comparative effects of PLs and VLs for laboratory delivery are mixed. Some studies have shown that VLs produce higher student science learning and achievement compared to PLs (Finkelstein et al., 2005; Gilman, 2006; Zacharia, 2007), while in other studies, PLs have produced greater student learning and academic achievement (Corter, Esche, Chassapis, Ma, & Nickerson, 2011; Dalgarno, Bishop, Adlong, & Bedgood, 2009). Additionally, some researchers have found that student learning and academic achievement is equivalent between PLs and VLs (Darrah, Humbert, Finstein, Simon, & Hopkins, 2014; Tatli & Ayas, 2013; Zacharia & Olympiou, 2011).

A possible reason for the inconsistency of findings regarding student learning outcomes in both PLs and VLs is the variability in conditions from one lab to another and the extent that the affordances of each delivery mode is provided by each unique laboratory during the investigated delivery. Physical labs (PLs) typically afford instructor or TA presence, such that students can receive both structured and spontaneous guidance. Whereas, VLs afford students more control of repetition, pacing, time spent learning, and access to guidance designed within the program. Further analysis of empirical research which explores the affordances of instructor presence and learner control can lend insight into the effectiveness of PL and VL laboratories (Smith, 2015; Zacharia, 2007; Zacharia, Olympiou, & Papaevripidou, 2008).

Theoretical Framework for Instructor Presence and Learner Control

Students control their learning by taking direct responsibility of their learning and pursuing further guidance by asking questions or accessing additional information (Merrill, 1980). The affordances of instructor presence and learner control within physical and virtual laboratory delivery modes and how these affordances facilitate student learning serves as a theoretical framework for this study (see Figure 1). Instructor presence allows learners to show their work, ask questions, and receive guidance from instructors during a course or during a lab regardless of mode of delivery (De Jong, Linn, & Zacharia, 2013; Picciano, 2002). In PLs, students can communicate with the instructor spontaneously and receive direct feedback as a means to help build their content knowledge and understanding of laboratory processes. In VLs, if instructors encourage communication at a distance, students can choose to take advantage of the specific instructor recommendation for communication about laboratory content and use of integrated guidance in the form of feedback, hints, and tooltips. Alternately, in VLs where communication is not actively encouraged, students must direct themselves to contact the instructor with questions and use instructor guidance within the lab. Instructor presence in VLs is defined here as the provision of instructor-student communication about the VL experience during or following their initial entry in the environment. Such learner control of communication with the instructor promotes constructivist learning (Dickey, 2005; Tobin, McRobbie, & Anderson, 1997).

The extent that learners control the pace, repetition, timing, access to instructor guidance, and sequence of content varies across modes of delivery. Instructors can direct students to control their learning by recommending that students repeat, review, and practice the lab content. While learners receive guidance to review learning materials, the decision to use learning environments for guidance rests solely on the learner (Hannafin, 1984; Merrill, 1980; Simsek, 2012; Williams, 1996).

	Learner Control	**Instructor Presence**
PL	Repetition • Bhargava et al., 2006	Instructor-Student Communication • De Jong et al., 2013 • Stang & Roll, 2014
	Pacing • Smetana & Bell, 2012	Instructor Guidance • Maldarelli et al., 2009 • NRC, 2006 • Hofstein et al., 2005
	Time Spent • Josephsen & Kristensen, 2006	
	Access To Available Guidance • NRC, 1997 • Zacharia et al., 2015	
VL	Repetition • Bhargava et al., 2006	Instructor-Student Communication • Picciano, 2002 • Humphries, 2007 • Richardson et al., 2015
	Pacing • Hasler, Kersten, & Sweller, 2007	Instructor Guidance • Johnson, 2002 • NRC, 1997
	Time Spent • Darrah et al., 2014 • Parker & Loudon, 2012	
	Access To Available Guidance • Honey & Hilton, 2011 • Lancaster, 2013 • Zacharia et al., 2015	

Figure 1. Theoretical Framework: Instructor presence and learner control.

Previous Research and the Need for Review

A seminal literature review by Ma and Nickerson (2006) examined 60 studies on physical, virtual, and remote labs. Their review showed that the body of studies on laboratory learning was dominated by technical and qualitative methods, and with few empirical studies. Additionally, they found that engineering was the most common subject of PL and VL studies, and that biology was the least studied. More recently, Brinson (2015) analyzed 56 empirical studies on physical, virtual, and remote labs. The purpose of the review was to build on Ma and Nickerson's (2006) work; the review specifically focused on literature published after 2006. The review of methodologies showed that scores on quantitative quizzes and tests and surveys and questionnaires were the most common measures used to compare PLs to VLs. In a majority of the reviewed articles, student learning outcomes in VLs were equivalent if not significantly better compared to PLs. Additionally, Ma and Nickerson provide evidence that students' level of satisfaction regarding their experiences using PLs and VLs impact their effectiveness as learning tools. In order to accurately inform educational practice and contribute to the scholarly body of research surrounding VLs, future studies assessing the comparative effects of VLs and PLs need to be informed by a wide variety of research methods and theoretical foundations (Brinson, 2015; Darrah et al., 2014; Flowers, 2011; Ma & Nickerson, 2006; Reese, 2013). In order to determine the possible connection between students' satisfaction and the effectiveness of PLs and VLs as learning tools, there is a need for further study to explore the relationship between student satisfaction in laboratory experiences and achievement (Ma & Nickerson, 2006).

Instructor presence in the form of instructor-student communication and interaction impacts student learning in PLs. So much so that, in their literature review on laboratory based learning in *America's Lab Report*, the NRC (2006) specifically addresses this deficiency as a limitation of their study. Clearly, this lack of research indicates the need to explore how the affordance of instructor presence can best impact student laboratory learning.

VLs attempt to compensate for instructor absence by providing students access to guidance as they need it. A review by Zacharia et al. (2015) measured the various types of guidance in the form of procedural directions, program dashboards, prompts, exploratory advice, scaffolds, and direct presentation of information that enhance student learning outcomes in computer based environments. The results of the 31 empirical studies reviewed offer that guidance allows learners greater control of their learning, and that the guidance provided in VLs, such as prompts and feedback, can positively affect student learning. However, further studies are needed to assess how guidance provided in VLs impacts student learning, specifically when students experience difficulties (Zacharia et al., 2015).

Research Purpose

This review serves to examine and summarize the recent literature on how the specific affordances of instructor presence and learner control provided within virtual and physical labs quantitatively impacts student achievement. Additionally, it serves to explore qualitative studies of how student experiences of using PL and VL environments are influenced by the provision of the affordances of instructor presence and learner control.

Research Questions

This review addresses gaps in the research by investigating relevant studies to answer the following questions:

1. How do physical and virtual laboratory delivery modes impact student achievement?

2. How are instructor presence and learner control defined within the context of physical and virtual laboratory environments?

3. How do the affordances of instructor presence and learner control within physical and virtual laboratory environments specifically impact student achievement?

4. How do students describe their experiences of using the affordances of instructor presence and learner control within physical and virtual laboratory environments?

5. What is the connection between student achievement and experience as a result of using the affordances of instructor presence and learner control within physical and virtual laboratory environments?

Materials and Methods

Literature Review Method

The comprehensive search that informed this literature review began with a keyword query across all available library databases, the initial keywords of “virtual labs” resulted in 412,991 results. To narrow down the choices to relevant literature, publications relating to fields outside of STEM subjects were automatically omitted by using the search terms “ virtual labs in STEM education” resulting in 62,646 results. From these, the results were narrowed to 54,754 total publications by using “virtual labs in STEM education subjects”. Further reduction was made through use of the search terms “virtual labs in STEM education AND efficacy”, “virtual labs in STEM education AND college biology”, and finally, “virtual labs in STEM education AND non-majors” which yielded a total of 645 entries. To find information about physical laboratories, the following key words were used "science laboratories", which yielded a total of 62, 743 results. Articles focused exclusively on educator attitudes, computer science instruction, Information Technology, and medical education were removed due to their limited application to the subject of biology. Remaining articles were filtered for relevance through a review of abstracts; articles that did not contain abstracts or were not available in English were omitted. After these sorting processes, a total of 126 articles were selected for their relevance regarding VLs in STEM education.

The publications excluded in the review included studies which lacked clearly defined research methods, analysis, and findings; as these would fail to inform the current analysis and future study. Additionally, publications which lacked peer review, were based solely on opinion, and had limited references were excluded.

Relevant research publications were assigned a weight based on the quality and the rigor of the study, following the methods of a related review by (Connolly, Boyle, MacArthur, Hainey, & Boyle, 2012). The publications that were the most relevant to the research questions of this review and possessed rigorous methods, analysis, and detailed results and discussion were analyzed in this review. Some studies which were less rigorous in their research methods and descriptive in their findings supplemented this review, but were not included in the analysis.

Literature Coding Method

The researcher read articles that were selected and uploaded them into MaxQDA where she coded them based on their relevance to each research question. A table that summarizes the coding schemes is included for reference. The coding schemes employed in this study are presented below (see Table 1).

Table 1

Literature Coding Schemes per Research Question

Research Question	Coding Scheme
RQ1. How do physical and virtual laboratory delivery modes impact student achievement?	"The impact of VL & PL on student achievement"
RQ2. How are instructor presence and learner control defined within the context of physical and virtual laboratory environments?	"Definition of Instructor Presence in PL" "Definition of Learner Control in PL" "Definition of Instructor Presence in VL" "Definition of learner control in VL"

(Continued)

RQ3. How do the affordances of instructor presence and learner control within physical and virtual laboratory specifically impact student achievement?	"IP in PL impact on student achievement" "LC in PL impact on student achievement" "IP in VL impact on student achievement" "LC in VL impact on student achievement"
RQ4. How do students describe their experiences of using the affordances of instructor presence and learner control within physical and virtual laboratory environments?	"Students experiences of using IP in PL" "Student experiences of using LC in PL" "Students experience of using IP in VL" "Student experiences of using LC in VL"
RQ5. What is the connection between student achievement and experience as a result of using the affordances of instructor presence and learner control within physical and virtual laboratory environments?	"Student achievement x experiences of IP in PL" "Student achievement x experiences of IP in VL" "Student achievement x experiences of LC in PL" "Student achievement x experiences of LC in VL"

Results

The Impact of Physical and Virtual Labs on Students' Achievement

Informed by the affordances of VL, numerous studies compare effects of PLs and VLs; however, the results of these studies remain mixed. A summary of important studies related to achievement in PLs and VLs is provided in this section (see Table 2).

Achievement in physical labs is less than in virtual labs. Some studies have shown that VLs can produce greater student learning and academic achievement compared to PLs. In a study on the effectiveness of virtual labs in an undergraduate biology course, Flowers (2011) found that students who completed virtual labs indicated that they provided greater understanding of biology concepts. He recommends that further study is needed to determine the effects of instructor-student communication on learning in PLs and VLs. In a study measuring the effects of physical experimentation and virtual experimentation on understanding electrical circuits in a sample of undergraduates enrolled in a physics course for pre-service elementary school teachers, Zacharia (2007) found that students who used the virtual labs showed greater knowledge acquisition and gained a greater conceptual understanding of physics. One proposed explanation for the difference in achievement was that the VL allowed students to repeat the experiment, thereby building their knowledge and understanding. In their research study that presented college undergraduate biology students with the opportunity to explore their learning with 10 biology VLs, Swan and O'Donnell (2009) found that the 263 students who opted to use the VLs outperformed PL students on laboratory practical tests. Based on observational and data feedback, it was found that students would repeat and review the VL to increase their understanding. For instance, Finkelstein et al. (2005) compared undergraduate college introductory physics students' use of virtual lab equipment to their use of hands-on lab equipment in modeling electrical circuits and found that students who used the simulation gained more knowledge of relevant physics concepts than those who used the equipment in person. A suggested reason for the finding is that students who used the simulation were better able to control their time spent learning through observation of electron flow, which is normally not visible in PL conditions. Additionally students were less distracted with the equipment set up and operation common to PL environments. In the subject of biology, Gilman (2006) found that freshman students majoring in biology who completed an online mitosis and meiosis lab significantly outperformed students who completed an equivalent lab physically. They attest that online environment had time saving applications and students could get just as much out of information from the online VL as they could in the PL.

Achievement in physical labs is greater than virtual labs. In certain cases, PLs produced greater student learning and academic achievement compared to VLs. A study by

Dalgarno et al. (2009) found that students who interacted with a PL environment scored slightly higher on apparatus identification and laboratory navigation tests than their VL environment counterparts. He relates that not all of the students made efficient use of their time spent learning in the VL, and experienced technology related issues. Additionally, Corter et al. (2011) found that undergraduate engineering students assigned to a PL treatment outperformed the VL group in both a content knowledge test and individual and group data collection processes. They suggest that these results may be due to the extended time that PL students spent, thoroughly running the experiment, collecting and analyzing data, and writing their results. Additional arguments regarding deficiencies of VLs come from national agencies which set the standards for science education. They take a firm stance that VLs are not acceptable replacements for PLs (ACS [American Chemical Society], 2014; NRC, 2006; NSTA [National Science Teachers Association], 2007), they offer that students should spend their time learning by investigations in PL settings, and that laboratory skills such as operating equipment and materials are necessary to students' learning.

Achievement in physical labs is equivalent to virtual labs. Darrah et al. (2014) compared the use of physics VLs to PLs in an undergraduate level introductory college physics course at two major universities. The data collected from the 135 student participants that used the physics VLs showed that VLs had statistically similar outcomes compared to PLs. In a study comparing 65 undergraduate non-majors college biology students who took an online biology course to those who took an equivalent face to face course, Johnson (2002) found that both groups performed equally well on an achievement post-test. In the study, students who completed experiments at a distance received weekly guidance from an instructor via a learning management system (LMS) bulletin board. In a pre-post test design study, Zacharia and

Olympiou (2011) explored the effects that physical and virtual labs have on undergraduate introductory physics students’ understandings of heat and temperature. Based on the 182 participants in the experimental groups of the study, virtual labs were found to produce equivalent learning outcomes compared to physical labs. They suggest that students' time spent learning using both physical and virtual materials resulted in the achievement of both groups. Additionally, Tatli and Ayas (2013) found that 9th grade chemistry students who used chemistry VLs demonstrated equivalent knowledge acquisition between chemistry pre and post-tests compared to their peers who performed PLs. They offer that students' time spent using the VL allowed them to complete more experiments than their PL peers and that VLs removed the time constraints associated with PLs. National educational agencies that actively support the use of VLs as a form of laboratory instruction include Next Generation Science Standards Lead States (2013), National Association of Biology Teachers (2009), and NSTA (2008).

Studies blending physical and virtual labs. Some studies have explored the integration of virtual labs as a supplement to physical, hands-on labs. While these studies contribute insight into how PLs and VLs impact student learning and achievement, they are not intended to answer the question of the comparative effects of PLs and VLs. A study by Toth, Morrow, and Ludvico (2009) explored efficacy of virtual labs in blended learning environments. In the study, freshman students in an introductory level biology course performed both virtual and physical based gel electrophoresis labs to learn about DNA technology. The findings of the study showed that students gained more knowledge about the process of gel electrophoresis through the blended learning environment with the completion of both the virtual and physical lab; however, students also expressed confusion related to minor differences between the two labs (Toth et al., 2009).

In a later study, Zacharia et al. (2008) examined the effects of a combination of virtual and physical labs on undergraduate introductory physics students' understanding of heat and temperature. They found that students understood concepts best when physical labs were supplemented with virtual labs, and attributed increased test scores to the immediacy offered by the virtual lab. They conclude that teachers are wise to use virtual labs to supplement content learned in face-to-face lecture environments.

Table 2

Select Studies on PLs & VLs Impact on Student Achievement

Study	**Sample Size**	**Study Design**	**Laboratory Type**	**Subject Area**	**Achievement measure**	**Impact on achievement**
Corter et al. (2011)	458	Randomized	PL-Beam Experiments VL-Beam Experiments	Undergraduate Engineering	8-item content knowledge test	PL group outperformed VL group on conceptual knowledge test
Dalgarno et al. (2009)	PL-11 VL-11	Post-Test	PL- Lab environment exploration VL- Virtual Chemistry Laboratory	Undergraduate Distance Chemistry	3 lab equipment identification tests	PL group outperformed VL group on tests
Darrah et al. (2014)	N=224 VL n=135	Post-Test Design	PL- Traditional Physics Lab VL- *Virtual Physics Lab*	Introductory College Physics	PostLab Quizzes Student Lab Reports Student Tests	PL =VL
Finkelstein et al.(2005)	Control PL-107+132 VL-99	Post-Test	Direct Current Circuit Laboratory	Introductory Algebra -based Physics Course	3 item challenge worksheet 3 dc questions on final exam	PL < VL

(Continued)

(Continued)

Gilman (2006)	PL-54 VL-52	Quasi-experimental mixed methods	PL-Chromosomes and cell division VL-Chromosomes and cell division	Majors Introductory Biology	1-Week Follow up cell division quiz	VL students outperformed PL students
Johnson. (2002)	65	Pre-Test/Post-Test	VL Biology PL Biology	Non-Majors College Biology	50 item multiple-choice test	PL=VL
Tatli and Ayas (2013)	90	Quasi-Experimental Pre-Test Post-Test Design	PL- "Chemical Changes" and "Recognizing Laboratory Materials and Equipment" VL-"Chemical Changes" and "Recognizing Laboratory Materials and Equipment"	9th Grade Chemistry	Chemical change Unit achievement Test Laboratory Equipment Test	PL = VL
Zacharia (2007)	88	Pre-Post Comparison	PL- Electric Circuits Module VL- Virtual Laboratories Electricity	Introductory Physics	4- open ended item pre test and post-test 13- item Electrical Circuits Test	VL group outperformed PL group on conceptual test
Zacharia and Olympiou (2011)	234	Pre-/posttest experimental	Heat and Temperature VL & PL	College Introductory Physics	Heat and Temperature conceptual test	PL=VL

The Definition of Instructor Presence in Physical and Virtual Labs

The goal of the second research question was to provide operational definitions of instructor presence and learner control within PL and VL environments. Summary tables of the definitions of instructor presence (see Table 3) and learner control (see Table 4) in PLs and VLs are presented below.

Definition of instructor presence in physical labs. Typically, researchers define instructor presence in PLs as having an instructor or TA physically available in-person for communication and to provide guidance during a laboratory section (De Jong et al., 2013). Instructor-student communication involves the student and laboratory instructor or TA communicating in-person during a laboratory section (Stang & Roll, 2014). Instructor guidance in PLs is when an instructor or TA is physically present during a lab. Guidance may be given in the following forms: providing pre-laboratory directions or demonstration (Maldarelli et al., 2009); monitoring student laboratory activity (NRC, 2006); checking for student understanding of laboratory work and procedures (Hofstein, Navon, Kipnis, & Mamlok-Naaman, 2005; NRC, 2006); and answering students' laboratory related questions (Hofstein et al., 2005; NRC, 2006).

Definition of instructor presence in virtual based labs. The literature identifies instructor presence in VLs as the instructor or TA being virtually available for communication and to provide guidance for students that complete labs online (Picciano, 2002). Instructor-student communication involves the student and laboratory instructor or TA communicating at a distance virtually, through e-mail, or over the telephone (Humphries, 2007; Richardson et al., 2015). Instructor guidance is where an instructor or TA is virtually present during a lab, guidance may be given in the following forms: providing answers to course and laboratory related questions (Johnson, 2002); assisting students with questions on VL operation and procedures (Johnson, 2002); and troubleshooting technical issues (NRC, 1997).

Table 3

Definition of Instructor Presence in PLs & VLs

Study	Study Design	Laboratory Type	Subject Area	Instructor Presence Affordance	Definition
de Jong et al.(2013)	Literature Review	PLs & VLs	Science & Engineering	Instructor Guidance	Instructor providing feedback in person and online
Hofstein et al. (2005)	Inquiry laboratory / student observation	Inquiry based chemistry lab	High school chemistry	Instructor Guidance	Students are able to ask lab related questions and receive help from an instructor
Johnson (2002)	Pre-Test/Post-Test	VL Biology PL Biology	Non-Majors College Biology	Instructor Guidance	Instructor is available virtually to provide guidance and answer student questions
Maldarelli et al.(2009)	Survey Study	Video pre-lab demonstration	College Biology	Instructor Guidance	providing pre-laboratory directions or demonstration
NRC (2006)	Report	Science Labs	Science	Instructor Guidance	Instructor is present to monitor student understanding of lab and to monitor lab activity

Definition of learner control in physical based labs. Learner control in PLs is the ability for students to control the pacing, repetition, time spent learning, and access to available guidance when they need it. In physical labs, repetition is the ability for students to interact with laboratory equipment multiple times and to repeat a laboratory investigation and instructional content (Bhargava, Antonakakis, Cunningham, & Zehnder, 2006). Pacing in physical labs refers to the ability of learners to control the progression, speed, and delivery of instructional content in a physical based environment (Smetana & Bell, 2012). This includes control of laboratory procedures, activities, and interaction with equipment and materials. In PLs students might control time spent completing laboratory activities through employment of laboratory procedures and interaction with laboratory equipment and materials (Josephsen & Kristensen, 2006). The instructor guidance that students receive in PL environments relates to learner control, as students have the ability to access guidance in laboratory environments as they need it.

Definition of learner control in virtual based labs. Learner control in VLs is the ability for students to control the repetition (Bhargava et al., 2006), pacing (Hasler, Kersten, & Sweller, 2007), time spent learning, and access to available guidance online when they need it (Zacharia et al., 2015). The affordance of directed learner control is described by Hannafin (1984). While learners receive guidance to review learning materials from instructors, the decision to use learning environments for guidance rests solely on the learner. An instructor may direct learners to control their learning by recommending that they use the online virtual lab content and environment as a review or study tool during or after they complete the laboratory. Repetition in VLs is the ability for students to log back in or repeatedly access content presented in the virtual environment (Bhargava et al., 2006). Pacing in VLs is where learners are able to control progression, speed, and delivery of instructional content (Hasler et al., 2007). Time spent is where learners are able to control the amount of time they spend learning within VLs (Darrah et al., 2014; Parker & Loudon, 2012), often this involves students accelerating through easy or already known content and spending more time learning difficult or new content**.** Access to available guidance is when students make use of feedback, hints, prompts, and tooltips in VLs as they need it (Honey & Hilton, 2011; Lancaster, 2013; Zacharia et al., 2015).

Table 4

Definition of Learner Control in PLs & VLs

Study	Study Design	Laboratory Type	Subject Area	Learner Control Affordance	Definition
Bhargava et al.(2006)	Survey Design	Virtual Torsion Lab	Undergraduate Engineering	Repetition Pacing Time spent	Students can repeat and review lab Students can work at their own speed VLs can replace less interesting PLs
Darrah et al.(2014)	Post-Test Design	PL- Traditional Physics Lab VL- *Virtual Physics Lab*	Introductory College Physics	Time Spent Learning	VLs allow students to conduct experiments without the equipment set up of PLs
Hannafin (1984)	Literature Review / Theoretical Paper	Computer assisted learning environments	All subjects	Directed Learner Control	Learners are given recommendation to use affordances and review learning materials, they must choose to do this
Hasler et al. (2007)	4 X 2 Animation Test Performance Design	Learner controlled and System controlled "Day and Night Phases" Animations	Middle school Physical / Earth Science	Pacing	Students are able to control the progression, speed, and delivery of instructional content
Lancaster (2013)	Design, Development, and Implementation Paper	Sapling Learning Interactive Chemistry Labs	General 9-16 Chemistry	Access to available Guidance	Students make use of feedback, hints, prompts, and tooltips in VLs as they need it
Smetana and Bell (2012)	Literature Review	Computer Simulations / VLs	Science	Pacing	The ability of learners to control the progression, speed, and delivery of instructional content in a PL environment

The Impact of Instructor Presence and Learner Control on Students' Achievement

Instructor presence in physical and virtual laboratory environments is provided through instructor-student communication and instructor guidance, a summary table of the impact of instructor presence on students' achievement is presented below (see Table 5). Learner control consists of features in PL and VL environments which allow for repetition, pacing, time spent, and students' access to available guidance as they need it. A summary table of the impact of learner control on students' achievement is presented below (see Table 6).

The impact of instructor presence on students' achievement in physical labs. Instructor presence in PLs allows learners to communicate, ask questions, and receive guidance from instructors during a course or during a lab (De Jong et al., 2013; Picciano, 2002). Instructor presence in the form of instructor-student communication has a positive impact on student achievement in PLs. Communication between instructors and students is a critical component of learning in PL environments. In PLs, direct communication and rapid feedback provided by instructors enhance student learning and understanding of course and laboratory content (De Jong et al., 2013; Picciano, 2002; Stuckey-Mickell & Stuckey-Danner, 2007). Additionally, the provision of direct instructional guidance in the form of feedback on laboratory processes and the errors made during inquiry facilitates student learning in PL environments (Klahr & Nigam, 2004).

The impact of instructor presence on students' achievement in virtual labs. Instructor presence in VL environments is provided through instructor-student communication and instructor guidance at a distance, where students are able to communicate and ask questions of an instructor online and via phone. VL environments with the correct amounts of instructor presence are linked to increased student learning and academic achievement (Adams, Paulson, & Wieman, 2009; Chamberlain, Lancaster, Parson, & Perkins, 2014). In online learning environments, such as VLs, communication between instructors and students is critical to students' success (Crippen, Archambault, & Kern, 2013; De Jong et al., 2013; Dunlap, Verma, & Johnson, 2016; Jaggars, Edgecombe, & Stacey, 2013; Picciano, 2002). In *Science Teaching Reconsidered*, the NRC (1997) specifically recommends that instructor communication and presence is needed to promote student learning in VL environments, and that the provision of such guidance can help students to avoid frustration when learning with technology. Additionally, the provision of instructor guidance through problem-solving processes facilitates student learning in STEM VL environments (Merrill, 1999; Podolefsky, Moore, & Perkins, 2013). Several studies indicate that the levels of guidance students receive while using VLs directly impact the levels of success in learning science concepts. Jonassen (2000) explained that learning scaffolds combined with interactive computer-based instruction, that he calls mindtools, should guide the design and development of technology-based learning environments. Additionally, the design of student-centered learning environments to enable student engagement in online learning must focus on delivery of well-constructed, simulated problems (Jonassen, 2000). Students acquire strong problem-solving skills by being presented with various instructional forms of problems and content, including computer based learning environments (Jonassen, 2001). The literature review by Zacharia et al. (2015) considered the amount of guidance given to students using virtual science labs. They found that guidance tools in the form of scaffolds were successful in helping students learn using technology and that guidance is more effective when it is offered multiple times within a virtual lab.

While instructor presence in VLs is usually beneficial to student learning, there are some cases in which it has a negative effect on student achievement. Chang, Chen, Lin, and Sung

(2008) and Chamberlain et al. (2014) found that too much instructor presence and guidance in VLs can be detrimental to student learning.

Table 5

The Impact of Instructor Presence on Students' Achievement in PLs & VLs

Study	Sample size	Study Design	Laboratory Type	Subject Area	Affordance	Achievement measure	Achievement Outcome
Adams et al. (2009)	100+ students	Interview 4 levels of guidance	PhET Electromagnetism Simulation	Physical Science	Instructor guidance	Students' interaction with VL	Students benefit from less invasive guidance
Chamberlain et al.(2014)	210 students	Quasi-experimental	PhET Acid-Base Solutions	Undergraduate General Chemistry	Instructor Guidance	One-Week Delayed Redraw Task	Light guidance groups drew more features of acid-base reactions.
Crippen et al.(2013)	35 science teachers	Survey Research	Inquiry based science labs	K-12 science	Instructor Student Communication	Laboratory teaching responses	It is necessary to include instructor student communication in online learning environments

The Impact of learner control on achievement in physical labs. While PLs generally offer limited opportunities for learner control, the affordance is not completely absent. To some extent, accessing available guidance as needed allows students in PLs to control their own learning (Zacharia et al., 2015). In physical based laboratories, this may involve asking the instructor or TA questions about the laboratory content, procedures, or how to use laboratory equipment during lab time (Hofstein et al., 2005; NRC, 2006). PLs typically lack the affordance of repetition due to limited resources such as chemicals, equipment, staff, time, and space (Bell, 1999; Bhargava et al., 2006; Brinson, 2015). As a result of these constraints, student learning in PLs is often negatively impacted (Josephsen & Kristensen, 2006; NRC, 1997). Additionally, PL environments offer students very little control of pacing (Bhargava et al., 2006; Smetana & Bell, 2012), the control of progression, speed, and delivery of instructional content. Many laboratory instructors, TAs, and laboratory sections must adhere to a strictly paced schedule due to limited resources such as time, space, finances, and equipment and materials (Bhargava et al., 2006; Brinson, 2015). Often in PLs students' assignments are prescriptive. Therefore, students have little control over how they spend their time. The set-up and operation of materials and equipment, and the procedures and activities within PL environments can negatively impact student learning, as available time to learn is constrained (Josephsen & Kristensen, 2006). Additionally, the time students take to complete PL activities is influenced by their understanding of procedures and instructions that accompany the lab, studies show that when students do not have the proper knowledge background needed for a lab, their achievement can be negatively impacted (NRC, 1997).

The impact of learner control on achievement in virtual labs. The key features identified within the literature that facilitate learner control in virtual based laboratory delivery modes are: repetition (Bhargava et al., 2006); pacing (Hasler et al., 2007); time spent (Darrah et al., 2014; Parker & Loudon, 2012); and students' access to available guidance as they need it (Malik, Martinez, Romero, Schubel, & Janowicz, 2014; Parker & Loudon, 2012). The affordance of learner control offered by VLs can also play a significant role in student achievement (Zacharia, 2007). In their study, Lee, Wong, and Fung (2010) found that 210 high school biology students who used the virtual V-Frog dissection to learn about frog anatomy experienced increased learning as measured by a post-test. They suggest that the reason for the learning gains was the learner control of repetition and pacing offered by the virtual lab. Further, Honey and Hilton (2011) suggest that VLs can be used to increase student learning and achievement, due to the learner control they provide.

In VLs, students can actively control their learning pace, repetition of selected lab experiences, and interaction with simulated lab equipment, experiments, and the instructor, thereby constructing their knowledge and observing modeled scientific phenomena (Dede, 1995; Dede, 2009; Pyatt & Sims, 2012; Schwab, 2012). The affordance of learner control offered in online learning environments such as virtual labs provides for a distinctly different educational experience compared to physical lab environments.

As educators implement virtual environments, mechanisms for encouraging learner control need to be considered and adopted (Hasler et al., 2007; Zacharia et al., 2015). The affordance of repetition has been shown to promote students' understanding, subject knowledge, and learning in VL environments (Campen, 2013; Flowers, 2011; Land & Zimmerman, 2015; Smetana & Bell, 2012; Toth et al., 2009; Zacharia et al., 2015). Multiple studies support the use of virtual labs as a supplemental review tool for increasing student learning of content taught in physical based lecture and lab environments (Campen, 2013; Flowers, 2011; Toth et al., 2009; Zacharia et al., 2008). However, there is still a need to assess how students take advantage of the affordance of repetition in VLs and to measure how repetition affects their learning of related content (Zacharia, 2007; Zacharia et al., 2015). The VL affordance of control of pacing, progression, speed, and delivery of instructional content provides a distinct learning advantage over PLs (Bhargava et al., 2006; Smetana & Bell, 2012). Hasler et al. (2007) found that middle school science students who had control of the pacing of virtual labs performed significantly better on a physical science content knowledge test than those who lacked control of pacing. In VLs, students appreciate having control over their learning and of the progression, speed, and delivery of instructional content. Zacharia (2007) and Zacharia et al. (2008) called for further study to determine how the pacing offered in VLs affects student learning and academic achievement. The findings of such studies help to inform educators, curriculum publishers, and instructional designers in how to best design and implement laboratory delivery modes which allow students the best use of their study time and repetition of content to enhance their learning. Learner control is also present in students' use of their time in lab-based instructional environments. The amount of time spent on tasks within physical based and virtual environments can impact how students acquire knowledge within these labs. The time students take to complete laboratory activities is influenced by their understanding of procedures and instructions that accompany the lab. Additionally, students are allowed more efficient use of class time when virtual labs are used to replace simple or less interesting physical labs (Bhargava et al., 2006). VLs may benefit students in that time spent within the VL environment allows them to focus more on learning content, removing the concerns of equipment set up that often accompany PLs, providing a more efficient use of class instructional time (Darrah et al., 2014; Parker & Loudon, 2012). Finally, in VLs, students control their own learning by accessing available guidance when they need it (Zacharia et al., 2015). In VLs, students can pursue guidance beyond a specific class-time by reaching out or responding to the instructor online or by accessing online scaffolds such as hints (Honey & Hilton, 2011; Zacharia et al., 2015), tooltips (Lancaster, 2013), directions (Zacharia et al., 2015), or feedback (Parker & Loudon, 2012; Podolefsky et al., 2013) provided in the virtual interface. In order to facilitate student achievement, VLs must consist of a variety of well-constructed instructional content, problems, and simulations. The provision of guidance in online learning environments such as VLs is critical to student success (Jonassen, 2000; Jonassen, 2001).

There are some instances where learner control can negatively impact student achievement, When proper directions, guidance, and procedures are lacking in VLs, students may engage in off-task behavior; using time inefficiently (Pedersen & Irby, 2014).

Table 6

The Impact of Learner Control on Students' Achievement in PLs & VLs

Study	Sample size	Study Design	Lab Type	Subject Area	Feature	Measure	Outcome
Lee et al.(2010)	210 high school students	Pre-test /post-test	V-Frog VL	High School Biology	pacing repetition	Post-test	VL increased student learning
Bhargava et al. (2006)	200	Survey design	Virtual Torsion Lab	Undergraduate Engineering	Pacing Repetition Time Spent	10-page Lab Reports Evaluation Survey	Some students felt the control offered by the VL increased their learning
Chang et al.(2008)	153 students Control group (N=39) Experimental Group 1 (N=39) Experimental Group 2(N=40) Experimental Group 3 (N=35)	Quasi-Experimental	PL- Optical Lenses Lab VL- Optical Lenses Simulation	Second year Junior-High School Physics	VL Guidance Prompting Hypothesis Menu Step Guidance	10-item pre-test and post-test	VL Group with specific step guidance performed lower than Experiment prompting and Hypothesis menu group
Parker and Loudon (2012)	851 undergraduate students	Survey Design	PL- Traditional VL- Sapling Organic Chemistry	Pre-Pharmacy Organic Chemistry	VL Feedback Time spent learning	Self- Reported Grades Survey	VL group experienced increased course grades
Podolefsky et al.(2013)	9 middle school students	Design and Development	PhET	Middle school students	Access to available guidance	Observation Interviews	Students felt guidance helped their learning in VL

Students' Experiences of Instructor Presence and Learner Control in PLs and VLs

The attitudes and experiences students have while using the features of physical and virtual laboratory environments can be critical to their learning. To answer the fourth research question, the review focused specifically on students' experiences of instructor presence and learner control and the features that comprise these affordances within physical and virtual laboratory environments. In some studies, students showed a preference toward PLs over VLs (Bhargava et al., 2006; Stuckey-Mickell & Stuckey-Danner, 2007). Gilman (2006) found approximately half of the student participants who completed an online cell division lab expressed a strong preference for in-class lab work. Other researchers found that it is possible for students to feel connected to a laboratory activity, even when it is done virtually (Annetta, Klesath, & Meyer, 2009); suggesting that STEM labs can be engaging, even when taught at a distance. For a summary of studies on students' experiences of instructor presence in PLs and VLs (see Table 7), additionally, a summary of students' experiences of learner control in PLs and VLs are provided (see Table 8).

Students' experiences of instructor presence in physical labs. The experiences of instructor presence that students have while learning in PLs can be positive. Students often show a preference for PLs as they believe that they afford greater levels of instructor-student communication (Bhargava et al., 2006; Gilman, 2006). Students are positive of their experiences to directly communicate with instructors and receive rapid feedback about laboratory instructional content, procedures, and questions (Bhargava et al., 2006). Robinson (2012) and Stang and Roll (2014) called for further study to explore students' experiences of instructor-student communication in PLs. Students' experiences of the guidance available in PLs also influence their preferences. Stuckey-Mickell and Stuckey-Danner (2007) found that students favor PLs over VLs and perceive that they afford greater levels of instructor guidance compared to VLs. Additionally, research has found that students are positive toward well delivered instructor guidance in lab based learning (Bhargava et al., 2006; Stuckey-Mickell & Stuckey-Danner, 2007).

Students' experiences of instructor presence in virtual labs. Students often report that their experiences of instructor presence in VLs are positive. Lim, Kim, Chen, and Ryder (2008) found that undergraduate college students who completed an online wellness course were positive about their interactions with an instructor in the online environment. Additionally, Humphries (2007) and Richardson et al. (2015) highlight the importance of instructor-student communication in online learning environments such as VLs, and recommend that further studies are needed to measure students' experiences of communication with instructors. The findings of such studies help to provide educators, curriculum researchers, and instructional designers insight into how students feel about instructor-student communication and guidance within laboratory delivery modes and inform strategies which enhance their learning. Additionally, Johnson (2002) found that undergraduate non-majors students enrolled in an online biology course are positive about the guidance provided by their instructor online. The results of their Likert survey indicate that students agree they would have been willing to take the course again with the same instructor.

However, other studies have found that students' experiences of instructor presence in VLs are negative. Gilman (2006) found that the lack of a physically available instructor in online VL environments negatively impacts students' experiences of instructor presence. Students expressed negative attitudes toward the lack of instructor-student communication while using a virtual lab to learn about cell division. Stuckey-Mickell and Stuckey-Danner (2007) conducted an exploratory inquiry study involving 38 student participants enrolled in two sections of an online introductory human biology course with in-person labs. The study substituted 10 physical physiology labs with virtual physiology labs and administered a survey to measure students' experiences in both laboratory environments. Results indicated that the students in the VLs missed the ability to ask questions and receive guidance and feedback from the instructor.

Table 7

Studies on Students' Experiences of Instructor Presence

Study	Sample size	Study Design	Laboratory Type	Subject Area	Instructor Presence Feature	Experience Outcome
Bhargava et al.(2006)	200 students	Survey design	Virtual Torsion Lab	Undergraduate Engineering	Instructor-student communication	Students preferred PL to VL due to instructor-student communication
Gilman (2006)	PL-54 VL-52	Quasi-experimental mixed methods	PL-Chromosomes and cell division VL-Chromosomes and cell division	Majors Introductory Biology	Instructor-Student Communication	Students expressed negative views toward the lack of in person instructor-student communication
Johnson (2002)	65	Pre-Test/Post-Test	VL Biology PL Biology	Non-Majors College Biology	Online instructor guidance	Students were positive about instructor guidance online
Lim et al.(2008)	153	Pre-test and post-test	Online wellness course	Health and wellness	Online instructor guidance	Students were positive about their online interactions with instructor
Stuckey-Mickell & Stuckey-Danner (2007)	38 college students	Exploratory Inquiry	Anatomy and Physiology and biology	Human Biology course	Instructor student communication and guidance	Students did not like the lack of a physically available instructor

Students' experiences of learner control in physical labs. In some circumstances, students' experiences of learner control in PLs are positive (Chen, Chang, Lai, & Tsai, 2014). Domin (1999) suggests that inquiry-based activities delivered in PLs allow students more control over their learning, thereby creating positive experiences. The time students take to complete laboratory activities is influenced by their understanding of procedures and instructions that accompany the lab. Often, PLs require students to operate specialized equipment and gather data as part of laboratory activities, which may result in experimental and measurement errors (Heradio et al., 2016; Olympiou & Zacharia, 2012). Students often view these errors as valuable learning opportunities, as they gain insight into the nature of science and experimentation (Toth et al., 2009).

Alternately, research shows that some students' experiences of learner control in PLs are negative (Chen et al., 2014). PLs often lack learner control of repetition as they are constrained by specific instructions and are limited by time and scheduling constraints (Brinson, 2015). PLs are often limited in resources such as chemicals, equipment, staff, time, and space (Bell, 1999; Bhargava et al., 2006) the limited opportunity for repetition can negatively impact students' experiences' of controlling their learning in PLs. The lack of pacing in PLs can lead to negative student experiences, Bhargava et al. (2006) and Smetana and Bell (2012) found that students can be constrained by their lack of control of pacing in PLs. Students have limited, if any, control of their time spent learning in PLs. Corter et al. (2007) found that some college undergraduate engineering students believed that PLs are a waste of time and do not benefit their learning. Students' time spent learning in PLs often requires following procedures, operating laboratory equipment, and correctly using materials. Errors in the laboratory process further constrain students' available time to learn (Josephsen & Kristensen, 2006). In PLs, students control their learning by accessing available guidance as they need it (Zacharia et al., 2015), this may involve asking the instructor or TA questions about the laboratory content, procedures, or how to use laboratory equipment during lab time (Hofstein et al., 2005; NRC, 2006). While students experience direct feedback from course instructors, often they may be hesitant to direct the questioning process; as a result, the initiation of inquiry must often come from the instructor

(NRC, 1996). If instructors do not initiate communication and provide guidance during labs, students may have negative learning experiences, as they may not feel they are getting the help they need (NRC, 1997).

Students' experiences of learner control in virtual labs. Students' experiences of the learner control offered in VLs can be positive (Lee et al., 2010). Studies demonstrate that these positive experiences of learner control often lead students to actually prefer VLs over PLs (Flowers, 2011), due to the increased control they have over their learning including opportunities for repetition (Bhargava et al., 2006); pacing of content (Bhargava et al., 2006; Thompson, Nelson, Marbach-Ad, Keller, & Fagan, 2010); time spent learning (Darrah et al., 2014; Parker & Loudon, 2012); and access to available guidance as they need it (Malik et al., 2014; Parker & Loudon, 2012). In VL environments, students can actively control their learning pace, repetition of selected lab experiences, and interaction with simulated lab equipment, experiments, and the instructor, thereby constructing their knowledge and observing modeled scientific phenomena (Dede, 1995; Dede, 2009; Pyatt & Sims, 2012; Schwab, 2012). VLs provide students the ability to control their learning by repeating simulated laboratory experiments and instructional content. Boggs (2006) and Lee et al. (2010) found that students appreciate the opportunities for repetition afforded by VLs and feel it is beneficial to their learning. In a study on the delivery of 10 Biology VLs to college undergraduate introductory biology students, Swan and O'Donnell (2009) used a survey to measure student attitudes of using VLs; students were positive about the opportunity for repetition afforded by the VLs. Students' ability to assume greater direction of their learning by controlling the pacing of instructional content and laboratory activities was a major identified factor toward preference for VLs (Bhargava et al., 2006; Thompson et al., 2010). In many studies, students expressed positive attitudes toward the speed at which VLs allow them to perform lab activities (Thompson et al., 2010; Toth et al., 2009). Students' experiences of the ability to control pacing of instructional media commonly presented in VLs such as videos, animations, and simulations were also positive. VLs may benefit students in that time spent within the VL environment allows them to focus more on learning content, removing the concerns of equipment set up that often accompany PLs, providing a more efficient use of class instructional time (Darrah et al., 2014; Parker & Loudon, 2012). A review of relevant studies showed that the majority of student experiences of controlling time spent learning while using VL were positive. One of the most common positive experiences described by students was that VLs are easy to use (Pyatt & Sims, 2007; Pyatt & Sims, 2012; Toth et al., 2009). Students also expressed that VLs were beneficial in the fact they removed a lot of the error that normally occurs in PL environments, which allows more efficient use of time for learning information (Toth et al., 2009). Additionally, students appreciate using their time learning in VLs to more carefully observe presented content such as diagrams, animations, slides, and models; an opportunity they perceive is lacking from PLs (Swan & O' Donnell, 2009). Finally, in VLs students experience learner control by accessing available guidance as needed (Zacharia et al., 2015); their learning experiences are influenced by the guidance afforded by VLs. The provision of online communication with an instructor, and online scaffolds such as hints (Honey & Hilton 2011; Zacharia et al., 2015), tooltips (Lancaster, 2013), and directions (Zacharia et al., 2015) may increase students' positive attitudes in using VLs as they facilitate control over learning. Studies by Malik et al. (2014) and Parker and Loudon (2012) found that undergraduate college students were positive about their experiences of completing organic chemistry homework through an interactive interface due to the feedback provided in the online environment. Additionally, Swan and O’Donnell (2009) found that students had positive attitudes about using VLs as a review tool due to being able to receive instant feedback.

Students' experiences of learner control in VLs can also be negative, leading students to prefer PLs over VLs. Students often feel that their time spent learning in VLs does not teach them the necessary skills of using laboratory materials and operating laboratory equipment (Flowers, 2011). Additionally, Chen et al. (2014) found that some students preferred the PLs to VLs due to the fact that in PLs they could physically interact with lab equipment and materials.

The provision of guidance in online learning environments such as VLs is critical to student success (Jonassen, 2000; Jonassen, 2001); however, students must actively choose to use these affordances. In VL environments, students can be are unaware of, or completely overlook the guidance available online. Stuckey-Mickell and Stuckey-Danner (2007) found that students who completed online physiology labs expressed that the VL lacked the feedback provided in PL; they specifically mention that the VL had embedded text feedback. When students perceive that proper directions, guidance, and procedures are lacking in VLs, they may engage in off-task behavior; using time inefficiently (Pedersen & Irby, 2014).

Table 8

Studies on Students' Experiences of Learner Control

Study	Sample size	Study Design	Laboratory Type	Subject Area	Learner Control Feature	Experience Outcome
Bhargava et al.(2006)	200 students	Survey design	Virtual Torsion Lab	Undergraduate Engineering	Pacing Repetition Time Spent	Students were positive about LC features in VL.
Chen et al. (2014)	68 students	Post-Test and Interview	Boyle's Law VL and PL	High School Physics	Time Spent	Some students missed hands-on interaction of PLs

(Continued)

Malik et al. (2014)	108 students	Survey Design	Connect Chemistry VL Traditional PL	Undergraduate Chemistry	Access to available guidance	Students appreciated the online embedded guidance
Parker & Loudon (2012)	443 students	Case Study	Sapling Chemistry	Undergraduate Chemistry	Access to available guidance	Students felt the guidance helped their learning
Pedersen & Irby (2014).	63 middle school students	Student Observations	Hurricane Hal	Middle School Earth/Physical Science	Access to available guidance Time Spent	Students confused by guidance expressed frustrated interaction with VL
Swan & O'Donnell (2009)	2478 college students	Post- Test Design	Biology VLs	College General Biology	Repetition Time Spent Learning	Students were positive about learner control in VL
Toth et al. (2009)	39 students	Mixed-Methods: Two time×two order-condition design	PL- Gel Electrophoresis VL- Virtual Gel Electrophoresis	College Freshman Introductory Biology	Pacing Time Spent	Students enjoyed methods and error of PL. Students enjoyed the ease, speed, and automation of VL.

The Connection between Students' Achievement and Experiences in PLs and VLs

The goal of the final, fifth, research question was to provide further understanding of the connection between student achievement and experience as a result of using the affordances of instructor presence and learner control in PLs and VLs.

Through the affordance of learner control, VLs can allow students greater involvement in their own learning (Podolefsky et al., 2013; Zacharia et al., 2015). Certain studies show a link between students' learning achievement and their experience of using the affordance of learner control offered by VLs. Research by Lee et al. (2010) found that the learner control offered by the V-Frog was positively related to students' perception of the VLs usefulness as a learning tool and resulted in increased learning. Additionally, VLs can facilitate students' interest in science content (Chen et al., 2016; Honey & Hilton, 2011) which can lead to increased achievement. Finally, other studies have shown that VLs can promote students' motivation to learn (Ahmed & Hasegawa, 2014; Akpan, 2002; Dede, 2004), thus increasing achievement.

Discussion

The discussion of the literature review results are provided below, they are organized based on the order of the research questions.

The Impact of Physical and Virtual Labs on Students' achievement

A large number of current studies examine the combined use of PLs and VLs (Flowers, 2011), this combination makes it fairly difficult to measure how the comparative effects and the affordances of each unique laboratory delivery mode impact student achievement. Further studies which distinctly compare PLs to VLs are needed to inform how each mode and the provided affordances impact student learning (Zacharia et al., 2015). Such studies could inform the design and implementation of both PLs and VLs and provide insight into application of VLs at institutions currently confined to the sole use of PLs. This information would benefit educators and institutions with interest in implementing VLs, and further guide instructional designers, curriculum publishers, and researchers of best practice in developing PLs and VLs.

The findings of this review demonstrate that in some cases achievement in PLs is less than VLs. These findings are in line with other studies which found similar results (Finkelstein et al., 2005; Gilman, 2006; Zacharia, 2007; Zacharia et al., 2008). In some studies the higher achievement outcomes were related to instructor presence; and the different amounts of instructor-student communication (Flowers, 2011; Picciano, 2002; Stuckey-Mickell & Stuckey-Danner, 2007; Zacharia et al., 2015) and instructor guidance (Ahmed & Hasegawa, 2014; Chen et al., 2016; Pedersen & Irby, 2014; Smith, 2015; Zacharia et al., 2015) afforded to students in PL and VL environments. Further studies are needed to inform how the amount and nature of instructor presence in VLs and PLs cause different achievement outcomes (Dixson, 2010; Richardson et al., 2015; Stuckey-Mickell & Stuckey-Danner, 2007; Watson, Watson, Richardson, & Loizzo, 2016). Additionally, the results of this study showed that the affordance of learner control contributed to the increased student achievement in VL over PL (Finkelstein et al., 2005; Gilman, 2006; Swan & O'Donnell, 2009; Zacharia, 2007); however, further study is needed into how the specific affordances of repetition (Zacharia, 2007; Zacharia et al., 2015), pacing (Zacharia, 2007; Zacharia et al., 2008), time spent learning, and access to available guidance specifically result in higher student achievement when using VLs.

The findings of this review demonstrate that in some cases achievement in VLs is less than PLs (Corter et al., 2011; Dalgarno et al., 2009). Instructor presence may have resulted in higher achievement outcomes; including the different amounts of instructor-student communication (Flowers, 2011; Picciano, 2002; Stuckey-Mickell & Stuckey-Danner, 2007; Zacharia et al., 2015) and instructor guidance (Ahmed & Hasegawa, 2014; Chen et al., 2016; Pedersen & Irby, 2014; Smith, 2015; Zacharia et al., 2015) afforded to students in PL and VL environments. Further studies are needed to inform how the amount and nature of instructor presence in VLs and PLs cause different achievement outcomes (Dixson, 2010; Richardson et al., 2015; Stuckey-Mickell & Stuckey-Danner, 2007; Watson et al., 2016). Additionally, the results of this study showed that the affordance of learner control contributed to the increased student achievement in PL over VL (Corter et al., 2011); however, further study is needed into how the specific affordances of repetition (Zacharia, 2007; Zacharia et al., 2015), pacing (Zacharia, 2007; Zacharia et al., 2008), time spent learning (Darrah et. al, 2014; Pedersen & Irby, 2014), and access to available guidance specifically result in higher student achievement when using PLs.

Achievement can be equivalent between PLs and VLs (Darrah et al., 2014; Tatli & Ayas, 2013; Triona & Klahr, 2003; Zacharia & Olympiou, 2011). However, further study is needed to determine how the affordance of instructor presence, including instructor- student communication (Flowers, 2011; Picciano, 2002; Stuckey-Mickell & Stuckey-Danner, 2007; Zacharia et al., 2015) and instructor guidance (Ahmed & Hasegawa, 2014; Chen et al., 2016; Pedersen & Irby, 2014; Smith, 2015; Zacharia et al., 2015) lead to similar learning outcomes in PLs and VLs. Further investigation is also warranted to inform how learner control of repetition (Zacharia, 2007; Zacharia et al., 2015), pacing (Zacharia, 2007; Zacharia et al., 2008), time spent learning (Darrah et. al, 2014; Pedersen & Irby, 2014), and access to available guidance (Yaman, Nerdel, & Bayrhuber, 2008; Zacharia et al., 2015) produce equivalent achievement between PLs and VLs.

Additionally, in many studies combined PLs and VLs were explored. Flowers (2011) indicated that the use of virtual labs as both pre-lab and post-lab review activities might benefit college biology students. Ultimately, this review shows that the results are still mixed in regard to the comparative effects of PLs versus VLs. This finding is in line with other studies which highlight deficits in current research (Brinson, 2015; Smetana & Bell, 2012).

The Definition of Instructor Presence in Physical and Virtual Labs

Definition of instructor presence in physical labs. Science education is constantly looking to inform how IP should be provided in PL learning environments. By determining a concise definition, and a framework for provision, we can further inform educators about good science teaching practices. In this review, learner control in PLs is defined as having an instructor or TA physically available in-person for communication and to provide guidance during a laboratory section (De Jong et al., 2013), and consists of instructor-student communication (Stang & Roll, 2014) and instructor guidance (Hofstein et al., 2005; Maldarelli et al., 2009; NRC, 2006).

Definition of instructor presence in virtual labs. As interest in virtual labs increases, and the use of online learning technologies in STEM courses increases, so does the viability of VLs. It is necessary to inform how instructor presence should be provided in online and VL science learning environments, specifically, in terms of instructor-student communication. By determining a concise definition, and a framework for provision of instructor, we can further inform instructional designers, educators, curriculum publishers, and researchers about effective online science teaching practices. In this review, instructor presence in VLs is defined as the instructor or TA being virtually available in-person for communication and to provide guidance for students that complete labs online (Picciano, 2002), and consists of instructor-student communication (Humphries, 2007; Richardson et al., 2015) and instructor guidance (Johnson, 2002; NRC, 1997).

Definition of learner control in physical labs. The field of science education is constantly looking to inform how labs can be improved through affording LC to allow students greater control of their own learning and promoting a sense of responsibility and interest in their learning. By determining a concise definition, and a framework for provision, we can further inform educators about good science teaching practices regarding promoting students' control and direction over their own learning in physical science lab environments. In this review, learner control in PLs is the ability for students to control the pacing, repetition, time spent learning, and access to available guidance when they need it, and consists of repetition

(Bhargava et al., 2006), pacing (Smetana & Bell, 2012), time spent learning (Josephsen & Kristensen, 2006), and access to available guidance as needed (Zacharia et al., 2015).

Definition of learner control in virtual labs. As interest in virtual labs increases, and the use of online learning technologies courses in STEM and viability of VLs increases, it is necessary to inform how learner control can be provided in online and VL science learning environments. To promote and allow students' greater direction of their own learning, which has been shown to positively impact success in learning in via technology, in online environments, and at a distance (Honey & Hilton, 2011; Podolefsky et al., 2013; Zacharia, 2007). By determining a concise definition, and a framework for provision of LC, we can further inform instructional designers, educators, curriculum publishers, and researchers about effective online science teaching practices. Many studies which define learner control in computer environments are older, due to technological advances, and the increasing capabilities of distance education, there is a need to inform the definition of learner control in the context of current and future online learning environments such as VLs. In this review, learner control in VLs is defined as the ability for students to control the repetition (Bhargava et al., 2006), pacing (Hasler et al., 2007), time spent learning, and access to available guidance online when they need it (Zacharia et al., 2015).

The Impact of Instructor Presence and Learner Control on Students' Achievement

This review focused on studies which identified the features and affordances of instructor presence and learner control within PL and VL delivery environments and measured the impact on student achievement. There is a need for further research into how student learning is influenced by instructor presence, including instructor-student communication (Flowers, 2011; Picciano, 2002; Stuckey-Mickell & Stuckey-Danner, 2007; Zacharia et al., 2015) and instructor guidance. With respect to learner control, further research is needed to assess how students take advantage of the affordance of repetition in VLs and to measure how repetition affects their learning of related content (Zacharia, 2007; Zacharia et al., 2015). Research is also needed to explain the relationship between the affordance of pacing offered by VLs, student learning, and academic achievement (Zacharia, 2007; Zacharia et al., 2008). The findings of such studies help to inform educators, curriculum publishers, and instructional designers in how to best design and implement laboratory delivery modes which allow students the best use of their study time and repetition of content to enhance their learning. Additionally, Hasler et al. (2007) recommend further study into learner control of pacing to assure the proper instructional design of online environments such as virtual labs, and that learner control of pacing should be implemented to increase student learning. Further, Honey and Hilton (2011) explain the benefit of pacing in that when instructional designers properly design VL environments, they provide delivery of unique science lessons tailored to individual learners. More research is needed to determine the effect that the ways time is spent has on student learning of content (Darrah et. al, 2014; Pedersen & Irby, 2014). Additionally, few studies compare both affordances of instructor presence and learner control across PL and VL. While numerous studies have combined the use of PLs and VLs (Flowers, 2011), this presents a challenge, as it is difficult to discern the effect that each of the individual affordances has on learning. The is a need for further study into how the specific affordances offered by virtual and physical labs modes of delivery compare, and how they influence student learning outcomes (Smith, 2015; Zacharia, 2007). Another issue that comes to light is that students may not actively use the affordances available to them; further study is needed to measure how students use the affordances of instructor presence and learner control, and to encourage their use (Dede, 2009; De Jong et al., 2013).

Students' Experiences of Instructor Presence and Learner Control in PLs and VLs

In the scope of the current study, there is relatively little research which describes or measures student learning experiences in PLs (NRC, 2006; Puttick, Drayton, and Cohen, 2015). However some studies show that students often feel anxious about performing labs (Dalgarno et al., 2009). Additionally, there is a need to expand on the body of literature which describes and measures students' learning experiences in online environments such as VLs (Humphries, 2007; Lee et al., 2010; Richardson et al., 2015). In terms of instructor presence, research shows that students in PL environments often struggle with questioning, and that instructors should encourage student communication to help alleviate feelings of frustration (NRC, 1996). Additionally, students' learning experiences are typically measured through Likert (Johnson, 2002; Stuckey-Mickell & Stuckey-Danner, 2007) surveys, open ended surveys or survey items (Gilman, 2006), or through questions embedded as part of a test or lab assignments (Bhargava et al., 2006). Further studies using a wider variety of qualitative methods such as focus groups are needed. Measurement of student experiences is necessary to inform learning institutions and educators how they can better design and deliver PLs and VLs to foster students' positive learning experiences of using instructor presence and learner control and encourage use of these affordances.

The Connection between Students' Achievement and Experiences in PLs and VLs

Learner control and the connection between student achievement and experiences. There are relatively few studies which compare students' learning experiences using the affordances of instructor presence and learner control to their achievement in PLs and VLs. Further study is needed on the connection between students' achievement and experiences to promote students use the affordances available to them in their PLs and VLs. Students may be more likely to use these affordances and respond positively if there is evidence their achievement will increase. The finding that there is a positive relationship between student achievement using

VLs and the affordance of learner control (Lee et al., 2010) relates to the concept that learners' are more likely to effectively use a learning tool when they perceive it as useful or beneficial.

Conclusion

Significance of the Study

The systematic literature review served to inform theory of instructor presence and learner control. An interesting finding of the review is that students in PLs do not always use instructor presence, in many cases the initiation of communication must come from the instructor (NRC, 1996). In regard to instructor presence in VLs, a study by Johnson (2002) found that students were able to interact and benefit from instructor guidance in an online environment. These findings suggest the need for instructional designers and educators to rethink their conception and definition of instructor presence, clearly, presence can be virtual, and can produce equivalent learning outcomes in PL and VL environments. The literature on instructor presence in PLs and VLs highlights the need for further studies which will help to build upon theory (Chen et al., 2016; Pedersen & Irby, 2014; Picciano, 2002; Stuckey-Mickell & Stuckey-Danner, 2007).

The literature revealed that students' in PLs do have the ability to control their learning through accessing available guidance from the instructor as they need it, however, they may be hesitant to do so (NRC, 1996; NRC, 1997), this can result in negative learning experiences. Additionally, learner control in VLs can be disrupted by the provision of too much guidance, unclear guidance, or when students' erroneously believe that it is absent (Pedersen & Irby, 2014; Stuckey-Mickell & Stuckey-Danner, 2007). There is a need for theoretical studies which explore students' experiences of instructor guidance in PLs and VLs and those which explore ways to encourage students' use of the affordance of learner control in PL and VL environments (Yaman et al., 2008; Zacharia et al., 2015).

Additionally, this review informs the design and development of PL and VL laboratories. Ahmed and Hasegawa (2014) found that there is a lack of instructional design and development models for creating VLs, nor is there a set of universal design features and criteria that guide effective teaching in these environments. Research has shown that VLs can offer instructor presence (Johnson, 2002), and can provide learner control (Hasler et al., 2007; Zacharia et al., 2015), however, further studies which inform their design and development are needed (Ahmed & Hasegawa, 2014).

Limitations

The review of the literature is limited by the fact that the use of virtual labs in biology science instruction is a developing field of research. Additionally, many studies surrounding virtual labs are confined to the use of large introductory level science courses in order to gain large enough populations for adequate statistical procedures (Ma & Nickerson, 2006).

Implications for Practice

This review seeks to inform instructional designers, educators, curriculum developers, researchers, and institutions of higher learning about the comparative effects and affordances of PLs and VLs in college STEM education. The potential positive implication of studying VLs includes broadening the laboratory component of science education options for college students.

Research shows that there is a lack of consensus on the exact definition of a virtual lab. In many studies, “virtual labs” and “web labs” are used interchangeably, and there is a need to find a more concise definition (Brinson, 2015; Ma & Nickerson, 2006). Interest in technology based learning tools is increasing. The use of virtual labs is informed by the fact that digital age ‘millennial’ students, familiar with multiple forms of technology (Dede, 2004), are entering colleges and enrolling in STEM courses. In a research article, Dede (2004) describes millennial as a population whose way of learning is grounded in “fluency in multiple media and in simulation-based virtual settings” (p.1). Relating that “computers and the Internet are depicted as the crucial technological force determining the characteristics of millennial (born after 1982)” (p.3) informs the recommendation for situated learning through immersive virtual environments, including virtual labs for science education (Dede, 2004). Research into the topic area of virtual labs is timely and relevant, especially with the increasing use of educational technology, including the increased offering of completely online science classes (Darrah et al., 2014; Johnson, 2002; Miller, 2008).

The use of virtual labs as learning tools in completely online environments has also been studied. In a study describing the effects of teaching secondary science in online learning environments, Crippen et al. (2013) found that many instructors still preferred traditional hands-on labs. A design and development article by Ahmed and Hasegawa (2014) describes the necessity of quality instructional design practices in implementing virtual labs in online learning. Instructional designers, educators, curriculum publishers, and learning institutions should realize the educational potential that VLs possess. They produce achievement outcomes equivalent, if not greater than PLs (Flowers, 2011; Johnson, 2002; Swan & O’Donnell, 2009). As such, it is necessary that further study is done to further explore their viability as a learning tool, taking into account students learning experiences, and the unique affordances of instructor presence and learner control provided by each.

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CHAPTER III: The Effects of Mode of Lab Delivery on Learning Biology Concepts

Abstract

We investigated the comparative effects of virtual lab and physical lab environments affording different treatments regarding instructor presence and learner control. Using analysis of variance, we compared test-scores of four treatment groups in an undergraduate biology course for non-majors: a physical lab with instructor presence, a virtual lab with no instructor presence, a virtual lab with instructor presence, and a virtual lab with instructor presence and direction for learning control of pace and repetition beyond lab time. Students in all delivery modes demonstrated learning immediately following treatment and maintained it a week later indicating that students both learned and retained knowledge across all four modes of delivery. There were no significant differences between test scores across treatment groups, indicating the virtual labs are as effective as physical labs. The findings serve to inform institutions of higher learning, curriculum publishers, and those interested in implementing virtual laboratories.

Keywords: distance education and tele-learning, interactive learning environments, simulations; teaching/learning strategies; virtual reality

Introduction

Physical labs (PLs) afford the physical presence of an instructor or teaching assistant (TA) for providing guidance, but virtual labs (VLs) afford more learner control of repetition, pacing, time spent learning, and access to available guidance than physical labs. Such affordances likely influence the impact that the different modes of delivery have on learning outcomes, suggesting that investigations controlling for these variables can lend insight into their effective applications (Smith, 2015; Zacharia, 2007; Zacharia, Olympiou, & Papaevripidou, 2008).

Theoretical Framework

Students control their learning by taking direct responsibility of their learning and pursuing further guidance through asking questions or accessing additional information (Merrill, 1980).

The affordances of instructor presence and learner control within physical and virtual laboratory delivery modes and how these affordances facilitate student learning serve as a theoretical framework for this study (see Figure 1). Instructor presence allows learners to show their work, ask questions, and receive guidance from instructors during a course or during a lab regardless of mode of delivery (De Jong, Linn, & Zacharia, 2013; Picciano, 2002). In PLs, students can communicate with the instructor spontaneously and receive direct feedback as a means to help build their content knowledge and understanding of laboratory processes. In VLs, if instructors encourage communication at a distance, students can choose to take advantage of the specific instructor recommendation for communication about laboratory content and use of integrated guidance in the form of feedback, hints, and tooltips. Alternately, in VLs where communication is not actively encouraged, students must direct themselves to contact the instructor with questions and use instructor guidance within the lab. Instructor presence in VLs is defined here as the provision of instructor-student communication about the VL experience during or following their initial entry in the environment. Such learner control of communication with the instructor promotes constructivist learning (Dickey, 2005; Tobin, McRobbie, & Anderson, 1997).

The extent that learners control the pace, repetition, timing, access to instructor guidance, and sequence of content varies across modes of delivery. Instructors can direct students to control their learning by recommending that students repeat, review, and practice the lab content. While learners receive guidance to review learning materials, the decision to use learning environments for guidance rests solely on the learner (Hannafin, 1984; Merrill, 1980; Simsek, 2012; Williams, 1996).

	Learner Control	**Instructor Presence**
PL	Repetition • Bhargava et al., 2006	Instructor-Student Communication • De Jong et al., 2013 • Stang & Roll, 2014
	Pacing • Smetana & Bell, 2012	Instructor Guidance • Maldarelli et al., 2009 • NRC, 2006 • Hofstein et al., 2005
	Time Spent • Josephsen & Kristensen, 2006	
	Access To Available Guidance • NRC, 1997 • Zacharia et al., 2015	
VL	Repetition • Bhargava et al., 2006	Instructor-Student Communication • Picciano, 2002 • Humphries, 2007 • Richardson et al., 2015
	Pacing • Hasler, Kersten, & Sweller, 2007	Instructor Guidance • Johnson, 2002 • NRC, 1997
	Time Spent • Darrah et al., 2014 • Parker & Loudon, 2012	
	Access To Available Guidance • Honey & Hilton, 2011 • Lancaster, 2013 • Zacharia et al., 2015	

Figure 1. Theoretical Framework: Instructor presence and learner control.

Literature Review

Previous research into virtual labs, instructor presence, and learner control serves as the foundation for this study. The specific features that comprise instructor presence in PL and VL environments include instructor-student communication and instructor guidance. Learner control consists of features in PL and VL environments which allow for repetition, pacing, time spent, and students' access to available guidance as they need it.

Comparative Effects of Physical labs and Virtual labs

Informed by the affordances of VL, numerous studies compare effects of PL and VLs; however, the results of these studies remain mixed. Some studies have shown that VLs can produce greater student learning and academic achievement compared to PLs. For instance, Finkelstein et al. (2005) compared undergraduate college introductory physics students' use of virtual lab equipment to their use of hands-on lab equipment and found that students who used the simulation gained more knowledge of relevant physics concepts than those who used the equipment in person. In a study measuring the effects of physical experimentation and virtual experimentation on understanding of electrical circuits in a sample of undergraduates enrolled in a physics course for pre-service elementary school teachers, Zacharia (2007) found that students who used the virtual labs gained a greater conceptual understanding of physics. In a later study, Zacharia et al. (2008) examined the effects that combination of virtual and physical labs had on undergraduate introductory physics students' understanding of heat and temperature. They found that students understanding of heat and temperature were better when physical labs were supplemented with virtual labs, and attributed increased test scores to the immediacy offered by the virtual lab. In the subject of biology, Gilman (2006) found that freshman students majoring in biology who completed an online mitosis and meiosis lab significantly outperformed students who completed an equivalent lab physically.

In certain cases, PL has produced greater student learning and academic achievement compared to VL. A study by Corter, Esche, Chassapis, Ma, and Nickerson (2011) found that undergraduate engineering students assigned to a PL treatment outperformed the VL group in both a content knowledge test and individual and group data collection processes. Additionally, Dalgarno, Bishop, Adlong, and Bedgood (2009) found that students who interacted with a PL environment scored slightly higher on apparatus identification and laboratory navigation tests than their VL environment counterparts. Additional arguments against VL come from several national agencies which set the standards for science education that clearly state VL is not an acceptable replacement for PL (ACS [American Chemical Society], 2014; National Research Council [NRC], 2006; NSTA [National Science Teachers Association], 2007).

Additionally, some researchers have found that student learning and academic achievement is equivalent between PLs and VLs. Zacharia and Olympiou (2011) explored the effects that physical and virtual labs have on undergraduate introductory physics students' understandings of temperature and heat. Virtual labs were found to produce equivalent learning outcomes compared to physical labs. Darrah, Humbert, Finstein, Simon, and Hopkins (2014) compared the use of virtual physics labs to physically based labs in an undergraduate level introductory college physics course at two major universities, and found that virtual physics labs had similar outcomes compared to hands-on labs. Tatli and Ayas (2013) found that 9th grade chemistry students who used simulations demonstrated equivalent knowledge acquisition compared to their peers who performed physically based experiments. National educational agencies which actively support the use of VLs as a form of laboratory instruction include Next Generation Science Standards Lead States (2013), National Association of Biology Teachers (2009), and National Science Teachers Association (2008).

Instructor presence. Instructor presence in physical and virtual laboratory environments is provided through instructor-student communication and instructor guidance. In PLs, direct communication and rapid feedback provided by instructors has been shown to enhance student learning and understanding of course and laboratory content (De Jong et al., 2013; Picciano, 2002; Stuckey-Mickell & Stuckey-Danner, 2007). The provision of instructional guidance facilitates student learning in physical (Klahr & Nigam, 2004) and virtual (Merrill, 1999; Podolefsky, Moore, & Perkins, 2013) science education environments. Alternatively, studies by Chang, Chin, Lin, and Sung (2008) and Chamberlain, Lancaster, Parson, and Perkins (2014) found that too much instructor presence and guidance in VL can be detrimental to student learning. VL environments with the correct levels of instructor presence are linked to increased student learning and academic achievement (Adams, Paulson, Wieman, 2009; Chamberlain et al., 2014). In online learning environments, such as VLs, communication between instructors and students is critical to students' success (Crippen, Archambault, & Kern, 2013; De Jong et al., 2013; Dunlap, Verma, & Johnson, 2016; Jaggars, Edgecombe, & Stacey, 2013; Picciano, 2002).

Learner control. PLs offer limited provision of learner control as they are constrained by specific instructions, are limited by time constraints, and offer limited opportunities for repetition (Brinson, 2015). The affordance of learner control offered in online learning environments such as virtual labs provides for a distinctly different educational experience compared to physical lab environments. According to Dron and Anderson (2016), "…an attendee [in an online learning experience] is always…uncontrolled by the teacher. Asynchronous course forums, blogs or guided exercises afford considerably greater [learner] control. This shift of control is the fundamental difference between online and face-to-face education" (p.544). As educators implement virtual environments, mechanisms for encouraging learner control need to be considered and adopted (Hasler, Kersten, & Sweller, 2007; Zacharia et al., 2015). In VL environments, students can actively control their learning pace, repetition of selected lab experiences, and interaction with simulated lab equipment, experiments, and the instructor, thereby constructing their knowledge and observing modeled scientific phenomena (Dede, 1995; Dede, 2009; Pyatt & Sims, 2012; Schwab, 2012).

The affordance of repetition has been shown to promote students' understanding, subject knowledge, and learning in VL environments (Campen, 2013; Flowers, 2011; Land & Zimmerman, 2015; Smetana & Bell, 2012; Toth, Morrow, & Ludvico, 2009; Zacharia et al., 2015). PLs typically lack the affordance of repetition due to limited resources such as chemicals, equipment, staff, time, and space (Bell, 1999; Bhargava, Antonakakis, Cunningham, & Zehnder, 2006). There is still a need to assess how students take advantage of the affordance of repetition in VLs and to measure how repetition affects their learning of related content (Zacharia, 2007; Zacharia et al., 2015).

Research studies have also shown that the VL affordance of control of pacing, progression, speed, and delivery of instructional content provides a distinct learning advantage over PLs (Bhargava et al., 2006; Smetana & Bell, 2012). When proper directions, guidance, and procedures are lacking in VLs, students may engage in off-task behavior, using time inefficiently (Pedersen & Irby, 2014). Zacharia (2007) and Zacharia, et al. (2008) called for further study to determine how the pacing offered in VLs affects student learning and academic achievement (Zacharia, 2007; Zacharia et al., 2008). The findings of such studies help to inform educators, curriculum publishers, and instructional designers in how to best design and implement laboratory delivery modes which allow students the best use of their study time and repetition of content to enhance their learning.

VLs may benefit students in that time spent within the VL environment allows them to focus more on learning content, removing the concerns of equipment set up that often accompany PLs, providing a more efficient use of class instructional time (Darrah et al., 2014;

Parker & Loudon, 2012).

Finally, in both PLs and VLs, students control their own learning by accessing available guidance when they need it (Zacharia et al., 2015). In physical based laboratories, this may involve asking the instructor or TA questions about the laboratory content, procedures, or how to use laboratory equipment during lab time (Hofstein, Navon, Kipnis, & Mamlok-Naaman, 2005; NRC, 2006). But, in VLs students can pursue guidance beyond a specific class-time by reaching out or responding to the instructor online or by accessing online scaffolds such as hints (Honey & Hilton, 2011; Zacharia et al., 2015), tooltips (Lancaster, 2013), directions (Zacharia et al., 2015), or feedback (Parker & Loudon, 2012; Podolefsky et al., 2013) provided in the virtual interface. In order to facilitate student achievement, VLs must consist of a variety of well-constructed instructional content, problems, and simulations. The provision of guidance in online learning environments such as VLs is critical to student success (Jonassen, 2000; Jonassen, 2001).

Purpose of the Study

The purpose of this study was to test the hypotheses that there would be statistically significant differences in non-majors college biology students' learning as measured by scores on a post-test administered immediately following lab completion and after a one week delay due to the comparative effects of four different modes of biology lab treatments: a physically based lab with instructor presence (PL), a virtual lab with no instructor presence (VL), a virtual lab with instructor presence (VLIP), and a virtual lab with instructor presence and direction for learner control of pace and repetition beyond lab time (VLIPLC). This study also investigated the influences of instructor presence and learner control on learning in virtual and physical lab environments.

Research Question and Hypotheses

This study was guided by the following quantitative research question and hypotheses:

1. What are the comparative effects of four modes of biology lab delivery on non-majors college biology students' test scores immediately following lab completion and after a one week delay? The four modes compared include the following:

a. a physical based lab with instructor presence (PL),

b. a virtual lab with no instructor presence (VL),

c. a virtual lab with instructor presence (VLIP), and

d. a virtual lab with instructor presence and direction for learner control of pace and repetition beyond lab time (VLIPLC).

This study tested three alternate hypotheses 1) The main effect of the modes of biology lab delivery, PL, VL, VLIP, and VLIPLC, on biology content knowledge will be statistically significant; 2) The main effect of time, a pre-test, an immediate recall post-test, and a delayed recall post-test on biology content knowledge will be statistically significant; 3) The mode of lab delivery by time interaction effect: the interaction between mode of biology lab delivery and time measured by achievement on mitosis and meiosis content knowledge post-tests given immediately after laboratory completion, and one week later will be statistically significant.

Materials and methods

This study served as the quantitative component of an overall quasi-experimental mixed method study which measured the impact of four laboratory delivery modes on students' achievement in a biology course for non-majors at a Hispanic Serving Institute (HSI) university in south Texas, during the Fall 2016 semester.

Participants

The population of interest in this study is non-majors college biology students enrolled at universities in the southern United States. A non-probability sampling was used to select participants from four intact sections of a non-majors introductory biology course (Orcher, 2014). Following IRB approval, all 98 students enrolled in four sections of the non-majors introductory biology course consented to participate in the pre-test, PL or VL activities, and post-tests. Due to absences and external factors, data were ultimately collected from 92 participants.

Each of the four sections was assigned to one of four distinct modes of delivery: PL (n = 21), VL (n = 25), VLIP (n = 22), and VLIPLC (n = 24). The majority of the participants were 18-24 years old (92.40%), were female (55.40%), and were sophomores (54.20%). With respect to ethnicity, (44.60%) were white, (33.70%) Hispanic, and (13.00%) African American. The demographic characteristics of the four modes of biology lab delivery groups: age, gender, ethnicity, college level, and major, are presented in Table 1.

Table 1

A Profile of Participants

Demographic Variables	Mode of Biology Delivery			
	VLIP (n=22)	VL (n=25)	PL (n=21)	VLIPLC (n=24)
Age	f / %	f / %	n/ %	f / %
18-24 years	20/90.90	22/88.00	21/100.00	22/91.70
25-34 years	0/0.00	3/12.00	0/0.00	1/4.20
35-44 years	0/0.00	0/0/00	0/0.00	1/4.20
45-54 years	1/4.50	0/0.00	0/0.00	0/0.00
55-64 years	1/4.50	0/0.00	0/0.00	0/0.00
Gender				
Male	11/50.00	9/36.00	11/52.40	10/41.70
Female	11/50.00	16/64.00	10/47.60	14/58.30
Ethnicity				
White	11/50.00	10/40.00	7/33.30	13/54.20
Hispanic	4/18.20	8/32.00	10/47.60	9/37.50
African-American	6/27.30	1/4.00	3/14.30	2/8.30
Other	1/4.500	6/24.00	1/4.80	0/0.00

(Continued)

College Level				
Freshman	2/9.10	1/4.00	2/9.50	0/0.00
Sophomore	9/40.90	12/48.0	16/76.20	13/54.20
Junior	6/27.30	12/48.0	3/14.30	11/45.80
Senior	5/22.70	0/0.00	0/0.00	0/0.00
Major				
Business	5/22.70	9/36.00	5/23.80	2/8.30
Computer Science	2/9.10	3/12.00	2/9.50	1/4.20
Education	2/9.10	1/4.00	3/14.30	7/29.20
Engineering	0/0.00	0/0.00	1/4.80	0/0.00
Liberal Arts	8/36.40	9/36.00	4/19.00	8/33.30
Life Science	1/4.50	0/0.00	0/0.00	0/0.00
Nursing	2/9.10	2/8.00	0/0.00	1/4.20
Physical Science	1/4.50	0/0.00	0/0.00	3/12.50
Other / Undecided	1/4.50	1/4.00	6/28.50	2/8.30

Note: PL - Physical, in-person, lab completed normally as part of the BIOL 1308 course.
VL - Virtual lab without instructor presence.
VLIP - Virtual lab with instructor presence.
VLIPLC - Virtual lab with instructor presence and direction for learner control.

Study Design

This quasi-experimental study employed a 4 by 3 repeated measures split plot design with one between-subjects factor, the mode of biology laboratory delivery (PL, VL, VLIP, and VLIPLC), and one within-subjects factor, time (pre-test, immediate post-test, and one-week delayed post-test). The four different modes of biology lab delivery served as the independent variable and student scores on two biology content knowledge post-tests administered immediately and one week after the completion of the biology labs served as the dependent variables. Each of the four intact sections of the non-major introductory biology course were randomly assigned as per Orcher (2014) to one of the experimental laboratory delivery modes. The aim of this design was to determine the differential effects that four biology lab treatments had on student achievement as measured by biology content-knowledge post-tests given immediately following completion of the lab and after a one week delay.

Materials

The topics of mitosis and meiosis served as the content presented to the four treatment groups because they are abstract and often difficult to visualize (Akpan, 2001; Dede, 1995; Zacharia, 2015) which can often lead to decreased student achievement; the recommendation of the course instructor, and their alignment with the scope and sequence of the course.

Prior to administration of the biology labs, the learning objectives for the PL and VL modes were compared to ensure equivalence. Additionally, the researcher met with the course instructor who reviewed the concepts covered in each lab and ensured alignment with course lecture and lab learning objectives, and served as a content expert to further validate equivalence. Content for each of the labs was further aligned through the implementation of Webb's depth of knowledge (DOK) to measure the cognitive levels presented by each laboratory learning objective (Webb, 1997; Webb, 2007). The overall learning objectives for the physical and virtual modes of laboratory delivery covered equivalent content; however, due to the differences between physical and virtual environments, some of the tasks students completed had slightly varied procedures. A summary of the content learning objectives present in the labs, sample tasks, and DOK levels are provided below see (Table 2).

Table 2

Learning objectives, Tasks, and DOK

Learning Objective	Lab Exercise		Sample Task		DOK Level
	Physical*	Virtual**	Physical*	Virtual**	
1. Discuss the functions of cell division.	6.1 The Cell Cycle	The Cell Cycle	" Identify why early scientists called interphase the 'resting stage' "	"Identify that interphase is the longest stage of the cell cycle"	3
2. Describe the cell cycle and how it is controlled.	6.1 The Cell Cycle	The Cell Cycle	"Identify how interphase prepares a cell for cell division"	"Identify interphase as the phase of the cell cycle in which growth occurs"	2
3. Distinguish and describe the three stages of interphase and the stages of mitosis.	6.1 The Cell Cycle	The Cell Cycle and Mitosis	"Describe the S phase of interphase" "Describe what is happening in the cell during mitosis"	"Place each image of the G1, S, or G2 phase of the cycle based on the descriptions" "Give the right stage of mitosis based on a description"	2
4.Draw/Identify and label the stages of interphase and mitosis.	6.1 The Cell Cycle	The Cell Cycle and Mitosis	"Draw and label interphase" "Sketch and identify each of the phases of mitosis"	"Assign the drawing of interphase to its correct label" "Given a microscopy illustration, identify which cell is at metaphase"	1
5. Compare and contrast mitosis and meiosis.	6.1 The Cell Cycle & 6.2 Meiosis	Mitosis and Meiosis	"Describe the stages of the cell cycle you observed" "Describe how many chromosomes does the nucleus of an *Ascaris* ovum has"	"Determine whether each phrase describes mitosis, meiosis, or both"	3
6. Explain the relevance of meiosis to sexual reproduction.	6.2 Meiosis	Mitosis and Meiosis	"Identify which types of cells would have a haploid number of chromosomes and a diploid number of chromosomes".	"Identify the correct haploid or diploid chromosome numbers to complete the passage about different types of cells"	3
7. Describe how chromosomes are reduced from diploid number (2n) to haploid number (n) in meiosis.	6.2 Meiosis	Meiosis	"Label, describe and sketch the stages of meiosis you observe"	" Label the illustration of the stages of meiosis with correct descriptions"	3
8. Describe the process of tetrad formation, synapsis, and crossing over	6.2 Meiosis	Meiosis	"Determine how many pairs of chromosomes a cell will have after meiosis I."	"Determine which cell shows the correct number of chromosomes pairs for meiosis I"	3

Note- *corresponds to PL exercises from *Exploring Biology in the Laboratory: Core Concepts* by Pendarvis and Crawley (2016).
** corresponds to VL *Mitosis and Meiosis Interactive* by Sapling Learning (2016).

Physical-based biology lab. The physical-based biology lab activity used in this study was selected from the course lab manual *Exploring Biology in the Laboratory: Core Concepts* by Pendarvis and Crawley (2016). The exercises employed in the PL laboratory delivery mode were taken from Chapter 6 of the lab manual: Splitting Up: Understanding Cell Division and Mitosis. Students in the PL delivery group completed exercise 6.1 The Cell Cycle and exercise 6.2 Meiosis in Animals. The materials used in the physical lab included: the lab manual, Compound Light Microscopes; prepared slides of a whitefish blastula, onion root tip, *Ascaris* ovaries, and animal testis; and colored pencils.

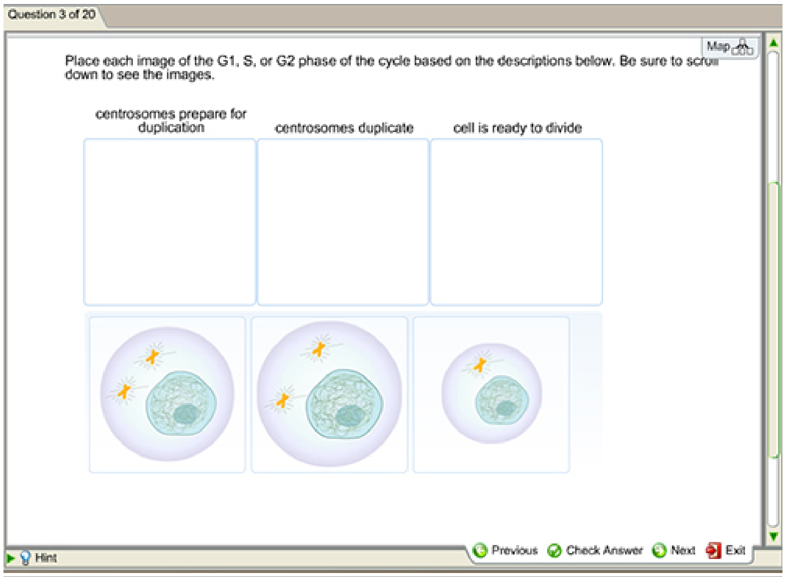
Virtual biology lab. The instructional delivery system and VL instrument used in this study were designed and published by Sapling Learning, an online educational resource company owned by Macmillan Learning. The instructional content provided within Sapling Learning's General Biology Course was selected for this study as it was specifically designed for non-majors, was not course text specific, and it was also unlikely that students had been exposed to the content before treatment.

Due to its open-ended format, The Sapling Learning *Mitosis and Meiosis Interactive* VL was aligned to mitosis and meiosis content learning objectives provided by Openstax Concepts of Biology in Chapter 6 Reproduction at the Cellular Level and Chapter 7 The Cellular Basis of Inheritance. The specific cell cycle, mitosis, and meiosis content within the VL were reviewed and compared to the cell cycle, mitosis, and meiosis content presented in the Openstax Concepts of Biology textbook.

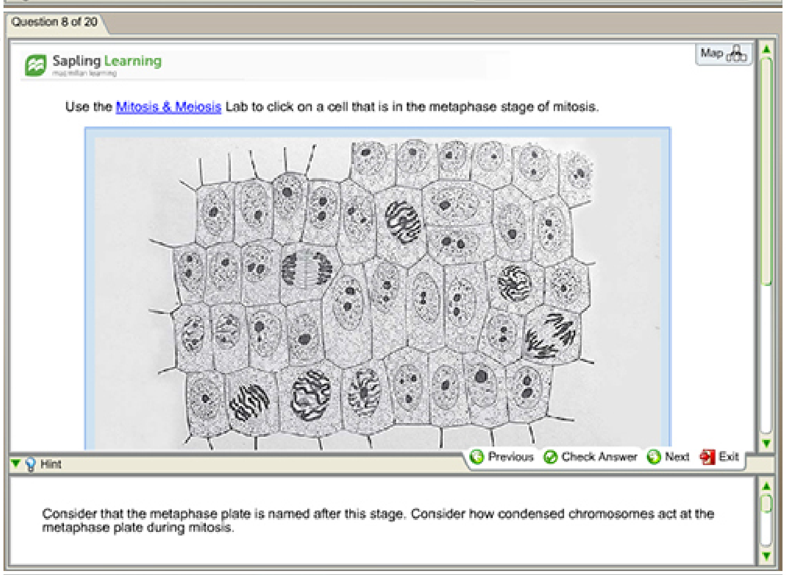
The Sapling Learning *Mitosis and Meiosis Interactive* VL is highly interactive, affording students the ability to manipulate objects within the interface, and receive guidance in the form of hints and feedback to increase their learning. Example student tasks taken from the Sapling system, and interactive features of the VL are shown in Figure 2. Following completion of the VL activities, the online environment used for all three online groups remained open for student review.

(continued)

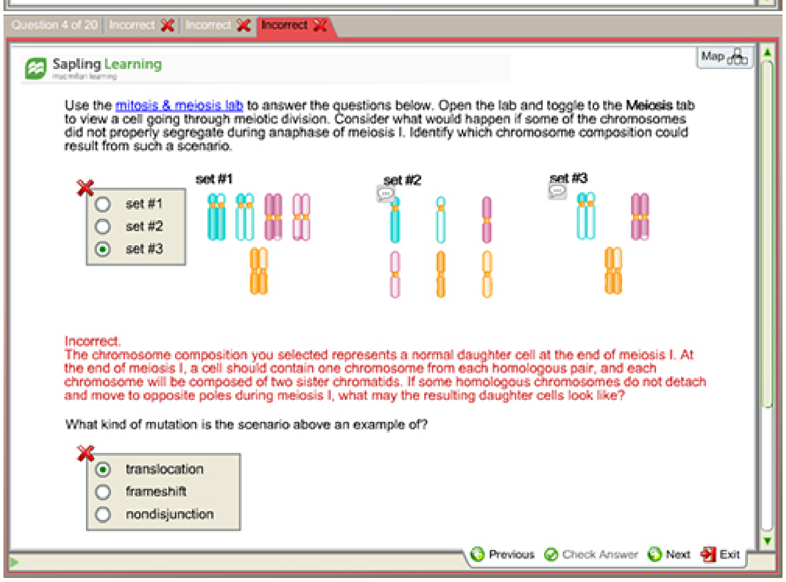
a.


Question 3 of 20
Map
Place each image of the G1, S, or G2 phase of the cycle based on the descriptions below. Be sure to scroll down to see the images.
centrosomes prepare for duplication
centrosomes duplicate
cell is ready to divide
Hint
Previous
Check Answer
Next
Exit

b.


Question 8 of 20
Map
Sapling Learning
Use the Mitosis & Meiosis Lab to click on a cell that is in the metaphase stage of mitosis.
Hint
Previous
Check Answer
Next
Exit
Consider that the metaphase plate is named after this stage. Consider how condensed chromosomes act at the metaphase plate during mitosis.

c.


Question 4 of 20
Incorrect
Incorrect
Incorrect
Map
Sapling Learning
Use the mitosis & meiosis lab to answer the questions below. Open the lab and toggle to the Meiosis tab to view a cell going through meiotic division. Consider what would happen if some of the chromosomes did not properly segregate during anaphase of meiosis I. Identify which chromosome composition could result from such a scenario.
set #1
set #2
set #3
Incorrect.
The chromosome composition you selected represents a normal daughter cell at the end of meiosis I. At the end of meiosis I, a cell should contain one chromosome from each homologous pair, and each chromosome will be composed of two sister chromatids. If some homologous chromosomes do not detach and move to opposite poles during meiosis I, what may the resulting daughter cells look like?
What kind of mutation is the scenario above an example of?
translocation
frameshift
nondisjunction
Previous
Check Answer
Next
Exit

(continued)

Figure 2. Screen shot of *Mitosis and Meiosis Interactive* question (a) the hint provided (b) and question feedback (c). Copyright 2017 Sapling Learning.

Instructor contact and affordances sheets. All four treatments were introduced to students in the science laboratory classroom or computer labs on campus. Paper-based job aids in the form of an instructor contact and affordance sheet were administered to all four laboratory delivery mode groups at the beginning of the lab sections. The sheets were designed to clearly communicate to students the affordances of their specific lab; provide contact information for the laboratory TA, course instructor, and researcher; and give additional information on how to access the laboratory exercise (Van der Meij & Van der Meij, 2014).

The instructor contact and affordance sheet for the PL group detailed the affordances of instructor presence through having an instructor physically available to answer questions, and hands-on learning through usage of laboratory equipment. It provided contact information for the researcher, course instructor, and TA. The instructor contact and affordance sheet for the VL group simply gave students information that they could access the VL anywhere they had internet access and provided contact information for the researcher, course instructor, and TA. The instructor contact and affordance sheet for the VLIP group gave a brief description of instructor presence, including students' ability to ask questions and receive guidance and provided contact information for the researcher, course instructor and TA. Finally, the instructor contact and affordance sheet for the VLIPLC group detailed the affordance of instructor presence by telling students that they could ask questions and receive guidance from the instructor; provided directed learner control through the suggestion that the students could log in following the standard laboratory section to use the VL as a review tool, and provided contact information for the researcher, course instructor and TA.

Instrumentation

A biology content pre-test, an immediate recall post-test, and a delayed one-week recall post-test measured learners' achievement on the topics of mitosis and meiosis. The pre-test, immediate post-test, and delayed one-week post-tests were constructed by selecting equivalent multiple-choice items from chapter test banks published in Openstax Biology and Concepts of Biology (Rice University, 2016). The Openstax test banks were selected due to their free open-ended format, their non-course specific text, and their alignment with learning objectives of both the PL and VL materials.

Prior to administration in this study, the content validity of the mitosis and meiosis content pre-test and post-tests was established by a university biology professor, who verified alignment with the biology course and laboratory instructional objectives. The content topic knowledge domains measured by the tests, test bank source, and representative number of assessment items are detailed in (Table 3) below.

The three tests were parallel in form and each consisted of 30 multiple-choice items covering the topic of meiosis and mitosis. The instruments were validated through a pilot administration involving 38 students in a college-level Anatomy and Physiology course, the reliability given by Cronbach's alpha for the three forms were (α =.71, .81, .84) respectively, indicating acceptable reliability (Nunnally, 1978). Analyses of the three tests revealed significant correlation between the forms, and acceptable discrimination indices. The item difficulty index for the 30 questions on each test ranged between 0.21 - 0.79, suggesting moderate difficulty level (Crocker & Algina, 1986).

Table 3

Test Item Content Topic Knowledge Domain and Items

Content Knowledge Domain	Source *,** Openstax	Items Number/ (%)
Mitosis and Cytokinesis	Bio Ch.10 & ConBio Ch.6	10/33.33
Meiosis	Bio Ch.11 & ConBio Ch.7	8/26.66
Introduction Genetic Material (Chromosomes)	Bio Ch.10 & ConBio Ch.6	4 /13.33
Chromosomes in Sexual Reproduction	Bio Ch.11 & ConBio Ch.7	3/10.00
Regulation of the Cell Cycle	Bio Ch.10	3/10.00
Introduction to Cell Division	ConBio Ch.6	1/ 3.33
Stages of the Cell Cycle	ConBio Ch.6	1/3.33

*Bio- denotes items selected from Openstax Biology Test Bank
**ConBio- denotes items selected from Openstax Concepts of Biology Test Bank
Note- Ch.6- Reproduction at the cellular level
Ch.7- The Cellular Basis of Inheritance
Ch. 10- Cell Reproduction
Ch.11- Meiosis and Sexual Reproduction

Data Collection Procedures

The biology content pre-test on the topic of mitosis and meiosis was given to students in all four treatment groups during standard course lecture hours. The biology content pre-test took approximately 30 minutes to complete, and was used to determine the extent that the groups' prior knowledge matched and served as a baseline method of measuring students' knowledge of the lab content before they began the PL and VL activities. The administration specific internal consistency measure of the pre-test was 0.62.

After completion of the pre-test, the researcher delivered the same mitosis and meiosis biology content lecture to all four lecture sections of the introductory biology course to ensure control, to provide students with the background knowledge that is traditionally given before they begin investigation in the laboratory environment, and to regulate exposure to content. Each lecture section lasted for a duration of 90 minutes.

Following delivery of the content lecture, students in all four sections of the course were assigned to read "Chapter 6: Cancer-DNA Synthesis, Mitosis, and Meiosis" in their course text, *Biology Science for Life* by Belk and Maier (2013). Additionally, all students were directed to read the regularly assigned pre-lab reading from the course lab manual *Exploring Biology in the Laboratory: Core Concepts* (Pendarvis & Crawley, 2016). Assigned pre-lab readings are a normal part of the biology course process. They help to ensure that students have a basic understanding of the content and concepts they will investigate in the laboratory (Reid & Shah, 2007).

Treatments

Prior to beginning the physical laboratory activity, students in the PL group received relevant guidance, where the TA ensured students had read the assigned pre-lab and course readings and communicated what students were expected to do for the lab; training, where the TA explained how to identify and distinguish that cells were in a phase of mitosis or meiosis; and demonstration, where the TA described proper procedures to follow, and gave the order and sequence for the laboratory exercise to assist in completing the physical based lab. Students in the PL delivery mode group were additionally given an instructor contact and affordances sheet, which the instructor read aloud from a treatment script. Students in the PL group completed the regularly assigned physical based biology lab with the instructor present, over a period of 50 minutes during standard course lab section hours as part of normal course process. As students worked on their lab, the course laboratory TA walked around the room to monitor use of lab equipment, answering questions and giving students guidance as needed. At the end of the laboratory section, students were encouraged to contact the course laboratory TA, instructor, and researcher via phone, e-mail, and the course BlackBoard learning management system, with any questions they had about the laboratory activity.

Virtual laboratory groups. Prior to beginning the tutorial and virtual biology lab activity, students in the three VL delivery groups were given an instructor contact and affordances sheet, which was read aloud by the instructor from a treatment script. Next, they completed an introductory tutorial provided by Sapling Learning that demonstrated how to answer questions, make use of feedback, hints, and tooltips, and navigate the virtual environment.

Students in the three VL delivery mode groups completed the assigned *Mitosis and Meiosis Interactive* virtual activity online in the Sapling Learning environment. Each of the three VL treatments were delivered over a period of 50 minutes inside a campus computer lab during standard course laboratory section hours. Prior to beginning the VL exercise, students in the three VL delivery mode groups were given verbal information about the affordances of instructor presence and learner control in their lab, read by the instructor from a treatment script.

Virtual laboratory with no instructor presence group. The instructor told students in the VL with no instructor presence group (VL) that they would work independently on the assigned exercise and questions, and would take a post-test immediately after they finished. Additionally, the instructor did not direct students to use the online VL content and environment as a study tool after they completed the laboratory activity, although they could choose to do so through self-direction. To simulate a completely virtual experience, no instructor presence was provided. The instructor left the computer lab and remained physically outside while students completed the laboratory exercise. A computer lab-aide with no knowledge of study content was physically present during the laboratory to troubleshoot any computer issues.

Virtual laboratory with instructor presence group. Students in the virtual laboratory with instructor presence group (VLIP) were told by the instructor that they would work independently on the assigned exercise and questions, and would take a post-test immediately after they finished. Instructor presence was provided by the instructor being physically present in the computer lab; students were encouraged to ask questions and received guidance as they completed the laboratory activity. The instructor did not recommend that students use the online virtual lab content and environment as a study tool after they completed the laboratory activity. At the end of the laboratory section, students were encouraged to contact the course laboratory TA, instructor, and researcher via phone, e-mail, and Blackboard, with any questions they had about the laboratory activity.

Virtual laboratory with instructor presence and directed learner control group. Students in the virtual laboratory with instructor presence and direction for learner control of pace and repetition beyond lab time group (VLIPLC) were told by the instructor that they would work independently on the assigned exercise and questions, and would take a post-test immediately after they finished. Instructor presence was modeled by the instructor being physically present in the computer lab, students were encouraged to ask questions and received guidance as they completed the laboratory activity. The instructor recommended that the students control their own learning by using the online virtual lab content and environment as a review or study tool after they complete the laboratory. At the end of the laboratory section, students were encouraged to contact the course laboratory TA, instructor, and researcher via phone, e-mail, and Blackboard, with any questions they had about the laboratory activity.

Immediately following completion of the physical and virtual labs, a second 30 item multiple-choice biology content test on the topics of mitosis and meiosis, that took approximately 30 minutes to complete, was administered to students in all four treatment groups during standard course lab section hours. The administration specific internal consistency measure of the immediate post-test was 0.76. One week after the immediate post-test, students in all four treatment groups took a final equivalent, 30 item multiple-choice delayed recall biology content post-test on the topics of mitosis and meiosis during standard course lab section hours. The delayed one-week post-test took approximately 30 minutes to complete. The administration specific internal consistency measure of the delayed one-week post-test was 0.81.

Data Analysis

An analysis of variance (ANOVA) revealed no statistically significant differences in the pre-test scores between the four modes of laboratory delivery, $F(3, 88) = 0.71$, $p = 0.54$, which indicated pre-experimental equivalence among treatment groups.

A 4 x 3 repeated measures ANOVA was used to determine the main effect of mode of delivery (H_1), the main effect of time (H_2), and the interaction effect of mode of delivery and time on a Mitosis and Meiosis content knowledge test (H_3) (Huck, 2000; Urdan, 2010). The mean difference effect sizes were computed to examine the practical significance of the findings by dividing the mean difference by the standard deviation of the mean difference and were characterized by .2 = small effect, .5 = medium effect, and > .8 = large effect (Cohen, 1988). The version 23 of the IBM Statistical Package for the Social Sciences (SPSS) was used for the purpose of data analysis.

Results

Descriptive statistics were used to summarize the results. The means and standard deviations for the outcome measures are presented in Table 4.

Table 4

Means and Standard Deviations for Mitosis and Meiosis Content Knowledge

	Pre-Test		Immediate Post-Test		Delayed One-Week Post-Test	
	M*	SD	M*	SD	M*	SD
PL (n=21)	10.90	3.38	16.48	5.34	18.10	4.17
VL (n=25)	9.76	4.24	18.92	3.88	17.96	4.84
VLIP (n=22)	9.73	2.85	17.45	4.16	16.36	5.79
VLIPLC (n=24)	11.04	5.18	17.83	5.16	18.00	6.52

* Theoretical Range: 1 – 30

Note: PL - Physical, in-person, lab completed normally as part of the BIOL 1308 course.
VL - Virtual lab without instructor presence.
VLIP - Virtual lab with instructor presence.
VLIPLC - Virtual lab with instructor presence and direction for learner control.

The equality of the covariance matrices assumption was met, *Box's M* = 25.57, $p = 0.16$. The sphericity assumption was met as the average of *Greenhouse-Geisser Epsilon* (0.87) and Huynh-Feldt Epsilon (0.92) was greater than 0.70 (Stevens, 2009). The homogeneity of variances assumption was met for pre-test, $F(3, 88) = 2.48$, $p = 0.06$, immediate post-test, $F(3,88) = 1.56$, $p = 0.20$, and delayed one-week post-test, $F(3, 88) = 1.05$, $p = 0.38$.

The time effect was statistically significant, $F(2,176) = 148.65$, $p < 0.01$. The mode of the delivery effect was not statistically significant, $F(3,88) = 0.38$, $p = 0.76$. The interaction effect of the mode of delivery and time was not statistically significant, $F(6,176) = 1.51$, $p = 0.18$. Results are summarized in Table 5.

Table 5

Mode of Delivery by Time ANOVA Summary Table

Source	SS	df	MS	F	p
Delivery Mode	52.80	3	17.60	0.38	0.76
S(Delivery Mode)**	4032.36	88	45.82		
Time	3234.89	2	1617.44	148.65*	< 0.01
Delivery Mode x Time	98.54	6	16.42	1.51	0.18
Time x S(Delivery Mode)***	1915.06	176	10.88		

*$p < 0.05$.

** First error term, participants nested in the mode of delivery

*** Second error term, time by participants nested in the mode of delivery interaction.

To better understand the time effect, mean difference effect sizes were computed to examine changes from the pre-test to immediate post-test, immediate post-test to delayed one-week post-test, and pretest to delayed one-week post-test in each of the delivery modes. To do so, mean difference was divided by the standard deviation of the mean difference and was characterized as 0.20 = small effect, 0.50 = medium effect, and > 0.80 = large effect (Cohen, 1988). As can be seen in Table 6, the largest difference was between pre-test to immediate post-test in the virtual laboratory (VL), followed by the virtual laboratory with the instructor present (VLIP), the virtual laboratory with instructor present and direction for learner control (VLIPLC), and the physical laboratory (PL) modes of the delivery. The pre-test to delayed one-week post-test increases were also substantial. The immediate post-test to delayed one-week post-test decreases were 0.25 (VL) and 0.34 (VLIP), the increases were 0.04 (VLIPLC) and 0.44 (PL). These results indicate that students in all delivery modes groups learned significantly between the pre-test and immediate post-test and between the pre-test to one-week delayed post-test.

Additionally, their scores between the immediate post-test and one-week delayed post-test remained consistent. In short, effects sizes suggested immediate effects but not delayed effects for the delivery modes.

Table 6

Mean Difference Effect Sizes

	Pre-Test to Immediate Post-Test	Immediate Post-Test to Delayed One-Week Post-Test*	Pre-Test to Delayed One-Week Post-Test
PL (n=21)	0.99	0.44	1.37
VL (n=25)	2.00	-0.25	1.71
VLIP (n=22)	1.95	-0.34	1.23
VLIPLC (n=24)	1.26	0.04	1.26

* The negative sign indicates the decrease from immediate posttest to delayed one-week post-test

Note: PL - Physical, in-person, lab completed normally as part of the BIOL 1308 course.
VL - Virtual lab without instructor presence.
VLIP - Virtual lab with instructor presence.
VLIPLC - Virtual lab with instructor presence and direction for learner control.

The sample sizes were small. A detailed power analysis was performed and showed that had there been 30 participants in each group, the interaction effect would have been statistically significant. Specifically, the following SPSS program was run and the power analysis results are depicted in Output 1.

```
matrix data var=group rowtype_ y1 to y3 /factor=group.
begin data
1 n 30 30 30
1 mean 9.73 17.45 16.36
2 n 30 30 30
2 mean 9.76 18.92 17.96
3 n 30 30 30
3 mean 10.90 16.48 18.10
4 n 30 30 30
4 mean 11.04 17.83 18.00
. stddev 4.26 4.32 4.30 5.62
. corr 1
. corr .34 1
. corr .42 .73 1
end data.
manova y1 to y3 by
group(1,4)/wsfactor=time(3)/print=cellinfo(means)signif(efsize)/matrix=in(*)/power/design.
```

Output 1

Power Analysis for Interaction Effect

Tests involving 'Time' Within-Subject Effect.

AVERAGED Tests of Significance for y using UNIQUE sums of squares

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN CELLS	2149.01	232	9.26		
TIME	4240.13	2	2120.06	228.88	<.01
Group BY TIME	129.73	6	21.62	2.33	.033

Discussion

This study revealed that students in all four modes of delivery did experience significant learning gains immediately after treatment and a week later. The finding that there were no significant differences in post-test scores across the four groups suggests that virtual labs can deliver biology content and produce learning outcomes equivalent to physical based labs. The mode of lab delivery had no significant impact on student achievement as measured by scores on mitosis and meiosis content knowledge post-tests administered immediately following lab completion and after a one-week delay.

Comparative effects of four modes of biology lab delivery (RQ1)

The affordance of instructor presence in the PL, VLIP, and VLIPLC groups did not produce measured learning outcomes that were significantly different from the VL group in which instructor presence was lacking. Students in the PL, VLIP, and VLIPLC delivery modes did make use of instructor presence by receiving procedural directions, guidance, and asking content related questions while actively participating in the lab. In the context of VL environments, the results of this study support the need for further research into the impacts that instructor presence and different levels of instructor guidance have on student achievement (Ahmed & Hasegawa, 2014; Chen et al., 2016; Pedersen & Irby, 2014; Smith, 2015; Zacharia et al., 2015).

This study additionally measured instructor presence through students' communication with the instructor while using VL environments. Based on the results, there is a need for further research into how student learning is influenced by instructor-student communication (Flowers, 2011; Picciano, 2002; Stuckey-Mickell & Stuckey-Danner, 2007; Zacharia et al., 2015). Students did not follow the specific recommendation implemented as a part of the study design to contact the course instructor, course laboratory TA, or the researcher with lab content related questions in the one week that elapsed between the lab and the delayed recall post-test. To more thoroughly investigate this phenomenon, a meeting was held with the course instructor, who explained that historically, students in the course have never contacted her or the TA with questions outside of the actual lab sessions.

Additionally, the specific direction for learner control provided to the VLIPLC group did not produce measured learning outcomes that were significantly different from the PL, VL, and VLIP groups in which directed learner control was lacking. The students in the three virtual lab sections VL, VLIP, and VLIPLC were provided the affordance of learner control through the virtual lab interface. While completing the lab, they directed their interaction within the virtual lab interface, controlled the pace at which they viewed content, took advantage of opportunity for repetition; accessed guidance provided through hints, feedback, and informational action icons within the lab as needed, and actively guided their own learning. The finding that students employed learner control features to enhance their interaction with the virtual lab is in-line with other studies (Hasler et al., 2007; Zacharia et al., 2015). However, the equivalent performance between the VL, VLIP, and VLIPLC groups necessitates further study to determine how the pacing (Zacharia, 2007; Zacharia et al., 2008); repetition (Zacharia, 2007; Zacharia et al., 2015); time spent learning (Darrah et. al, 2014; Pedersen & Irby, 2014); and access to available guidance (Yaman, Nerdel, & Bayrhuber, 2008; Zacharia et al., 2015) offered by VL environments affects student learning and academic achievement.

In the design of this study, the VLIPLC group was given specific direction for learner control by the instructor recommending that the students log back in to repeat the online virtual lab and use it as a study tool for the course for the one week following lab completion. Through monitoring student login activity in the Sapling Learning General Biology instructor dashboard, it was found that none of the students in the virtual lab groups logged back into the virtual lab after they had completed it in the scheduled lab sections. This trend was also true for students in the lab group who were given specific direction for learner control.

Although the study design incorporated the instructor's recommendation for specific lab delivery groups to take advantage of the affordances of instructor presence and learner control, none of the students took advantage of these affordances. Additionally, students in all delivery groups scored relatively low on the pre-test, immediate post-test, and one-week delayed post tests; the highest score on the tests was an 87 %. However, the results indicate that students did learn between the pre-test and immediate post-test, and between the pre-test and one-week delayed post-test. Had students used the affordances of instructor presence and learner control, they may have seen greater learning and achievement between the immediate post-test and one-week delayed post-test. The consistency of scores between the immediate post-test and one-week delayed post-test indicates that students retained knowledge. Despite the differences in modes of lab delivery and the available affordances, there ultimately was no measurable significant difference between the groups. This finding provides further support to previous research (Darrah et al., 2014; Tatli & Ayas, 2013; Triona & Klahr, 2003; Zacharia & Olympiou, 2011) indicating that virtual labs can produce measurable learning outcomes equivalent to physical labs, even without additional instructor guidance or students' taking advantage of repeating and reviewing a lab after initial completion.

Conclusions

Summary of findings

Although students in each mode of delivery learned significantly, both immediately following treatment and a week later, the mode of lab delivery had no significant impact on student achievement. There were no significant differences in post-test scores across the four groups, suggesting that virtual labs can deliver biology content and produce learning outcomes equivalent to physical based labs. Had students used the affordances of instructor presence and learner control, they may have seen greater learning and achievement between the immediate post-test and one-week delayed post-test. The findings of this study bring up further implications for research and practice.

Significance of the Study

Findings from this study inform science educators about the instructor presence which is afforded in physical labs and learner control which is afforded in virtual labs. This study seeks to contribute to the academic body of knowledge about virtual biology labs, and to provide further information about their use in college courses. A second goal of this study is to inform the practice of using virtual labs as a viable science learning resource, especially in college and online course environments. The potential positive implications of this study include broadening the laboratory component of science education options for college students. Virtual biology labs have the potential to help online learners, non-science majors students, students with disabilities, and other students who may not have the scientific background, time, or resources to complete a physically based lab.

Limitations and Delimitations

This study was limited by small sample sizes due to the fact there was only one non-majors biology course offered at the university during the fall 2016 semester. While overall participation was high, with (n=92) out of (N=98) students completing the study, participants were dropped due to absence during the lecture or laboratory treatments. Time was an additional constraint of the study; the lecture and physical and virtual laboratories delivered were a part of course instruction and had to follow the scope and sequencing identified within the course syllabus. As a result, student delayed learning outcomes were measured after only a one week delay. Future studies with less rigid scheduling structure and greater allotment of time would be able to measure the delayed effects of mode of laboratory delivery over a greater period of time.

An additional limitation of the study was the short duration of each of the four biology delivery mode treatments; each treatment lasted for only 50 minutes. To provide a more thorough measurement of the effects of the four different modes of biology on student achievement, future studies might be designed to test the cumulative difference of modes over an entire course.

Implications for Further Research

The results of this study are in-line with many other studies which indicate that physical and virtual laboratory delivery modes produce similar or equivalent learning outcomes (Darrah et al., 2014; Tatli & Ayas, 2013; Triona & Klahr, 2003; Zacharia & Olympiou, 2011). This study served to further inform how physical and virtual laboratory delivery modes compare in the subject of biology. Further studies are needed in the subject of biology, especially at the college level (Flowers, 2011; Ma & Nickerson, 2006).

Additionally, further studies are needed to specifically determine how the affordance of instructor presence (Dixson, 2010; Richardson et al., 2015; Stuckey-Mickell & Stuckey-Danner, 2007; Watson, Watson, Richardson, & Loizzo, 2016) impacts student achievement. Insight is needed into specific types of instructor presence, including the levels of guidance provided by VLs to promote successful student learning in STEM subjects (Ahmed & Hasegawa, 2014; Chen et al., 2016; Pedersen & Irby, 2014; Smith, 2015; Zacharia et al., 2015). There is also a need to determine how instructor presence affects student learning in online and VL environments; specifically, how varying degrees of communication provided by instructors can facilitate increased learning of content knowledge (Flowers, 2011; Picciano, 2002; Stuckey-Mickell & Stuckey-Danner, 2007; Zacharia et al., 2015). The affordance of learner control's influence on student achievement in PL and VL also requires further research (Brown, Howardson, & Fisher, 2016; Chamberlain et al., 2014; Chang et al., 2008; Zacharia et al., 2008). In the context of learner control, more research is needed into the effect that the affordance of repetition offered by VL environments has on student learning (Zacharia, 2007; Zacharia et al., 2015). Further research is needed to determine how the effect of students' time spent in PL and VL environments impacts achievement (Darrah et. al, 2014; Pedersen & Irby, 2014). Additionally, to provide proper levels of guidance in PL and VL and to ensure students make use of provided guidance, further research is needed into the specific presentation and types of guidance which promote learning and academic achievement (Yaman et al., 2008; Zacharia et al., 2015). Continued studies on repetition, pacing, time spent, and how students access available guidance in PLs and VLs serves to inform educators, instructional designers, curriculum publishers, and institutions of higher learning in how they can more effectively design and implement virtual laboratories to maximize efficient use of learner control. Finally, studies that encourage students' use of the affordances of instructor presence and learner control in PLs and VLs should be conducted.

As found in previous research, a constraint of many studies exploring virtual laboratory environments is that they are confined by small sample sizes. Studies on delivery involving larger sample sizes would be of benefit to the field of research (Ma & Nickerson, 2006). Finally, this study revealed that students did not take advantage of the provided affordances of instructor presence and learner control outside of laboratory sections. Further study is needed to explore how educators, curriculum publishers, and research institutions can encourage students to use affordances provided by physical and virtual laboratories to assist in their learning (Dede, 2009; De Jong et al., 2013).

A longer duration of treatment is warranted to gain better insight into the impact that the four different modes of biology lab delivery and the affordances of instructor presence and learner control have on student achievement. As previously mentioned the duration of each of the four laboratory treatments was only 50 minutes, due to time constraints and the necessity to keep with the established schedule on the course syllabus. Future studies might be designed to test the cumulative difference of the laboratory delivery modes over an entire semester of a course.

Additionally, this study focused specifically on a sample of non-major biology students. Previous studies on virtual laboratory delivery modes have been similarly confined to using non-major or introductory classes in order to gain large sample sizes (Brinson, 2015; Ma & Nickerson, 2006) or because of resistance from college faculty and staff to alter the traditional laboratory format of majors science courses (Crippen et al., 2013; Hallyburton & Lunsford, 2013; Zacharia, 2007). Future studies exploring how the modes of lab delivery and their affordances impact student achievement in majors biology courses are of particular interest (Hallyburton & Lunsford, 2013), specifically those which simultaneously measure and compare the effects of laboratory delivery modes in both majors and non-majors biology courses.

This study did not assign grades for students' use of the affordances of instructor presence and learner control presented by the laboratory delivery modes, additionally; use of the affordances outside of the scheduled laboratory sections was non-existent. Further study is needed to investigate how students use the affordances of instructor presence and learner control offered by the laboratory delivery modes and their impact on achievement. To accomplish this goal, it is recommended that future studies integrate instructor presence and learner control as part of an actual graded assignment. The incorporation of study designs where students must actively communicate with the instructor about laboratory content either in-person or online; or log back in to repeat and review a virtual lab may increase students' use of these affordances and provide better measurable outcomes.

Implications for Practice

An interesting question pertaining to educational practice is raised by this study: "How can instructors further encourage students to take advantage of the affordances of instructor presence and learner control?" While this question has been examined in depth in physical learning environments, further studies investigating online virtual lab environments are required (Campen, 2013; Flowers, 2011; Reese, 2013; Stuckey-Mickell & Stuckey-Danner, 2007) to establish their effectiveness as a learning tool and to inform potential adopters, instructional designers, and curriculum or academic researchers. The provision of instructor presence (Dixson, 2010) and learner control (Lee, Wong, & Fung, 2010; Brown et al., 2016) has been shown to promote achievement when used; however, there is a need for further practice to actively ensure that students are taking advantage of the benefits.

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CHAPTER IV: A Qualitative Exploration of Students' Experiences of Instructor Presence and Learner Control in Physical and Virtual Labs

Abstract

We investigated students' experiences of using the affordances of instructor presence and learner control in virtual lab and physical lab environments. Using one interview and three focus groups, we explored students' experiences in four treatment groups in an undergraduate biology course for non-majors: a physical lab with instructor presence, a virtual lab with no instructor presence, a virtual lab with instructor presence, and a virtual lab with instructor presence and direction for learning control of pace and repetition beyond lab time. Students in all delivery modes expressed that they felt laboratory activities were beneficial to their learning. Students in the physical lab group viewed instructor presence positively, but attributed negative experience to lack of learner control. Students in the virtual lab groups appreciated their abilities to control their learning during lab time but did not take advantage of instructor presence or ability to repeat the lab outside of class time. The benefits of instructor presence and learner control presented by each mode of lab delivery are discussed, and recommendations for further study are provided in the conclusion. The findings serve to inform institutions of higher learning, curriculum publishers, and those interested in implementing virtual laboratories.

Keywords: distance education and telelearning, interactive learning environments, simulations; teaching/learning strategies; virtual reality

Introduction

Physical labs (PLs) provide students with the experience of having an instructor or teaching assistant (TA) physically present to provide guidance; but in virtual labs (VLs) learners experience greater control of repetition, pacing, time spent learning, and access to available guidance than physical labs. Students' experiences of learning in these different environments may influence the impact that the labs have on learning outcomes, and their usefulness as learning tools. Research exploring students' experiences in physical and virtual laboratory delivery modes can lend insight into their effective design and applications.

Theoretical Framework

Students control their learning by taking direct responsibility of their learning and pursuing further guidance by asking questions or accessing additional information (Merrill, 1980).

The affordances of instructor presence and learner control within physical and virtual laboratory delivery modes and how these affordances facilitate student learning serves as a theoretical framework for this study (see Figure 1). Instructor presence allows learners to show their work, ask questions, and receive guidance from instructors during a course or during a lab regardless of mode of delivery (De Jong, Linn, & Zacharia, 2013; Picciano, 2002). In PLs, students can communicate with the instructor spontaneously and receive direct feedback as a means to help build their content knowledge and understanding of laboratory processes. In VLs, if instructors encourage communication at a distance, students can choose to take advantage of the specific instructor recommendation for communication about laboratory content and use of integrated guidance in the form of feedback, hints, and tooltips. Alternately, in VLs where communication is not actively encouraged, students must direct themselves to contact the instructor with questions and use instructor guidance within the lab. Instructor presence in VLs is defined here as the provision of instructor-student communication about the VL experience during or following students’ initial entry in the environment.

The extent that learners control the pace, repetition, timing, access to instructor guidance, and sequence of content varies across modes of delivery. Instructors can direct students to control their learning by recommending that students repeat, review, and practice the lab content. While learners receive guidance to review learning materials, the decision to use learning environments for guidance rests solely on the learner (Hannafin, 1984; Merrill, 1980; Simsek, 2012; Williams, 1996). Such learner control of communication with the instructor promotes constructivist learning (Dickey, 2005; Tobin, McRobbie, & Anderson, 1997).

	Learner Control	**Instructor Presence**
PL	Repetition • Bhargava et al., 2006	Instructor-Student Communication • De Jong et al., 2013 • Stang & Roll, 2014
	Pacing • Smetana & Bell, 2012	Instructor Guidance • Maldarelli et al., 2009 • NRC, 2006 • Hofstein et al., 2005
	Time Spent • Josephsen & Kristensen, 2006	
	Access To Available Guidance • NRC, 1997 • Zacharia et al., 2015	
VL	Repetition • Bhargava et al., 2006	Instructor-Student Communication • Picciano, 2002 • Humphries, 2007 • Richardson et al., 2015
	Pacing • Hasler, Kersten, & Sweller, 2007	Instructor Guidance • Johnson, 2002 • NRC, 1997
	Time Spent • Darrah et al., 2014 • Parker & Loudon, 2012	
	Access To Available Guidance • Honey & Hilton, 2011 • Lancaster, 2013 • Zacharia et al., 2015	

Figure 1. Theoretical Framework: Instructor presence and learner control.

Literature Review

Comparative Effects of Physical and Virtual Labs

Informed by the affordances of VL, numerous studies compare effects of PL and VLs; however, the results of these studies remain mixed. Some studies have shown that VLs can produce greater student learning and academic achievement compared to PLs (Finkelstein et al., 2005; Gilman, 2006; Zacharia, 2007; Zacharia, Olympiou, & Papaevripidou, 2008). In certain cases, PLs have produced greater student learning and academic achievement compared to VLs (Corter, Esche, Chassapis, Ma, & Nickerson, 2011; Dalgarno, Bishop, Adlong, & Bedgood, 2009). Additionally, some researchers have found that student learning and academic achievement is equivalent between PLs and VLs (Darrah, Humbert, Finstein, Simon, & Hopkins, 2014; Tatli & Ayas, 2013; Zacharia & Olympiou, 2011).

Previous research into virtual labs, instructor presence, and learner control serves as the foundation for this study. The specific features that comprise instructor presence in PL and VL environments include instructor-student communication and instructor guidance. Learner control consists of features in PL and VL environments which allow for repetition, pacing, time spent, and students' access to available guidance as they need it.

Students' Experiences of Instructor Presence and Learner Control

The attitudes and experiences students have while using the features of physical and virtual laboratory environments can be critical to their learning. Therefore, we explored how students describe their experiences using the affordances of instructor presence and learner control and the features that comprise these affordances within physical and virtual laboratory environments. Gilman (2006) found approximately half of the student participants who completed an online cell division lab expressed a strong preference for in-class lab work. Other researchers found that it is possible for students to feel connected to a laboratory activity, even when it is done virtually (Annetta, Klesath, & Meyer, 2009); suggesting that STEM labs can be engaging, even when taught at a distance.

Instructor presence. Students often show a preference for PLs as they believe that they afford greater levels of instructor-student communication (Bhargava, Antonakakis, Cunningham, & Zehnder, 2006; Gilman, 2006) and instructor guidance (Stuckey-Mickell & Stuckey-Danner, 2007) than VLs. Students are positive of their experiences to directly communicate with instructors and receive rapid feedback about laboratory instructional content, procedures, and questions (Bhargava et al., 2006).

The experiences of instructor presence that students have while learning in VLs can be positive. In online learning environments, such as VLs, communication between instructors and students is critical to students' success (Crippen, Archambault, & Kern, 2013; De Jong et al., 2013; Dunlap, Verma, & Johnson, 2016; Jaggars, Edgecombe, & Stacey, 2013; Picciano, 2002). Lim, Kim, Chen, and Ryder (2008) found that undergraduate college students who completed an online wellness course were positive about their interactions with an instructor in the online environment. Additionally, the provision of instructional guidance facilitates student learning in virtual science education environments (Merrill, 1999; Podolefsky, Moore, & Perkins, 2013). Maldarelli et al. (2009) found that 70% of students who received virtual guidance in the form of lab demonstration video tutorials showing correct operation of biology lab equipment expressed positive views that the videos were beneficial to their learning.

However, other studies have found that students' experiences of instructor presence in VLs are negative. The lack of a physically available instructor in online VL environments was shown to negatively impact students' experiences of instructor presence. Stuckey-Mickell and Stuckey-Danner (2007) conducted an exploratory inquiry study involving 38 student participants enrolled in two sections of an online introductory human biology course with in-person labs. The study substituted 10 physical physiology labs with virtual physiology labs and administered a survey to measure students' experiences in both laboratory environments. Results indicated that the students in the VLs missed the ability to ask questions and receive guidance and feedback from the instructor. Gilman (2006) found that students expressed negative attitudes toward the lack of instructor-student communication while using a virtual lab to learn about cell division. Alternatively, studies by Chang, Chen, Lin, and Sung (2008) and Chamberlain, Lancaster, Parson, and Perkins (2014) found that too much instructor presence and guidance in VL can be just as detrimental to student learning.

Communication between instructors and students is a critical component of learning in PL environments. Robinson (2012) and Stang and Roll (2014) called for further study to explore students' experiences of instructor-student communication in PLs. VL environments with the correct amounts of instructor presence are linked to increased student learning and academic achievement (Adams, Paulson, & Wieman, 2009; Chamberlain et al., 2014). In *Science Teaching Reconsidered*, the NRC [National Research Council] (1997) specifically recommends that instructor communication and presence is needed to promote student learning in VL environments, and that the provision of such guidance can help students' to avoid frustration when learning with technology. Humphries (2007) and Richardson et al. (2015) highlight the importance of instructor-student communication in online learning environments such as VLs, and recommend that further studies are needed to measure students' experiences of communication with instructors. The findings of such studies help to provide educators, curriculum researchers, and instructional designers insight into how students feel about instructor-student communication and guidance within laboratory delivery modes and inform strategies which enhance their learning.

Learner control. In some circumstances, students' experiences of learner control in PLs are positive (Chen, Chang, Lai, & Tsai, 2014). The time students take to complete laboratory activities is influenced by their understanding of procedures and instructions that accompany the lab. Often, PLs require students to operate specialized equipment and gather data as part of laboratory activities, which may result in experimental and measurement errors (Heradio et al., 2016; Olympiou & Zacharia, 2012). Students often view these errors as valuable learning opportunities, as they gain insight into the nature of science and experimentation (Toth, Morrow, & Ludvico, 2009).

Alternately, research shows that some students' experiences of learner control in PLs are negative (Chen et al., 2014). PLs often lack learner control of repetition as they are constrained by specific instructions and are limited by time and scheduling constraints (Brinson, 2015). PLs are often limited in resources such as chemicals, equipment, staff, time, and space (Bell, 1999; Bhargava et al., 2006) the limited opportunity for repetition can negatively impact students' experiences' of controlling their learning in PLs. Additionally, Bhargava et al. (2006) and Smetana and Bell (2012) found that students can be constrained by their lack of control of pacing in PLs. The lack of control of time spent learning in PLs can also result in negative student experiences, (Corter et al., 2007) found that some college undergraduate engineering students believed that PLs are a waste of time and do not benefit their learning. Students' time spent learning in PLs often requires following procedures , operating laboratory equipment, and correctly using materials, errors in the laboratory process further constrain students' available time to learn (Josephsen & Kristensen, 2006). In PLs, students control their learning by accessing available guidance as they need it (Zacharia et al., 2015), this may involve asking the instructor or TA questions about the laboratory content, procedures, or how to use laboratory equipment during lab time (Hofstein, Navon, Kipnis, & Mamlok-Naaman, 2005; NRC, 2006).

While students experience direct feedback from course instructors, often they may be hesitant to direct the questioning process; as a result, the initiation of inquiry must often come from the instructor (NRC, 1996). If instructors do not initiate communication and provide guidance during labs, negative student learning experiences may occur, as they may not feel they are getting the help they need (NRC, 1997).

Students' experiences of the learner control offered in VLs can be positive (Lee, Wong, & Fung, 2010). Studies demonstrate that these positive experiences of learner control often lead students to actually prefer VLs over PLs (Flowers, 2011), due to the increased control they have over their learning including opportunities for repetition (Bhargava et al., 2006); pacing of content (Bhargava et al., 2006; Thompson, Nelson, Marbach-Ad, Keller, & Fagan, 2010); time spent learning (Darrah et al., 2014; Parker & Loudon, 2012); and access to available guidance as they need it (Malik, Martinez, Romero, Schubel, Janowicz, 2014; Parker & Loudon, 2012). The affordance of repetition has been shown to promote students' understanding, subject knowledge, and learning in VL environments (Campen, 2013; Flowers, 2011; Land & Zimmerman, 2015; Smetana & Bell, 2012; Toth et al., 2009; Zacharia et al., 2015). Studies by Boggs (2006) and Lee et al. (2010) found that students appreciate the opportunities for repetition afforded by VLs and felt it was beneficial to their learning. Students' ability to assume greater direction of their learning by controlling the pacing of instructional content and laboratory activities was a major identified factor toward preference for VLs (Bhargava et al., 2006; Thompson et al., 2010). In many studies, students expressed positive attitudes toward the speed at which VLs allow them to perform lab activities (Thompson et al., 2010; Toth et al., 2009). VLs may benefit students in that time spent within the VL environment allows them to focus more on learning content, removing the concerns of equipment set up that often accompany PLs, providing a more efficient use of class instructional time (Darrah et al., 2014; Parker & Loudon, 2012). A review of relevant studies showed that the majority of student experiences of controlling time spent learning while using VL were positive. One of the most common positive experiences described by students was that VLs are easy to use (Pyatt & Sims, 2007; Pyatt & Sims, 2012; Toth et al., 2009). Students also expressed that VLs were beneficial in the fact they removed a lot of the error that normally occurs in PL environments, which allows more efficient use of time for learning information (Toth et al., 2009). In VLs, students experience learner control through their accessing available guidance as needed (Zacharia et al., 2015). Students learning experiences are also influenced by the guidance afforded by VLs. The provision of online communication with an instructor, and online scaffolds such as hints (Honey & Hilton, 2011; Zacharia et al., 2015), tooltips (Lancaster, 2013), and directions (Zacharia et al., 2015) may increase students' positive attitudes in using VLs as they facilitate control over learning. Studies by Malik et al. (2014) and Parker and Loudon (2012) found that undergraduate college students were positive about their experiences of completing organic chemistry homework through an interactive interface due to the feedback provided in the online environment.

Students' experiences of learner control in VLs can also be negative, leading students to prefer PLs over VLs. In some cases, students expressed that their time spent learning in VLs did not teach them the necessary skills of using laboratory materials and operating laboratory equipment (Flowers, 2011). Additionally, Chen et al. (2014) found that some students preferred the PLs to VLs due to the fact that in PLs they could physically interact with lab equipment and materials. The provision of guidance in online learning environments such as VLs is critical to student success (Jonassen, 2000; Jonassen, 2001); however, students must actively choose to use these affordances. In some cases, students in VL environments are unaware of, or completely overlook the guidance available online. Stuckey-Mickell and Stuckey-Danner (2007) found that students who completed online physiology labs expressed that the VL lacked the feedback provided in PL; they specifically mention that the VL had embedded text feedback. When students perceive that proper directions, guidance, and procedures are lacking in VLs, they may engage in off-task behavior; using time inefficiently (Pedersen & Irby, 2014).

In VL environments, students can actively control their learning pace, repetition of selected lab experiences, and interaction with simulated lab equipment, experiments, and the instructor, thereby constructing their knowledge and observing modeled scientific phenomena (Dede, 1995; Dede, 2009; Pyatt & Sims, 2012; Schwab, 2012). Further study is needed on students' experiences of learner control in PLs (NRC, 2006; Puttick, Drayton, & Cohen, 2015) and VLs (Lee et al., 2010) to inform the design and development of affordances which promote positive student learning outcomes. There is still a need to assess students' experiences using the affordance of repetition in VLs. Previous research studies have also shown that the VL affordance of control of pacing, progression, speed, and delivery of instructional content provides a distinct learning advantage over PLs (Bhargava et al., 2006; Smetana & Bell, 2012), however, further study is needed to determine how the pacing offered in VLs impacts students' learning experiences. Zacharia et al. (2015) called for further study of how guidance can be effectively delivered in VLs, it is particularly important to understand students' experiences of accessing guidance as they need it in these environments.

The findings of such studies help to inform educators, curriculum researchers, and instructional designers in how to best design and implement laboratory delivery modes which afford students control of their learning. In order to encourage use of the affordances present in PL and VL, it is also important to understand students' experiences of controlling their learning in these environments. As educators implement virtual environments, mechanisms for encouraging learner control need to be considered and adopted (Hasler, Kersten, & Sweller, 2007; Zacharia et al., 2015).

Purpose of the Study

The purpose of this study was to qualitatively explore how non-majors college biology students describe their experiences of instructor presence and learner control of pace and repetition in each of four lab treatments.

Research Question

This study was guided by the following qualitative research question:

1. How do non-major college biology students describe their experiences of instructor presence and learner control of pace and repetition in each of the four treatments? The four modes compared include the following:

a. a physical based lab with instructor presence (PL),

b. a virtual lab with no instructor presence (VL),

c. a virtual lab with instructor presence (VLIP) , and

d. a virtual lab with instructor presence and direction for learner control of pace and repetition beyond lab time (VLIPLC).

Materials and Methods

This study served as the qualitative component of an overall quasi-experimental mixed method study which measured the impact of four laboratory delivery modes on students' achievement in a biology course for non-majors at a Hispanic Serving Institute (HSI) university in south Texas; during the Fall 2016 semester.

Participants

The population of interest in this study is non-majors college biology students in a university in the southern United States. Convenience sampling (Orcher, 2014) was used to select focus group participants from four intact sections of a non-majors introductory biology course. Following IRB approval, all 98 students enrolled in four sections of the non-majors introductory biology course consented to participate in the pre-test, PL or VL activities, and post-tests. Due to absences and external factors, data was ultimately collected from 15 participants.

One interview and three focus groups were conducted for each of the four sections assigned to four distinct modes of delivery: PL (n = 5), VL (n = 4), VLIP (n = 1), and VLIPLC (n = 5). The majority of the participants were 18-24 years old (93.33%), were female (73.33%), and were sophomores (66.67%). With respect to ethnicity, (46.67%) were white, (40.00%) Hispanic, (6.67%) African American, and (6.67%) other ethnicity. Potential focus group participants were identified when the researcher passed out the consent forms, and explained the focus groups would be audio recorded, students were made aware that in order to participate; they would need to consent to being audio recorded. The following week, a printed scheduling chart was distributed to the students who gave consent, and used to identify the date and times for each focus group. Immediately following the final post-test, students signed a focus group confirmation sheet, agreeing to the established date and time for their class section. The demographic characteristics of the participants for each of the four modes of biology lab delivery focus groups age, gender, ethnicity, college level, and major, are presented in Table 1.

Table 1

A Profile of Participants

Demographic Variables	Biology Delivery Mode Focus Group PL (n=5)	VL (n=4)	VLIP (n=1)	VLIPLC (n=5)
Age	f / %	f / %	f/ %	f / %
18-24 years	5/100.00	4/100.00	1/100.00	4/80.00
25-34 years	0/0.00	0/0.00	0/0.00	1/20.00
35-44 years	0/0.00	0/0.00	0/0.00	0/0.00
45-54 years	0/0.00	0/0.00	0/0.00	0/0.00
55-64 years	0/0.00	0/0.00	0/0.00	0/0.00
Gender				
Male	0/0.00	1/25.00	1/100.00	2/40.00
Female	5/100.00	3/75.00	0/0.00	3/60.00
Ethnicity				
White	1/20.00	2/50.00	0/0.00	4/80.00
Hispanic	3/60.00	1/25.00	1/100.00	1/20.00
African-American	1/20.00	0/0.00	0/0.00	0/0.00
Other	0/0.00	1/25.00	0/0.00	0/0.00
College Level				
Freshman	0/0.00	1/25.00	1/100.00	0/0.00
Sophomore	4/80.00	3/75.00	0/0.00	3/60.00
Junior	1/20.00	0/0.00	0/0.00	2/40.00
Senior	0/0.00	0/0.00	0/0.00	0/0.00
Major				
Business	1/20.00	3/75.00	0/0.00	1/20.00
Computer Science	0/0.00	0/0.00	0/0.00	1/20.00
Education	2/40.00	0/0.00	0/0.00	0/0.00
Engineering	0/0.00	0/0.00	0/0.00	0/0.00
Liberal Arts	1/20.00	1/25.00	1/100.00	2/40.00
Life Science	0/0.00	0/0.00	0/0.00	0/0.00
Nursing	0/0.00	0/0.00	0/0.00	0/0.00
Physical Science	0/0.00	0/0.00	0/0.00	1/20.00
Other / Undecided	1/20.00	0/0.00	0/0.00	0/0.00

Note: PL - Physical, in-person, lab completed normally as part of the BIOL 1308 course.
VL - Virtual lab without instructor presence.
VLIP - Virtual lab with instructor presence.
VLIPLC - Virtual lab with instructor presence and direction for learner control.

Study Design

Each of the four intact sections of the non-major introductory biology course were randomly assigned to one of the experimental laboratory delivery modes (Orcher, 2014). The qualitative study employed three focus groups and one interview to explore students' experiences of using the affordances of instructor presence and learner control in each of the four distinct modes of biology lab delivery. The results of the study serve to further explain the quantitative results of a previous study (Creswell, 2014; Creswell & Plano Clark, 2006; Creswell, Plano Clark, Gutmann, & Hanson, 2003; Ivankova, Creswell, & Stick, 2006).

Materials

The topics of mitosis and meiosis served as the content presented to the four treatment groups because they are abstract and often difficult to visualize (Akpan, 2001; Dede, 1995; Zacharia, 2015) which can often lead to decreased student achievement, thus emphasizing the need for lab experience and encouraging variability of lab experience; the recommendation of the course instructor, and their alignment with the scope and sequence of the course.

Prior to administration of the biology labs, the learning objectives for the PL and VL modes were compared to ensure equivalence. Additionally, the researcher met with the course instructor who reviewed the concepts covered in each lab and ensured alignment with course lecture and lab learning objectives, and served as a content expert to further validate equivalence. Content for each of the labs was further aligned through the implementation of Webb's depth of knowledge (DOK) to measure the cognitive levels presented by each laboratory learning objective (Webb, 1997; Webb, 2007). The overall learning objectives for the physical and virtual modes of laboratory delivery covered equivalent content; however, due to the differences between physical and virtual environments, some of the tasks students completed had slightly different procedures. A summary of the content learning objectives present in the labs, sample tasks, and DOK levels are provided below see (Table 2).

Table 2

Learning objectives, Tasks, and DOK

Learning Objective	Lab Exercise		Sample Task		DOK Level
	Physical*	Virtual**	Physical*	Virtual**	
1. Discuss the functions of cell division.	6.1 The Cell Cycle	The Cell Cycle	" Identify why early scientists called interphase the 'resting stage' "	"Identify that interphase is the longest stage of the cell cycle"	3
2. Describe the cell cycle and how it is controlled.	6.1 The Cell Cycle	The Cell Cycle	"Identify how interphase prepares a cell for cell division"	"Identify interphase as the phase of the cell cycle in which growth occurs"	2
3. Distinguish and describe the three stages of interphase and the stages of mitosis.	6.1 The Cell Cycle	The Cell Cycle and Mitosis	"Describe the S phase of interphase" "Describe what is happening in the cell during mitosis"	"Place each image of the G1, S, or G2 phase of the cycle based on the descriptions" "Give the right stage of mitosis based on a description"	2
4.Draw/Identify and label the stages of interphase and mitosis.	6.1 The Cell Cycle	The Cell Cycle and Mitosis	"Draw and label interphase" "Sketch and identify each of the phases of mitosis"	"Assign the drawing of interphase to its correct label" "Given a microscopy illustration, identify which cell is at metaphase"	1
5. Compare and contrast mitosis and meiosis.	6.1 The Cell Cycle & 6.2 Meiosis	Mitosis and Meiosis	"Describe the stages of the cell cycle you observed" "Describe how many chromosomes does the nucleus of an *Ascaris* ovum has"	"Determine whether each phrase describes mitosis, meiosis, or both"	3
6. Explain the relevance of meiosis to sexual reproduction.	6.2 Meiosis	Mitosis and Meiosis	"Identify which types of cells would have a haploid number of chromosomes and a diploid number of chromosomes"	"Identify the correct haploid or diploid chromosome numbers to complete the passage about different types of cells"	3
7. Describe how chromosomes are reduced from diploid number (2n) to haploid number (n) in meiosis.	6.2 Meiosis	Meiosis	"Label, describe and sketch the stages of meiosis you observe"	" Label the illustration of the stages of meiosis with correct descriptions"	3
8. Describe the process of tetrad formation, synapsis, and crossing over	6.2 Meiosis	Meiosis	"Determine how many pairs of chromosomes a cell will have after meiosis I."	"Determine which cell shows the correct number of chromosomes pairs for meiosis I"	3

Note- *corresponds to PL exercises from *Exploring Biology in the Laboratory: Core Concepts* by Pendarvis and Crawley (2016).
** corresponds to VL *Mitosis and Meiosis Interactive* by Sapling Learning (2016).

Physical-based biology lab. The physical-based biology lab activity used in this study was selected from the course lab manual *Exploring Biology in the Laboratory: Core Concepts* by Pendarvis and Crawley (2016). The exercises employed in the PL laboratory delivery mode were taken from Chapter 6 of the lab manual: Splitting Up: Understanding Cell Division and Mitosis. Students in the PL delivery group completed exercise 6.1 The Cell Cycle and exercise 6.2 Meiosis in Animals. The materials used in the physical lab included: the lab manual, Compound Light Microscopes; prepared slides of a whitefish blastula, onion root tip, *Ascaris* ovaries, and animal testis; and colored pencils.

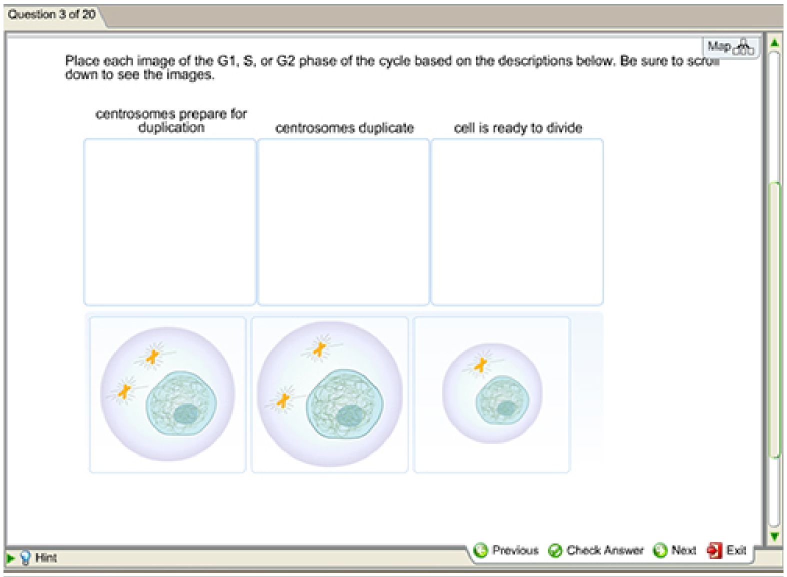
Virtual biology lab. The instructional delivery system and VL instrument used in this study were designed and published by Sapling Learning, an online educational resource company owned by Macmillan Learning. The instructional content provided within Sapling Learning's General Biology Course was selected for this study as it was specifically designed for non-majors, was not course text specific, and it was also unlikely that students had been exposed to the content before treatment.

Due to its open-ended format, The Sapling Learning *Mitosis and Meiosis Interactive* VL was aligned to mitosis and meiosis content learning objectives provided by Openstax Concepts of Biology in Chapter 6 Reproduction at the Cellular Level and Chapter 7 The Cellular Basis of Inheritance. The specific cell cycle, mitosis, and meiosis content within the VL were reviewed and compared to the cell cycle, mitosis, and meiosis content presented in the Openstax Concepts of Biology textbook.

The Sapling Learning *Mitosis and Meiosis Interactive* VL is highly interactive, affording students the ability to manipulate objects within the interface, and receive online guidance in the form of hints, tooltips, and feedback to increase their learning. Example student tasks taken from the Sapling system and interactive features of the VL are shown in Figure 2. Following completion of the VL activities, the online environment used for all three online groups remained open for student review.

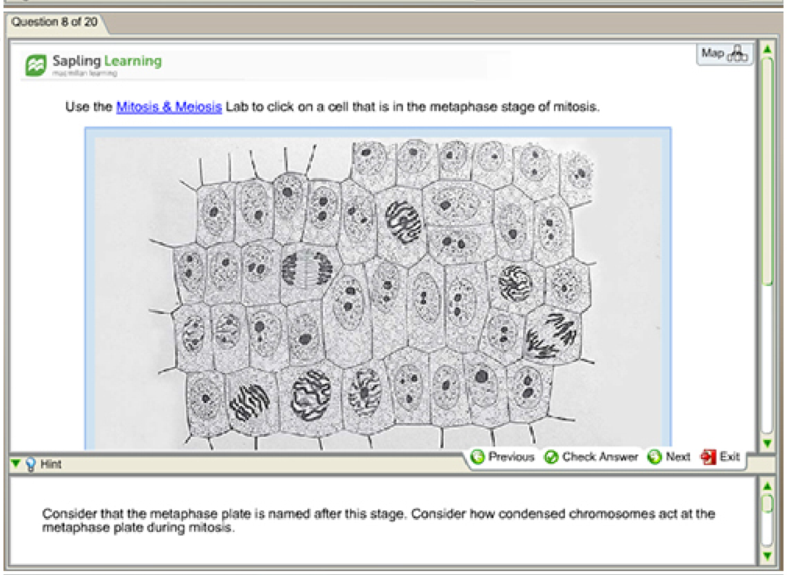
(continued)

a.



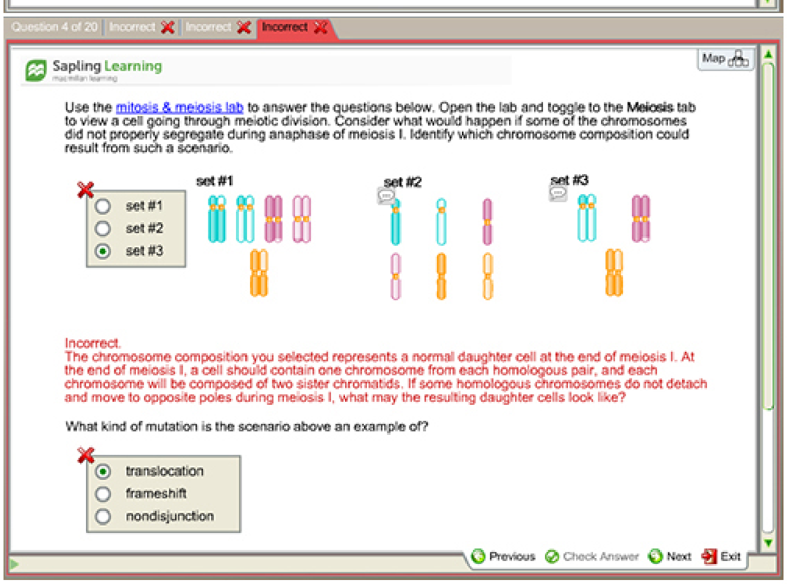
Question 3 of 20
Map
Place each image of the G1, S, or G2 phase of the cycle based on the descriptions below. Be sure to
down to see the images.
centrosomes prepare for duplication
centrosomes duplicate
cell is ready to divide
Previous
Check Answer
Next
Exit
Hint

b.



Question 8 of 20
Map
Sapling Learning
Use the Mitosis & Meiosis Lab to click on a cell that is in the metaphase stage of mitosis.
Hint
Previous
Check Answer
Next
Exit
Consider that the metaphase plate is named after this stage. Consider how condensed chromosomes act at the metaphase plate during mitosis.

c.



Question 4 of 20
Incorrect
Incorrect
Incorrect
Map
Sapling Learning
Use the mitosis & meiosis lab to answer the questions below. Open the lab and toggle to the Meiosis tab to view a cell going through meiotic division. Consider what would happen if some of the chromosomes did not properly segregate during anaphase of meiosis I. Identify which chromosome composition could result from such a scenario.
set #1
set #2
set #3
Incorrect.
The chromosome composition you selected represents a normal daughter cell at the end of meiosis I. At the end of meiosis I, a cell should contain one chromosome from each homologous pair, and each chromosome will be composed of two sister chromatids. If some homologous chromosomes do not detach and move to opposite poles during meiosis I, what may the resulting daughter cells look like?
What kind of mutation is the scenario above an example of?
translocation
frameshift
nondisjunction
Previous
Check Answer
Next
Exit

(continued)

Figure 2. Screen shot of *Mitosis and Meiosis Interactive* question (a) the hint provided (b) and question feedback (c). Copyright 2017 Sapling Learning.

Instructor contact and affordances sheets. All four treatments were introduced to students in the science laboratory classroom or computer labs on campus. Paper-based job aids in the form of an instructor contact and affordance sheet were administered to all four laboratory delivery mode groups at the beginning of the lab sections. The sheets were designed to clearly communicate to students the affordances of their specific lab; provide contact information for the laboratory TA, course instructor, and researcher; and give additional information on how to access the laboratory exercise (Van der Meij & Van der Meij, 2014).

The instructor contact and affordance sheet for the PL group detailed the affordances of instructor presence through having an instructor physically available to answer questions, and hands-on learning through usage of laboratory equipment. It provided contact information for the researcher, course instructor, and TA. The instructor contact and affordance sheet for the VL group simply gave students information that they could access the VL anywhere they had internet access and provided contact information for the researcher, course instructor, and TA. The instructor contact and affordance sheet for the VLIP group gave a brief description of instructor presence, including students' ability to ask questions and receive guidance and provided contact information for the researcher, course instructor and TA. Finally, the instructor contact and affordance sheet for the VLIPLC group detailed the affordance of instructor presence by telling students that they could ask questions and receive guidance from the instructor; provided directed learner control through the suggestion that the students could log in following the standard laboratory section to use the VL as a review tool, and provided contact information for the researcher, course instructor and TA.

Instrumentation

The study employed qualitative focus group questions developed by the researcher which served to explain the results from the initial quantitative study (Creswell, 2014; Creswell & Plano Clark, 2006; Creswell et al., 2003). The protocol used for the one interview was that of a semi-structured interview (Jonassen, Tessmer, & Hannum, 1999), where the researcher constructed a set of pre-established questions to explore the topics of instructor presence and learner control to guide the data collection process and to explore the student's experience of learning in the lab. During the interview, the researcher introduced herself, stated the purpose of the meeting, and read questions from the script, listening to the student and taking note of his responses (Jonassen et al., 1999). The protocol used to explore students' learning experiences in the PL, VL, and VLIPLC groups was the focus group (Jonassen et al., 1999), where the researcher constructed a set of pre-established questions to explore the topics of instructor presence and learner control to guide the data collection process and discussion moderation process. During each of the focus groups, the researcher introduced herself, stated the purpose of the meeting, moderated the discussions using scripted questions, and listened to the students, taking notes of their responses (Jonassen et al., 1999).

The goal of the focus groups and the interview was to explore the ways that non-majors college biology students described their experiences in physical or virtual based biology labs. The lead questions for each lab delivery group were as follows:

Physical Lab Group

1. How did the lab help you to learn biology content?

2. Did you seek or receive help from your instructor, if so, how?

3. If you received help, what kind of help did you receive?

4. Were you satisfied with the amount of time that it took to complete the lab?

5. Were you comfortable using the equipment needed for the lab?

6. Do you feel that repeating this lab would add to your understanding of the topic?

7. What did you like about the lab?

8. What did you not like about the lab?

9. Would you have preferred to do this lab on the computer, why?

Virtual Lab Group

1. How did the lab help you to learn biology content?

2. How many times did you repeat the lab and how?

3. How much time did you spend on the lab?

4. Were you satisfied with the amount of time that it took to complete the lab?

5. Did you use the lab as a review tool and how?

6. Do you feel that repeating this lab would add to your understanding of the topic?

7. What did you like about using the lab?

8. What did you not like about using the lab?

9. Would you have preferred to do this lab in-person, why?

Virtual Lab with Instructor Presence Group

1. How did the lab help you to learn biology content?

2. Did you seek or receive help from your instructor while completing the virtual lab, if so, how?

3. Did you use the tutorials provided with the lab, did you find them helpful?

4. How many times did you repeat the lab and how?

5. How much time did you spend on the lab?

6. Did you use the lab as a review tool and how?

7. What did you like about using the lab?

8. What did you not like about using the lab?

9. Would you have preferred to do this lab in-person, why?

Virtual Lab with Instructor Presence and Learner Control Group

1. How did the lab help you to learn biology content?

2. Did you seek or receive help from your instructor while completing the virtual lab, if so, how?

3. How many times did you repeat the lab and how?

4. How much time did you spend on the lab?

5. Did you use the lab as a review tool and how?

6. Do you feel that repeating this lab would add to your understanding of the topic?

7. What did you like about using the lab?

8. What did you not like about using the lab?

9. Would you have preferred to do this lab in-person, why?

Data Collection Procedures

The one interview and three focus groups were all conducted at a regional South Texas University. Prior to the interview and focus groups, all participants signed a consent form agreeing to participation and being audio recorded. All participants were reminded that their data would be kept anonymous, and confidential. The researcher followed the lead questions for each group, moderated the interview and focus group discussions, and took memos.

After completion of the pre-test, the researcher delivered the same mitosis and meiosis biology content lecture to all four lecture sections of the introductory biology course to ensure control, to provide students with the background knowledge that is traditionally given before they begin investigation in the laboratory environment, and to regulate exposure to content. Each lecture section lasted for a duration of 90 minutes.

Following delivery of the content lecture, students in all four sections of the course were assigned to read "Chapter 6: Cancer-DNA Synthesis, Mitosis, and Meiosis" in their course text, *Biology Science for Life* by Belk and Maier (2013). Additionally, all students were directed to read the regularly assigned pre-lab reading from the course lab manual *Exploring Biology in the Laboratory: Core Concepts* (Pendarvis & Crawley, 2016). Assigned pre-lab readings are a normal process of the biology under investigation. They help to ensure that students have a basic understanding of the content and concepts they will investigate in the laboratory (Reid & Shah, 2007).

Treatments

Prior to beginning the physical laboratory activity, students in the PL group received relevant guidance, where the TA insured students had read the assigned pre-lab and course readings and communicated what students were expected to do for the lab. The TA explained how to identify and distinguish among cells in a phase of mitosis or meiosis, demonstrated proper procedures to follow, and gave the order and sequence for the laboratory exercise to assist in completing the physical based lab. Students in the PL delivery mode group were additionally given an instructor contact and affordances sheet, which the instructor read aloud from a treatment script. Students in the PL group completed the regularly assigned physical based biology lab with the instructor present over a period of 50 minutes during standard course lab section hours as part of normal course process. As students worked on their lab, the course laboratory TA walked around the room to monitor use of lab equipment, answering questions and giving students guidance as needed. At the end of the laboratory section, students were encouraged to contact the course laboratory TA, instructor, and researcher via phone, e-mail, and the learning management system, with any questions they had about the laboratory activity.

Virtual laboratory groups. Prior to beginning the tutorial and virtual biology lab activity, students in the three VL delivery groups were given an instructor contact and affordances sheet, which was read aloud by the instructor from a treatment script. Next, they completed an introductory tutorial provided by Sapling Learning that demonstrated how to answer questions, make use of feedback, hints, and tooltips, and navigate the virtual environment.

Students in the three VL delivery mode groups completed the assigned *Mitosis and Meiosis Interactive* virtual activity online in the Sapling Learning environment. Each of the three VL treatments were delivered over a period of 50 minutes inside a campus computer lab during standard course laboratory section hours. Prior to beginning the VL exercise, students in the three VL delivery mode groups were given verbal information about the affordances of instructor presence and learner control in their lab read by the instructor from a treatment script.

Virtual laboratory with no instructor presence group. The instructor told students in the VL with no instructor presence group (VL) that they would work independently on the assigned exercise and questions, and would take a post-test immediately after they finished and a week later. Additionally, the instructor did not direct students to use the online VL content and environment as a study tool after they completed the laboratory activity, although they could choose to do so through self-direction. To simulate a completely virtual experience, no instructor presence was provided. The instructor left the computer lab and remained physically outside while students completed the laboratory exercise. A computer lab aide with no knowledge of study content was physically present during the laboratory to troubleshoot any computer issues.

Virtual laboratory with instructor presence group. Students in the virtual laboratory with instructor presence group (VLIP) were told by the instructor that they would work independently on the assigned exercise and questions, and would take a post-test immediately after they finished and a week later. Instructor presence was provided by the instructor being physically present in the computer lab; students were encouraged to ask questions and received guidance as they completed the laboratory activity. The instructor did not recommend that students use the online virtual lab content and environment as a study tool after they completed the laboratory activity. At the end of the laboratory section, students were encouraged to contact the course laboratory TA, instructor, and researcher via phone, e-mail, and Blackboard, with any questions they had about the laboratory activity.

Virtual laboratory with instructor presence and directed learner control group. Students in the virtual laboratory with instructor presence and direction for learner control of pace and repetition beyond lab time group (VLIPLC) were told by the instructor that they would work independently on the assigned exercise and questions, and would take a post-test immediately after they finished and a week later. Instructor presence was modeled by the instructor being physically present in the computer lab, students were encouraged to ask questions and received guidance as they completed the laboratory activity. The instructor recommended that the students control their own learning by using the online virtual lab content and environment as a review or study tool after they complete the laboratory. At the end of the laboratory section, students were encouraged to contact the course laboratory TA, instructor, and researcher via phone, e-mail, and Blackboard, with any questions they had about the laboratory activity.

Data Analysis

The qualitative interview and focus group data was audio recorded using the voice memo feature of an iPhone 6 with a hand-held recorder as a backup device. The audio was then transcribed verbatim into Microsoft Word ® following transcription; the audio data was erased. In order to guide the focus group coding process and maintain organized qualitative analysis, the researcher constructed analytic memos, as suggested by Saldana (2009). The textual data from Word® was uploaded into MAXQDA 12, and sorted into codes, categories, and themes.

The methodological framework that guided the data analysis of the study was interpretivism (Crotty, 1998). The researcher sought to explore how non-majors college biology students gave meaning to their laboratory based learning through their description of their experiences using the affordances of instructor presence and learner control in PL and VL environments. The first cycle coding method was structural coding, where qualitative data was categorized according to each mode of biology lab treatment to further explain the research hypotheses and data from the prior quantitative study (Saldana, 2009). Following structural coding, the qualitative data was analyzed further through the second cycle coding method of magnitude coding detailed in Saldana (2009). In magnitude coding, the researcher assigned alphanumeric values to describe the frequency of student responses and attitudes related to mode of biology lab delivery, instructor presence, and learner control to support and explain quantitative data (Saldana, 2009). The researcher coded students' positive experiences of laboratory based learning and using the affordances of instructor presence and learner control with a (+) symbol. When students had a neutral opinion of learning or did not use the affordances of instructor presence and learner control, the responses were coded as (0=). Finally, when students expressed a negative view toward labs, or did not find an affordance helpful, their responses were coded as (-). The magnitude coding scheme used in the study and its suitability for data analysis is informed by previous research (Chen et al., 2014; Miles & Huberman, 1994; Saldana, 2009).

A review of the literature gave the researcher a pre-conceived notion of the codes categories and themes that would result from analysis of the qualitative data, which can occur in qualitative research (Kawulich, 2017). The questions asked during the interview and focus groups were designed to explore students' experiences of instructor presence and learner control in the PL and VL environments. This resulted in some of the codes, categories, and themes matching the topics discussed in the literature; however, the researcher remained objective through the analysis process, and assigned appropriate themes to the resultant codes and categories.

The researcher sought to find out the specific ways that students used the physical and virtual biology labs and how students felt about learning using each of the unique biology lab delivery modes. Through qualitative analyses, the study explored how instructor presence and learner control can be used to enhance virtual labs as a learning tool.

Results

The qualitative component of the sequential explanatory mixed methods study addressed the research question: How do undergraduate non-major college biology students describe their experiences of instructor presence and learner control of pace and repetition in each of four treatments? One interview and three focus groups were conducted to explore students' experiences of the affordances of instructor presence and learner control presented in four distinct modes of biology lab delivery: a physical based lab; a virtual lab; a virtual lab with instructor presence; and a virtual lab with instructor presence and directed learner control.

During the interview and focus groups, additional qualitative questions emerged that helped to directly explained and enhance the results from the initial quantitative study (Creswell, 2014; Creswell & Plano Clark, 2006; Creswell et al., 2003). The additional questions are described in the results of each unique laboratory delivery group.

Interview and Focus Group Results

An analysis of the data from the interview and the three focus groups resulted in three themes: *instructor presence*, *learner control,* and *unique laboratory experiences*. Within the three themes, eight categories were derived: instructor-student communication; instructor-guidance; repetition; pacing; time spent learning; access to available guidance as needed; students' insight into learning; and students' suggestions to improve labs. (Table 3) shows the three themes and their eight categories.

Table 3

Themes and Categories for Students' Experiences

Theme 1: Instructor Presence

- Instructor-Student Communication
- Instructor Guidance

Theme 2: Learner Control

- Repetition
- Pacing
- Time Spent Learning
- Access To Guidance As Needed

Theme 3: Unique Laboratory experiences

- Students' insight into learning
- Students' suggestions to improve labs

The first theme, *Instructor Presence,* emerged as students in the PL group discussed how they communicate with the lab TA and receive guidance during their lab; students in the VL group described how they did or did not communicate with the lab TA and instructor after completion of the virtual lab; the VLIP interview participant described how he used the affordance of instructor presence; and students in the VLIPLC group described how and if they communicated with the lab TA and instructor after completion of the virtual lab. Their discussions centered on instructor-student communication and instructor guidance.

Physical lab group. In regard to instructor- student communication, the students explained that they "didn't really ask any questions, and that the TA would "float around during the lab" and "if she heard you talking about something that didn't sound right, she would explain it to you more."

In terms of describing the instructor guidance, one PL participant mentioned "she kind of directed you on where to find the answer", another described that as the TA walked around the room, "if she saw you looked like you needed help, then she would help you." Ultimately all of the participants agreed that the TA would "teach the lab content without teaching it", allowing them independence while completing the lab.

Virtual lab group. In discussion of instructor- student communication, the students unanimously expressed that they did not attempt contact with the course instructor or TA following the lab. However, one student did relate that the "lecture and virtual lab, was perfect" in terms of communication.

In terms of describing instructor guidance, which was lacking from their virtual lab, one participant mentioned she found "the little tricks on memorizing the cells" presented during the lecture, as helpful guidance.

Virtual lab with instructor presence group. When asked about instructor- student communication and if he made contact with the course instructor or TA following the lab, the student said "no" he explained "I didn't have to use that or anything, I guess." However, one student did relate that the "lecture and virtual lab, was perfect" in terms of communication.

There was an instructor present for the virtual lab section to provide guidance and answer student questions. The student expressed that "it was helpful" and that he "personally didn't need it." However, he did provide insight into instructor guidance "you always hear some people are better hands-on learners, some people are better guided by a presence. Someone actually being present there, just in case they have questions or aren't too sure, just in case something is a little bit vague for them."

Virtual lab with instructor presence and learner control group. As students discussed instructor- student communication, they unanimously expressed that they did not attempt contact with the course instructor or TA following the lab. However, students did make use of instructor-student communication during lab time. "I liked having an instructor there too, just in case I had questions" explained one student. Another student expressed that he felt he could do the lab "either" with an instructor present "or" without.

The students also made use of instructor guidance during lab time. In terms of describing instructor guidance, one participant felt that "it was kind of like a good backup to have." A summary of the PL, VL, VLIP, and VLIPLC group participants' responses to *Instructor Presence* is included in (Table 4)

Table 4

Students' Experiences, Theme 1: Instructor Presence

Theme 1 : Instructor Presence
Physical Lab
Instructor Student Communication:
• "If she heard you talking about something that didn't sound right, she would explain it to you more, without you needing to ask questions."
• "She kind of teached it without teaching it"
• "We wouldn't ask her a specific question; it was just kind of like a ' are we going in the right direction?' type of question."
Instructor Guidance:
• "She kind of just like bounces around"
• "She was walking around, and if she saw you looked like you needed help, then she would help you"
• "She kind of directed you on where to find the answer"
Virtual Lab
Instructor Student Communication:
• "Yeah, the lecture and the virtual lab, that was perfect"
Instructor Guidance:
• "Your little tricks on how to memorize things, I think quirky things helped a lot"
Virtual Lab with Instructor Presence
Instructor Student Communication:
• "I didn't have to use that [communication] or anything, I guess"
• "I didn't receive anything communication wise"
Instructor Guidance:
• "Some learners are better guided by a presence"
• "Yes, it was helpful, I personally didn't need it"
Virtual Lab with Instructor Presence and Learner Control
Instructor Student Communication:
• " No one contacted the instructor or TA"
• " I think either [with the instructor] or [without the instructor]"
Instructor Guidance:
• " I liked having an instructor there too, just in case I had questions"

As students described their experiences of control and lack thereof over their learning in the PL environment and their experiences of control over their learning in the VL, VLIP, and VLIPLC environments, the second theme, *Learner Control*, emerged.

Physical lab group. The lack of repetition was a major factor in students' learning experience. All of the participants expressed that they felt constrained by "moving on" to a different lab every week, one student said, "I don't really remember any of our labs." Additionally, all of the participants agreed that "more review" would be "helpful." Students also expressed their lack of control over pacing of the lab, explaining that they "feel rushed" and that often they are presented with a lot of material to "cram in during lab." One student explained she "felt more rushed" when using the microscopes, as there weren't enough for every person. Overall, the students related that most of the time they are "just trying to hurry and finish" their PL assignment. The lack of learner control was also present in the time students spent learning in the PL environment, one student described concern in completing the drawing component of the lab assignment saying "it had metaphase I and metaphase II, and before and after. I was like, oh my god, which one!?" Another student expressed that "it was a lot of material" to cover in one lab. The limited amount of time for learning lab content caused one student to exclaim "it like, left my mind." The participants also expressed that they do not ask the TA or course instructor questions about the lab after it is finished. One student explained that if she needed to review the content covered during the lab, she would just "read the book."

Virtual lab group. When asked if they had logged back in to repeat the virtual lab after the standard course time, all of the students said "no." The students stated that their upcoming exam on content not covered by the virtual lab had been the reason. However, during the lab section itself, students did express that they played the cell animation in the virtual lab multiple times. Students also liked the control they had over pacing of the lab. One student expressed she liked how the lab was "individually paced." Another student enjoyed how the virtual lab afforded the opportunity to "go back and revisit the stuff." Learners also appreciate the control they had regarding time they spent learning in the VL environment, one student described how he would "look at the animation before answering a question." Another described her enjoyment of having the time to "spend a couple of minutes per question." Ultimately, the students all perceived that they made efficient use of their time completing the virtual lab and that the laboratory assignment questions went well with the lab. The participants also expressed that they did access the available guidance in the virtual lab as needed. Prior to beginning the VL activity, students completed an introductory tutorial to learn how to navigate and use the features of the virtual interface. Students found the tutorial useful, "I feel like I wouldn't have used the animations. I wouldn't have known how to use it to the best of what it gave you" said one student, " Yeah, it gave you all the tools you were actually able to use….it helped with learning how to use the pictures, made sure you knew how to do it, it sure helped" agreed another. In regard to the informational icons provided within the virtual lab, one student explained that using them "helped a little bit." Another student said that they "explained what part of the pictures were to help you understand what was going on." A third student liked how the lab "gave information instead of just pictures." Students also found the hints provided in the virtual lab to be helpful, "I liked how it gave a hint on the bottom sometimes", explained one student, "It took a little hint sometimes." Students also used the question feedback provided by the virtual lab, "it helped to explain more than just 'Yay! You got it right, here you go!'…. in case you might have guessed, you get to know what the actual answer was", exclaimed one student. The researcher additionally explained that the maximum attempts for each of the laboratory assignment questions were set to three tries, as a follow up students were asked if they employed the hints and feedback provided in the lab before their final attempt, the students all said "yes."

Virtual lab with instructor presence group. When the student was asked if he had logged back in to repeat the virtual lab after the standard course time, he said "no. I did not." Additionally, the student shared that he did not repeat the lab during class time, saying he "just kind of 'one shotted' it for the most part." In regard to pacing, the student expressed that he felt the virtual lab " was clunky in the way it felt when you were trying to use the system itself." The student acknowledged that the VL environment allowed him to control the way he spent his time learning, he described that using the informational tabs provided through the question feedback system " allowed him to refer back " to review his answers. The student also described that he did access the available guidance in the virtual lab as needed. In regard to using the hints provided by the system, the student had mixed opinions "some of it was vague, and some of it was very helpful", he explained. The hints also caused some confusion, he described one particular question "it gave you the answer as a hint… and even if you put the correct answer, it would be like 'wrong'." He also used the question feedback provided by the virtual lab, " when you answered a question wrong, it would open up a mini-tab inside that quiz itself and it did that continuously, which that's ok. But I find it a little bit 'off' as a way to put it."

Virtual lab with instructor presence and learner control group. In the discussion, students were asked if they had logged back in to repeat the virtual lab after the standard course time, they all said "no." The students had an upcoming test on unrelated content; "I didn't think about it for me because of the test" explained one "basically, it wasn't on our test so I didn't review it" explained another. However, during the lab section itself, students did take advantage of repeating the content "you can go back to the beginning and repeat it super-easy" exclaimed one, "I referred to animations quite often", expressed another. Students were also positive of their control over pacing of the lab, "I liked it because it gave me the independence, [to] like work at my own pace. I could do it how I want to do it." Another student also enjoyed the freedom of working independently "You were able to go at your own pace, because some people are faster learners than everyone else." Additionally, the students appreciated that there was no extensive set up of lab equipment "It took longer to set up than to do the lab. It took longer than it should, where we could have been learning. Whereas the virtual lab, we could just go and log-in and everything is already ready for us." "I think it goes back to learning at your own pace too, because we had three or four other people, so we all had to do it together. And that slows it down, a lot" remarked another student.

Students also felt more in control of their time spent learning in the VLIPLC environment, one student described how she "went through the lab, and if a question came up, I would go to that specific part." Again, students described that they had little control of their time spent learning in the PL due to limited lab equipment "I think this actually saves time, without getting out the microscopes and getting everyone set-up. And you have to make sure when using the microscopes, everything is adjusted." "And like in the lab setting, they don't usually have a microscope for everyone. You have to share, so like, you can't sit there and look at each slide and you have to move on." Ultimately, all of the students expressed they were comfortable with the virtual lab and felt they made efficient use of their time spent learning.

The participants also expressed that they did access the available guidance in the virtual lab as needed. Prior to beginning the VL activity, students completed an introductory tutorial to learn how to navigate and use the features of the virtual interface. "At first going through the tutorial, it was like helpful to learn the system. Because every system is different. But kind of towards the end, it was like some of the stuff wasn't necessary" said one student, " I know sometimes different systems have a tutorial video so you can just watch it….so that might help better than actually doing it" he added. In regard to the informational icons provided within the virtual lab, all of them students found them to be helpful. The students had mixed feelings regarding the hints within the lab, " I think some of them were helpful and then some of them… I didn't really understand what it was trying to get at, so it really didn't help me personally….some of them were, some of them weren't", explained one student. Another student agreed "if I would get a question wrong, it's like I obviously didn't know what they were talking about. And they would still just confuse me even more, sometimes…but not on all of them, just on some of them." The researcher additionally explained that the maximum attempts for each of the laboratory assignment questions were set to three tries, as a follow up students were asked if they employed the feedback provided in the lab to help answer the questions. Students were fine with and understood the limited amount of attempts, however, expressed concerns about the feedback. One student expressed that the feedback did not tell him specifically which parts of his answer were incorrect, saying "it just told me my answer was wrong." A summary of the PL, VL, VLIP, and VLIPLC group participants' responses to *Learner Control* is presented in (Table 5) below.

Table 5

Students' Experiences, Theme 2: Learner Control

Theme 2 : Learner Control
Physical Lab Repetition: • "I feel like we move on" • "There is no point [to review] when we are moving on to something else next week" Pacing: • "It felt kind of rushed" Time Spent Learning: • "It like, left my mind" • "It was a lot of material" Access to available guidance as needed: • "I didn't really ask any questions" • "I just read the book"

(Continued)

Virtual Lab

Repetition:

- "We can go back and 'revisit' that stuff"

Pacing:

- " I liked how it was individually paced"

Time Spent Learning:

- " I went through the virtual lab, then went through it and bounced back"

Access to available guidance as needed:

- " It gave me information instead of 'just pictures'"

Virtual Lab with Instructor Presence

Repetition:

- "I just kind of 'one shotted' it for the most part"

Pacing:

- "It was clunky in the way it felt when you were trying to use the system itself"

Time Spent Learning:

- " The [mini-tabs] allow a person to refer back if they keep missing a question further and further and further"

Access to available guidance as needed:

- " I find it a little bit 'off' as a way to put it"
- "Even if you put the correct answer, it would be like 'wrong'.

Virtual Lab with Instructor Presence and Learner Control

Repetition:

- " I referred to the animations quite often"
- "You can go back"
- "Basically, it wasn't on our test so I didn't review it"

Pacing:

- " I could do it how I want to do it"

Time Spent Learning:

- " You kind of did it on your own time"

Access to available guidance as needed:

- " Some of the [hints] were helpful, some of them weren't"

The third theme, *Unique Laboratory Experiences*, was found as students' in the PL group described what they liked about their physical lab, what they didn't like, and their opinions toward the use of an alternate virtual lab; and as the students in the VL, VLIP, and VLIPLC groups described what they liked about their virtual lab, what they didn't like, and described their feelings of completing the alternate physical lab.

Physical lab group. Students expressed their insight of learning in physical labs. One student enjoyed having an engaging classroom lecture before starting the lab and enjoyed the "sperm and egg puppet" examples presented by the researcher. Another student expressed her preference for physical labs as she considered herself a "physical learner." However, the students did express the lack of microscopes, and felt confined by the fact they worked in groups where "everyone wanted to see the cells." When presented with the idea of trying an alternate, virtual version of the lab, one of the students was hesitant explaining she would rather "be in the classroom actually 'seeing it'." When the researcher provided a little more description of the animation and interactivity provided by the virtual lab, the students changed their minds and agreed that they would be willing to try it. Ultimately, all the students felt the physical lab helped their learning. A new category, students' suggestions to improve labs, emerged from students describing their lab experiences. Students expressed that they needed "more time to learn the concepts", "more opportunities for review", and "more examples."

Virtual lab group. Students shared their experiences of learning in virtual labs. During the focus group, one student jubilantly shouted "Pirates Make Awesome Thieves!" in reference to a mnemonic way to remember the phases of mitosis presented by the researcher during the lecture. Again, one student explained they felt that the lecture improved their understanding of lab content "I liked having a lesson beforehand and then going into the lab, it helped a lot in knowing what you said and seeing the animations." Students did experience some issue with the virtual lab related to the questions, "Yeah, that gave me some trouble, the different images" explained one student, "what was hard is that it had different pictures and they all looked kind of the same" expressed another. Students also shared their perceptions of some of the physical labs they had done in the past, "we still need labs that are not like as hard as what the actual biology students do, but are more advanced so I am actually learning instead of just going", explained one student. Another student expressed that the physical labs could be overwhelming, "we get so much thrown at us at once. We have just one lab per week, so it makes it a little bit harder to remember." When the students were asked if they would like to try an alternate, physical version of the lab, they unanimously said "no", one student explained "I think I got what I needed from the virtual lab personally." All of the students felt positive about the virtual lab, describing that they "liked how it showed [cellular] movement" and " liked the diagram that you could click on to and click through the phases and see everything actually happen." Additionally, all of the students expressed that the virtual lab helped their learning, enabling them to "see [content] better" and that with the animations "you couldn't just memorize that same picture; you had to understand what was going on in the picture."

A new category, students' suggestion to improve labs, emerged from students' describing their lab experiences. One student suggested an edit for some of the cellular image questions "color would have helped a little bit more." Other students felt that the virtual lab was easy to use and designed well, "I didn't see a problem" replied one student, " yeah" agreed another student, " honestly, it was really good, and laid out well" expressed another. Overall, students were positive about their experiences using the virtual lab, one student eagerly replied "I didn't think I was going to like it, because I have never been into online learning, but I was really surprised. I really liked that lab!"

Virtual lab with instructor presence group. When the student was asked what he liked about the virtual lab, he explained "what I did like about the presentation [of the lab] itself was that it does show you the transition between each phase" and "it serves as a model." The student was asked if he would have preferred to do the regular, physical lab, instead "I think a combination of the two would be most useful" he expressed, "I think the model would help because it shows the transition and would give people a better representation and memory."

Despite experiencing minor confusion caused by the hints and question feedback, the student explained that the virtual lab helped his learning," I personally think that it's very helpful."

As the student described his lab experience, a new category, students' suggestion to improve labs, emerged. He provided multiple editing suggestions he felt would improve the virtual lab. One major suggestion was to "polish the lab in terms of balancing out the color scheme"; the student felt that the interface was "very white." He additionally suggested that using the virtual lab was somewhat "clunky" and recommended that "updates polish out the defects or makes it a little better." He concluded, "Like I said, it just needs polishing and it'd be fine."

Virtual lab with instructor presence and learner control group. In their discussion, the students shared their insight toward their learning in virtual labs. Again, students did experience some issue with the virtual lab, particularly with the questions which included real cell microscopy images "I thought that was kind of difficult, to be honest" explained one student, "we were used to looking at the animations, not the physical. So it was kind of hard to make sure you clicked on the right one and that you understood what it actually looks like" expressed another. Students also shared their perceptions of some of the physical labs they had done in the past, their experiences in physical labs were predominantly centered on laboratory equipment and setup. One student commented "There weren't enough microscopes for everyone" explained one student, "at least four to one microscope, which was challenging; because we had people with different visions. So we had to keep adjusting it, that's one of the problems I had." An additional issue was brought up by another student, "and finding plugs too, because our biology lab classroom, we aren't in a regular classroom. We are in a side classroom, so we had to keep finding plugs to put the microscopes in that would actually reach the microscope, it was a little tricky." When the students were asked if they would like to try an alternate, physical version of the lab, they expressed they liked using the virtual lab. One student explained " I think if I was a biology major, if I was in the major, I would; because it's interesting to see everything….I was fine with the virtual lab and seeing it the animation way." All of the students felt positive about the virtual lab, describing that "it was helpful that you could click on the different stages" and "it showed how the [cells] changed from one stage to the next stage, that was helpful." Additionally, the students enjoyed the animations and expressed they were "very smooth." The students also were positive about the control the virtual labs offered them over their own learning. Finally, students appreciated the ease of use afforded by the lab "it's easier than like a textbook with the pictures" remarked one student "I think it was easier to learn versus our actual labs" added another.

A new category, students' suggestion to improve labs, emerged from students' describing their lab experiences. Students' suggestions for revision focused on clarifying the hints and feedback provided by the lab and "giving more information or examples of how to apply it in real life situations." Overall, students were positive about their experiences using the virtual lab "I would like to use this thing, it's easier. Like you said, it's available anywhere we have internet. Like, you don't have to carry around a textbook to review, it's already there" exclaimed a student. A summary of the theme *Unique Laboratory Experiences* is presented for the PL, VL, VLIP, and VLIPLC groups in (Table 6) below.

Table 6

Students' Experiences, Theme 3: Unique Laboratory Experiences

Theme 3 : Unique Laboratory Experiences
Physical Lab
Students' insight into learning:
• "There's not enough microscopes"
• "Four or five people to a group"
• "I am more of a physical learner"
• "I prefer learning by myself"
• "I like to study on my own and work together in a lab"
• "I am not really 'getting it'.
Students' suggestions to improve labs:
• "I'd want a longer amount of time"
• "It'd be cool if you could actually 'see' the cells"
Virtual Lab
Students' insight into learning:
• "Honestly, it was really good and laid out well"
• "I liked how it showed [cellular] movement"
• "I think I got what I needed from the virtual lab personally"
Students' suggestions to improve labs:
• "Color would have helped a little bit more"
• "I didn't see a problem.
Virtual Lab with Instructor Presence
Students' insight into learning:
• " I personally think that it's very helpful, just needs polishing is all"
• " You always hear people are better 'hands-on' learners"
Students' suggestions to improve labs:
• "I can also say like it needs kind of an update"
• "You could try to improve just the overall color scheme"
• "Updates kind of polish out the defects"
Virtual Lab with Instructor Presence and Learner Control
Students' insight into learning:
• " I was fine with the virtual lab and seeing it the animation way"
• " I thought that it was easy for online"
• " I like it better than the regular lab"
• " It's easier than like a textbook with the pictures"
Students' suggestions to improve labs:
• " It didn't tell me which [answers] were wrong or out of place"

Discussion

The results of the focus groups and interview indicate that students were very interested in the learning experiences offered by the PL and VL delivery modes. The following pages provide a discussion into the helpful insights students shared about their learning.

Students' experiences of instructor presence and learner control (RQ1)

A previous quantitative study by McQueen and Cifuentes (2017) found that the affordances of instructor presence and learner control did not produce significantly different learning outcomes among the PL, VL, VLIP, and VLIPLC groups. This finding provides further support to previous research (Darrah et al., 2014; Tatli & Ayas, 2013; Triona & Klahr, 2003; Zacharia & Olympiou, 2011) that virtual labs can produce measurable learning outcomes equivalent to physical labs, even without additional instructor guidance or students taking advantage of learner control by repeating and reviewing a lab after initial completion. In the scope of the current study, there is relatively little research which describes or measures student learning experiences in PLs (NRC, 2006; Puttick et al., 2015). Additionally, there is a need to expand on the body of literature which describes and measures students' learning experiences in online environments such as VLs (Humphries, 2007; Lee et al., 2010; Richardson et al., 2015).

Students’ experiences of instructor presence in physical labs. Students in the PL delivery mode did make use of instructor presence by receiving procedural directions, guidance, and asking content related questions while actively participating in the lab. However, they did not follow the specific recommendation implemented as a part of the study design to contact the course instructor, course laboratory TA, or the researcher with lab content related questions in the one week following the lab. To more thoroughly investigate this phenomenon, a meeting was held with the course instructor, who explained that historically, students in the course have never contacted her or the TA with questions outside of the actual lab sessions. Students were positive about their experiences of communicating with the TA to receive assistance and feedback during their lab. This finding is in line with other studies where students described the benefits of instructor student communication. Another interesting finding is that the students did not actively ask the TA questions, they waited for her to initiate help. Other research shows that students in PL environments often struggle with questioning, and that instructors should encourage student communication to help alleviate feelings of frustration (NRC, 1996). Students also expressed the benefit of receiving instructor guidance, they enjoyed that the TA would guide them on where to find information in a way that made them feel they were learning independently. This finding is similar with other studies which describe that proper guidance should allow students to build upon their learning (De Jong et al., 2013; De Jong, Sotiriou, & Gillett, 2014). Additionally, research has found that students are positive toward well delivered instructor guidance in lab based learning (Bhargava et al., 2006; Stuckey-Mickell & Stuckey-Danner, 2007). In addition to assisting students with learning laboratory content, the TA provided help by teaching students how to operate microscopes. Instructor guidance in the form of pre-lab demonstrations and showing students how to properly operate laboratory equipment is an important component of laboratory instruction (Maldarelli et al., 2009).

Students' experiences of instructor presence in virtual labs. Students in the VLIP and VLIPLC delivery modes did make use of instructor presence by receiving procedural directions, guidance, and asking content related questions while actively participating in the lab. In regard to instructor-student communication, the students in the VL group unanimously expressed that they did not attempt contact with the course instructor or TA following the lab. However, they did relate that the lecture provided before the lab was a form of communication which was beneficial to their learning in the virtual environment. Additionally, the student in the VLIP group did not communicate with the instructor or TA during the lab, or following. The student expressed that he felt it was not necessary. Similar to the other virtual groups, students in the VLIPLC group did not attempt communication with the instructor or TA outside of lab time. However, students did make use of instructor-student communication during lab time, some of the students were positive about the availability of communication during the lab; others were neutral, and expressed that it did not have an effect on their learning experience.

Based on the results, there is a need for further research into how student learning is influenced by instructor-student communication and how such communication can be afforded in VLs (Flowers, 2011; Picciano, 2002; Stuckey-Mickell & Stuckey-Danner, 2007; Zacharia et al., 2015). Students did not follow the specific recommendation implemented as a part of the study design to contact the course instructor, course laboratory TA, or the researcher with lab content related questions in the one week that elapsed between the lab and the delayed recall post-test. Similar to the PL group, the course instructor explained that students in the course have never contacted her or the TA with questions outside of the actual lab sessions.

An interesting finding related to instructor guidance is that students in the VL environment, in which the affordance was lacking, equated the guidance provided during the pre-lab lecture as a beneficial to their learning in the lab environment. In the VLIP group, an instructor was present for the virtual lab section to provide guidance and answer student questions. Again, the student expressed a neutral opinion, and described that while the presence did not personally affect his learning experience, he could see the merit of instructor presence for other students who may have questions or for use in future labs. During the lab students in the VLIPLC group made use of the instructor guidance, their experiences learning were positive, and they viewed the opportunity to receive instructor guidance as beneficial to their learning. The finding that some of the students' from the VL groups found the guidance of an instructor helpful to their learning while using the online VL is supported by research from NRC (1997) and Podolefsky et al. (2013) which recommends that instructors should be available to guide students as they use computers to learn science concepts, such guidance can mitigate students' feelings of frustration.

Students' experiences of learner control in physical labs. The lack of repetition available in the PL mode greatly impacted students' learning experiences. The group felt constrained by the limited opportunity for repetition and expressed that it negatively affected their learning. However, students felt optimistic that additional opportunities to review lab content would benefit their learning. Additionally, students in the PL group viewed the limited control of progression, speed, and delivery of instructional content as disadvantageous to their learning. They often felt rushed during the lab and that they were overloaded with too much material to learn in the given amount of time. A major reason for this is that there was a lack of microscopes that the students had to share with others; as a result they were unable to work at their own pace. Students also expressed their concern over their lack of control of how they spent their time learning during the lab. They worried about having enough time to view the cells and complete the cellular drawing activity that was a part of their lab assignment. They also felt overwhelmed by the amount of material they had to cover during one lab section, explaining that they often felt it negatively impacted their ability to learn. The students explained that they did not access available guidance by contacting the instructor or TA with questions following the lab. They felt that communication was not productive since they would cover a new topic in their lab the following week. Other students preferred to refer to the course text as a means of guidance and review.

The findings from the PL focus group are similar to other studies which measure students' experiences learning in PLs. The students did not appreciate the lack of repetition in their lab. Other studies have found that students often feel anxious about performing labs (Dalgarno et al., 2009), which could be due to the pacing of labs and that lack of laboratory equipment and materials can hinder progress in labs (Bell, 1999), students in the focus group expressed these concerns. The students also explained that they struggle to manage their time learning during the lab, Corter et al. (2007) found that the constraint of limited time can lead to negative student attitudes toward lab learning. The students' also expressed reluctance to contact their instructor outside of class time; the hesitance to further seek guidance is in line with other research which suggests that instructors must often direct questioning and interaction with students (NRC, 1996).

Students' experiences of learner control in virtual labs. In the design of this study, the VLIPLC group was given specific direction for learner control by the instructor recommending that the students log back in to repeat the online virtual lab and use it as a study tool for the course for the one week following lab completion. Additionally, students in the three virtual lab sections VL, VLIP, and VLIPLC were provided the affordance of learner control through the virtual lab interface. While completing the lab, they directed their interaction within the virtual lab interface, controlled the pace at which they viewed content, took advantage of the opportunity for repetition; accessed guidance provided through hints, feedback, and informational action icons within the lab as needed, and actively guided their own learning.

Students in the VL group did not repeat the lab after class time. An interesting finding is that students did not log back in due to an upcoming biology test on unrelated content, they expressed that they were more concerned about studying the material that would be on their graded course exam. Despite the lack of repetition outside of class time, the students were positive about the ease of repeating the lab, and expressed they repeated it multiple times during the actual class. Alternately, the student in the VLIP group was positive about the lab itself, but expressed he did not see the need for repetition of the lab. Again, the students in the VLIPLC group did not log in to repeat the lab after the standard course time. Similar to the VL group, the students expressed concern for their upcoming test. However, students did see the educational value of the lab itself, were positive about the ease of repetition, and repeated the lab several times during the lab section.

The VL group students' experiences of the control of pacing offered by the virtual lab were positive; they were appreciative of the freedom to work at their own pace. Alternately, while positive of the experience of the virtual lab overall, the student in the VLIP group did express some frustration in regard to pacing, he felt that the online interface was somewhat outdated and slow, not allowing him to progress at the rate he wanted. Similar to the VL group, student experiences in the VLIPLC group were positive. They enjoyed the control they had over the pacing of the lab content. The students enjoyed the freedom of working independently and at their own pace provided by the lab. Additionally, the students appreciated that there was no need for set up, operation, and tear down of lab equipment. Finally, the students expressed positive views of the fact that the virtual lab was instantly accessible online, and everything was ready in the virtual interface.

The virtual lab also provided the additional affordance of allowing students to efficiently control their time spent learning. In the VL group, students were positive of how they could view content in the order and ways in which they wanted. Ultimately, the students all perceived that they made efficient use of their time completing the virtual lab and that the laboratory assignment questions went well with the lab. In the VLIP group, the student acknowledged that the VL environment allowed him to control the way he spent his time learning, he was positive about being able to use his time to review his answers through the embedded feedback system. Students were positive and felt more in control of their time spent learning in the VLIPLC environment. Again, they appreciated being able to go through the content in the ways they wanted. Additionally, they expressed that the virtual lab allowed them more efficient use of their learning time as they were not confined to the availability, set up, and operation of laboratory equipment. Ultimately, all of the students expressed they were comfortable with the virtual lab and felt they made efficient use of their time spent learning.

The finding that students in the virtual lab groups employed learner control features to enhance their interaction with the virtual lab is in-line with other studies (Hasler et al., 2007; Zacharia et al., 2015). The unanimous lack of repetition outside of class time for all virtual lab groups and the concern over an upcoming unrelated test expressed by the VL and VLIPLC groups are similar to other research, where students in labs often focus more on completing what needs to be done for a grade. While students will often employ the affordance of repetition during class time (Campen, 2013; Toth et al., 2009), more study is needed to promote and communicate the relevance of repetition outside of the lab. The learning benefits offered through the control of pacing in VLs has been previously described in the literature (Bhargava et al., 2006; Hasler et al., 2007; Smetana & Bell, 2012). The finding that a majority of students' experiences of pacing were positive is supported by Thompson et al. (2010). Alternately, other research indicates that technology related issues can cause frustration in learners, often leading them to possess less favorable attitudes toward learning virtually (Podolefsky et al., 2013), such was the case in the VLIP group. All of the virtual lab groups were positive about the control they had over their time spent learning in the online environment. Studies by Pyatt and Sims (2012) and Toth et al. (2009) found similar results, especially due to the fact that VLs remove the constraints of traditional labs.

Students had mixed views of the guidance provided by the virtual interface. In terms of the pre-lab tutorial, participants in the VL group felt that it helped them in learning how to navigate and use the features of the virtual to their fullest. Whereas, in the VLIPLC group some students found it helpful, but they believed that it was a bit long, and one student expressed that a video tutorial would have been preferred. The students also made use of the informational icons and tooltips embedded in the VL interface, all of the students agreed that they were helpful in explaining what was occurring during the virtual lab and for providing information. Additionally, students accessed guidance through the hint system provided by the VL, while students in all groups recognized the value of receiving the hints; they had mixed experiences toward their usefulness. In the VLIP group, the student described that some hints were helpful and others were vague and confusing, the same was true of the VLIPLC group. Students also used the question feedback provided by the virtual lab. The VL group explained that the feedback allowed them to direct their own learning, measure their understanding of content, and explain their errors. The VLIP student appreciated the value of the provided guidance, but expressed a negative opinion of how the feedback was displayed as a series of tabs within the interface. Similarly, the students in the VLIPLC group expressed concerns about the question feedback, explaining it did not allow them to see which specific parts of a question they got incorrect; this led to confusion and frustration. These findings are in line with other studies that inform the design and delivery of guidance in virtual learning environments, which explain guidance can be useful if designed and implemented correctly (De Jong et al., 2014; Zacharia et al., 2015). However, if students perceive guidance features provided by VLs as confusing or unclear, it can lead to confusion negative attitudes, and disinterest in learning (Pedersen & Irby, 2014).

Conclusion

Summary of findings

In terms of instructor presence, none of the groups contacted the instructor or TA outside of class time to ask questions about their labs. Students in the PL group felt that they benefit from the affordance of instructor presence by receiving direct in person guidance and communication. Some of the students in the VL groups viewed the opportunity to access instructor presence when it was provided, as positive, however; they did not feel it was necessary to their learning.

Ultimately, students in all lab delivery modes expressed that their lab was beneficial to their learning. However, students in the PL group felt constrained by the lack of microscopes and the limited control they had over the repetition, pacing, time spent in their learning. In the VL groups, all of the students did express they felt in control of the pacing, repetition, time spent learning, and guidance provided by the lab interface. However, they did express confusion related to the hints, tutorials, and feedback provided within the system. Additionally, none of the students repeated the lab following their lab section. The findings of this study bring up further implications for research and practice.

Significance of the Study

Findings from this study inform science educators about students' experiences of using instructor presence which is afforded in physical labs and learner control which is afforded in virtual labs. Specifically, students in PL environments are positive about their experiences of communicating with an instructor to receive direct feedback and guidance about their lab based learning. However, when using VL environments students appreciate the presence of an instructor, but do not feel that it is absolutely necessary to their learning, due to embedded guidance offered by the VL interface. In PLs students often experience limited learner control of repetition, pacing, time spent learning, and access to available guidance. The lack of control can lead PL learners to experience negative feelings of anxiety and being rushed. Additionally, the lack of equipment and time constraints present in PLs often lead students to hurry through assignments and do what they need to do to get a satisfactory grade. Whereas, VLs allow students greater agency over their own learning, as they are able to control the repetition, pacing, time spent learning, and access available guidance within these labs. Students are positive about the affordances offered by VLs, even when they present minor confusion, and see VLs as a valuable and useful learning tool. This study sought to contribute to the academic body of knowledge about virtual biology labs, their use in college courses, and how students feel about using these learning tools. A second goal of this study is to inform the practice of instructional design and use of virtual labs as a viable science learning resource, especially in college and online course environments. When using VLs, learners are cognizant of the layout and design features within these environments. New generations of students are entering colleges with increased proficiency in using software and technology, they expect virtual learning environments that operate smoothly and provide concise, clear, and easy to use instructional content. Surprisingly, they are tolerant of minor glitches and issues within VLs; however, when too many are present, it creates frustration and negative experiences, potentially lessening their efficacy as a learning tool. As such, the findings of this study inform the fields of education and instructional design by presenting instructional designers, educators, researchers, and curriculum designers with further suggestion of how to improve VLs to promote positive student learning and experiences. Additional potential positive implications of this study include broadening the laboratory component of science education options for college students. Virtual biology labs have the potential to help online learners, non-science majors students, students with disabilities, and other students who may not have the scientific background, time, or resources to complete a physically based lab.

Limitations and Delimitations

This study was limited by small focus group sample sizes due to the fact there was only one non-majors biology course offered at the university during the fall 2016 semester. Originally 63 students consented to participate in the focus groups; however data was only collected from 15 students. Additionally, there were low focus group participation numbers, so much so that the VLIP focus group had only one participant and resulted in an interview. Time was an additional constraint of the study; the lecture and physical and virtual laboratories delivered were a part of course instruction and had to follow the scope and sequencing identified within the course syllabus. Many of the participants who initially consented to the focus groups did not show up due to schedule conflicts. Future studies with less rigid scheduling structure and greater allotment of time would be able to explore the effects of extended learner control afforded by VLs over a greater period of time.

An additional limitation of the study was the short duration of each of the four biology delivery mode treatments; each treatment lasted for only 50 minutes. To provide more insight into students' experiences in the four distinct modes of laboratory delivery, future studies might be designed to explore the impact of the delivery modes over an entire course.

Implications for Further Research

This study served to further inform how physical and virtual laboratory delivery modes compare in the subject of biology; further studies are needed in the subject of biology, especially at the college level (Flowers, 2011; Ma & Nickerson, 2006).

Additionally, further studies are needed to specifically determine how the affordance of instructor presence (Humphries, 2007; Richardson et al., 2015; Robinson, 2012; Stang & Roll, 2014) impacts students' learning experiences. Insight is needed into specific types of instructor presence, including the levels of guidance provided by VLs (Ahmed & Hasegawa, 2014; Chen et al., 2016; Pedersen & Irby, 2014; Smith, 2015; Zacharia et al., 2015) to promote positive student learning experiences in STEM subjects. There is also a need to determine how instructor presence affects student learning experiences in online and VL environments; specifically, in regard to instructor-student communication (Humphries, 2007; Richardson et al., 2015). The affordance of learner control's influence on student learning experiences in PL and VL also requires further research (Lee et al., 2010; NRC, 2006; Puttick et al., 2015). Additionally, to provide proper levels of guidance in PL and VL and to ensure students make use of provided guidance, further research is needed into the specific presentation and types of guidance which promote learning and academic achievement (Yaman, Nerdel, & Bayrhuber, 2008; Zacharia et al., 2015) and the impact of such guidance on students' learning experiences. Continued studies on students' experiences of repetition, pacing, time spent, and access available guidance in PLs and VLs serves to inform educators, instructional designers, curriculum publishers, and institutions of higher learning in how they can more effectively design and implement virtual laboratories to maximize efficient use of learner control.

As stated in previous research, a constraint of many studies exploring virtual laboratory environments is that they are confined by small sample sizes. Studies on delivery involving larger sample sizes would be of benefit to the field of research (Ma & Nickerson, 2006). Finally, this study revealed that students did not take advantage of the provided affordances of instructor presence and learner control outside of laboratory sections, further study is needed to explore how educators, curriculum publishers, and research institutions can encourage students to use affordances provided by physical and virtual laboratories to assist in their learning (Dede, 2009; De Jong et al., 2013).

A longer duration of treatment is warranted to gain better insight into how students describe their experiences using the four different modes of biology lab delivery and the affordances of instructor presence and learner control. As previously mentioned the duration of each of the four laboratory treatments was only 50 minutes, due to time constraints and the necessity to keep with the established schedule on the course syllabus. Future studies might be designed to explore students' experiences of the laboratory delivery modes over an entire semester of a course.

Additionally, this study focused specifically on a sample of non-major biology students. Previous studies on virtual laboratory delivery modes have been similarly confined to using non-major or introductory classes in order to gain large sample sizes (Brinson, 2015; Ma & Nickerson, 2006) or because of resistance from college faculty and staff to alter the traditional laboratory format of majors science courses (Crippen et al., 2013; Hallyburton & Lunsford, 2013; Zacharia, 2007). Future studies exploring students' experiences in the modes of lab delivery and how they use provided affordances are of particular interest (NRC, 2006; (Humphries, 2007; Lee et al., 2010; Richardson et al., 2015), specifically those which simultaneously measure and compare laboratory delivery mode experiences in both majors and non-majors biology courses.

This study did not assign grades for students' use of the affordances of instructor presence and learner control presented by the laboratory delivery modes, additionally; use of the affordances outside of the scheduled laboratory sections was non-existent. Further study is needed to investigate students' experiences using the affordances of instructor presence and learner control offered by the laboratory delivery modes. To accomplish this goal, it is recommended that future studies integrate instructor presence and learner control as part of an actual graded assignment. Incorporating study designs where students must actively communicate with the instructor about laboratory content either in-person or online; or log back in to repeat and review a virtual lab may increase students' use of these affordances and provide better measurable outcomes.

Implications for Practice

An interesting question pertaining to educational practice is raised by this study, "How can instructors further encourage students to take advantage of the affordances of instructor presence and learner control?" While this question has been examined in depth in physical learning environments, there is a need for further study in online virtual lab environments (Campen, 2013; Flowers, 2011; Reese, 2013; Stuckey-Mickell & Stuckey-Danner, 2007) to establish their effectiveness as a learning tool and to inform potential adopters, instructional designers, and curriculum or academic researchers. The provision of instructor presence (Dixson, 2010) and learner control (Brown, Howardson, & Fisher, 2016; Lee et al., 2010) has been shown to promote positive learning experiences and achievement when used; however, there is a need for further practice to actively ensure that students are taking advantage of the benefits.

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CHAPTER V: SUMMARY AND CONCLUSION

To insure that students in science, technology, engineering, and mathematics (STEM) courses are receiving the maximum benefit from laboratory investigations, it is necessary for instructional designers, curriculum developers, and educators to consider the affordances of instructor presence and learner control offered within physical lab (PL) and virtual lab (VL) environments.

Three manuscripts comprising a mixed methods research approach were presented in this dissertation. First, a systematic literature review of instructor presence and learner control in PL and VL environments in STEM classes, second, a quantitative quasi-experimental study of the effects of mode of lab delivery on learning biology concepts in a sample of non-majors college undergraduate students, and third, a qualitative quasi-experimental study of students' learning experiences using the affordances of instructor presence and learner control in PL and VL environments.

Summary of the Results

Chapter II

Chapter II presented a systematic literature review of the studies conducted to: test the comparative effects of physical and virtual labs, measure the impact of the affordances of instructor presence and learner control on students' achievement in PL and VL delivery modes, and explore students' learning experiences using the affordances of instructor presence and learner control.

The findings on the comparative effects of PLs and VLs were mixed. In some cases the achievement in VLs was greater than that of PLs (Finkelstein et al., 2005; Gilman, 2006; Zacharia, 2007; Zacharia et al., 2008), alternately, there were some cases in which PLs actually produced greater achievement than VLs (Corter, Esche, Chassapis, Ma, & Nickerson, 2011; Dalgarno, Bishop, Adlong, & Bedgood, 2009), and others where learning was equivalent between both methods of laboratory delivery (Darrah, Humbert, Finstein, Simon, & Hopkins, 2014; Tatli & Ayas, 2013; Triona & Klahr, 2003; Zacharia & Olympiou, 2011). Additionally, students in PL were positive of their experiences due to the presence of an instructor (Bhargava et al., 2006; Gilman, 2006), whereas in VL students expressed positive views of the learner control offered to them through the VL (Bhargava et al., 2006; Lee et al., 2010; Malik, Martinez, Romero, Schubel, & Janowicz, 2014; Parker & Loudon, 2012). There is also a specific need for further study and research of students' learning experiences in PL and VL environments (Humphries, 2007; Lee et al., 2010; NRC, 2006; Puttick et al., 2015; Richardson et al., 2015).

Chapter III

Chapter III presented a quantitative study exploring the comparative effects of four distinct modes of biology lab delivery and how the affordances of instructor presence and learner control in each of the four modes impacts student learning outcomes. The four distinct modes compared were: a) a physical based lab with instructor presence (PL), b) a virtual lab with no instructor presence (VL), c) a virtual lab with instructor presence (VLIP), and d) a virtual lab with instructor presence and direction for learner control of pace and repetition beyond lab time (VLIPLC).

The findings were that students in each mode of delivery learned significantly, both immediately following treatment and a week later, the mode of lab delivery had no significant impact on student achievement. The scores four all four groups remained consistent between the post-test immediately following the labs and the post-test given one week later, this indicates that all students retained knowledge. Additionally, there were no significant differences in post-test scores across the four groups, suggesting that VLs can deliver biology content and produce learning outcomes equivalent to PLs. Finally, the study showed that students in the PL and VL groups did not take advantage of the affordance of instructor presence and learner control. Even under the specific recommendation of an instructor to do so following the class. Had students taken advantage of the affordances of instructor presence and learner control following their lab, achievement scores on the delayed one week post-test may have been higher. The study highlights the need for educators, instructional designers, and curriculum developers to further study ways to encourage students to take advantage of the affordances of instructor presence and learner control provided by PL and VL delivery modes.

Chapter IV

Chapter IV further elaborated on the results of the quantitative study through qualitative methods exploring students' experiences using the affordances of instructor presence and learner control in PL and VL environments. Data were collected through three focus groups and one interview where students expressed their opinions of learning using the labs, provided insight into their previous lab experiences, and offered suggestions for improving the labs.

The findings were that none of the groups employed the use of instructor presence outside of class time by contacting the instructor or TA outside to ask questions about their labs. Students in the PL group felt that they benefit from the affordance of instructor presence by receiving direct in person guidance and communication. Some of the students in the VL groups viewed the opportunity to access instructor presence when it was provided, as positive, however; they did not feel it was necessary to their learning.

The qualitative data revealed the main reasons students in the PL group did not pursue instructor communication following lab class is because they felt it was not relevant due to the rapid pacing of their semester labs. It is important that educators find new ways to encourage students in PLs to communicate following scheduled lab time, to help them increase their knowledge and achievement. Students in the VL groups expressed that they did not communicate with the instructor because they felt that received the support they needed from the guidance embedded in the VL interface. Students in online environments such as VLs will often rely solely on the guidance provided by the interface. It is imperative that instructional designers, educators, and curriculum developers continue to research and develop effective online guidance that supports student learning.

The students in the PL group also expressed that they felt constrained by the lack of microscopes and the limited control they had over the repetition, pacing, time spent in their learning. These findings support other literature by Chen, Chang, Lai, and Tsai (2014), Corter et al. (2007), and Smetana and Bell (2012) which show that students in PL environments often have very little control of their learning and face obstacles such as limited laboratory equipment and resources. Educators, curriculum developers, and learning institutions should explore new PL delivery methods to allow students greater control of their learning and to conserve resources. Possible suggestions to achieve this goal include: supplementing some PL activities with VLs (Bhargava et al., 2006), using VLs as a pre-lab activity to prepare students for PLs (Toth et al., 2009), or using VLs as a review tool following PLs (Zacharia et al., 2008).

In the VL groups, all of the students did express they felt in control of the pacing, repetition, time spent learning, and guidance provided by the lab interface. However, they also voiced their confusion related to the hints, tutorials, and feedback provided within the system. Additionally, the focus groups revealed that students in the VL groups did not take advantage of the affordance of repetition by logging back in following class time. Their reason for this was their concern in preparing for an upcoming biology test on unrelated content; which was for a course grade. They did not see the relevance of using the VL as a study tool for the test. However, they expressed they would use it as a review tool for a content related test. These findings indicate that it is necessary for instructional designers, curriculum developers, and educators to design and implement VLs that students can directly apply to their learning. It is also critical that instructors communicate the relevance of VLs to their courses and frequently remind students of the resource.

Ultimately, instructional designers and researchers need to further explore ways to promote and encourage students to use the affordance of instructor presence and learner control available in PL and VL environments.

Discussion of the Results

These results bring up several very interesting implications to the fields of instructional design, STEM education, and curriculum research. First, the equivalent performance between the PL group and the VL groups provides support to the research that VLs produce equal learning outcomes to PLs (Darrah et al., 2014; Tatli & Ayas, 2013; Triona & Klahr, 2003; Zacharia & Olympiou, 2011). This finding is even more intriguing in the fact than none of the students made use of the affordances of instructor presence or learner control outside of the scheduled lab section. This suggests that VLs can be a viable online learning tool even without the presence of an instructor to guide the laboratory activity and provide communication and feedback to students. Additionally, this indicates that VLs can successfully provide guidance through designed hints (Honey & Hilton, 2011; Zacharia et al., 2015), tool tips (Lancaster, 2013), and tutorials (Zacharia et al., 2015) embedded in the interface. During the laboratory section, students in the PL group interacted with equipment and followed procedures to closely examine cells in the different phases of mitosis and meiosis; VL students performed an equivalent task and exercised learner control through interaction with the animated cells in the VL. This suggests that VLs can deliver the same content and produce equal learning outcomes, even without the hands-on operation of PL equipment and materials, but they also save time (Bell, 1999; Parker & Loudon, 2012), resources (Brinson, 2015; Cooper et al., 2015; Hallyburton & Lunsford, 2013; Muhamad et al., 2012; Pyatt & Sims, 2012), space (Bhargava et al., 2006; Brinson, 2015), and money (Bhargava et al., 2006; Brinson, 2015; Ma & Nickerson, 2006; Muhamad et al., 2012).

Finally, additional implications relate to students' experiences using the PL and VL delivery modes and the affordances provided by each. The reasons provided by the students' for why they did not use the affordance of instructor presence outside of class time communicate a very powerful message about laboratory based instruction. Students in the PL group expressed that communication following labs was lacking in relevance due to the fast paced semester scheduling and the fact new content was covered every week. Whereas students in the VLs felt the VL provided them with enough information and guidance to direct their own learning and answer their questions. Despite the lack of instructor student communication outside of class time, PL students feel they benefit from instructor presence during the lab, and VL students saw the value of instructor presence as a good back up to their own directed learning. These findings suggest that educators and curriculum designers should pay special attention to facilitating communication during PLs, but should also seek new strategies for encouraging instructor student communication following labs. Additionally, instructional designers and curriculum publishers should take care to design and develop VLs with well constructed guidance, as many students learning online may solely rely on the guidance provided within VLs.

Students in PL environments often have less than ideal experiences controlling their learning during labs (Bhargava et al., 2006; Corter et al., 2007; Smetana & Bell, 2012), to promote positive achievement and learning experiences, educators and curriculum designers must find novel ways in which to incorporate learner control elements into PL activities. Similarly, instructional designers and curriculum publishers should continue to design and develop high quality interactive VLs which provide features that facilitate students' achievement and positive experiences of controlling their learning.

Finally, the finding that students in all laboratory delivery modes felt the lab contributed to their learning is a message of hope for educators and institutions of learning. The importance of a helpful instructor who is knowledgeable in their subject matter and delivers well designed instruction is vital to students' success in STEM subjects. As such, institutions of learning, curriculum publishers, educators, and instructional designers should all work in concert to promote quality STEM instruction, curriculum materials, and technologies which continue to facilitate positive student achievement and learning experiences, whatever the mode of lab delivery.

Theoretical Implications

The study additionally served to answer the need for further research posited by Ahmed and Hasegawa (2014) and provides theoretical insight into the design and implementation of PLs and VLs. The result of equivalent performance between the PL and VL delivery modes suggests that it is possible for students to successfully learn even without the physical presence of an instructor. A likely reason for this result is that VL environments with properly designed guidance in the form of hints (Honey & Hilton, 2011; Zacharia et al., 2015), tooltips (Lancaster, 2013), directions (Zacharia et al., 2015), and feedback (Parker & Loudon, 2012; Podolefsky, Moore, & Perkins, 2013) can effectively provide immediate and individualized support to online learners. However, when guidance is not clear, organized, or properly designed, it can be detrimental to student learning and lead to negative attitudes about the use of VLs (Pedersen & Irby, 2014; Stuckey-Mickell & Stuckey-Danner, 2007). These finding provide an interesting theoretical implication for instructional designers and digital curriculum developers, the guidance embedded in VLs must be clear, easy to use, and well designed. Research shows that students were able to interact and benefit from instructor guidance in an online environment (Johnson, 2002). This suggests the need for instructional designers and educators to rethink their conception and definition of instructor presence, VL environments can deliver presence (De Jong et al., 2013; Merrill, 1999; Podolefsky et al., 2013), and can produce equivalent learning outcomes to PLs (Darrah et al., 2014; Tatli & Ayas, 2013; Zacharia & Olympiou, 2011). The instructor-student interaction that occurred in the PL environment also brings implication for STEM education. In the study the students in the PL group did not initiate communication, but rather, waited for the TA's guidance. This finding highlights the necessity that educators in PL environments actively monitor students during laboratory investigations, check for understanding, and initiate communication as needed (NRC, 1996).

Research has shown that VLs can provide learner control (Hasler, Kersten, & Sweller, 2007; Zacharia et al., 2015). In the VL groups, students assumed responsibility for their own learning by controlling the repetition (Bhargava et al., 2006; Boggs, 2006; Lee et al., 2010), pacing (Thompson et al., 2010; Toth et al., 2009), and their time spent learning (Darrah et al., 2014; Parker & Loudon, 2012) during the course section. Students were positive about the affordance of learner control and enjoyed the cellular animations and interactive questions provided within the VL; this finding is similar to studies by Berney and Bétrancourt (2016) and

Gilman (2006) who describe the positive effects on animations on students' learning. However, none of the students practiced learner control through repeating the lab following class time. This finding is interesting in light of the fact that students automatically used the learner control features during class without the direction of an instructor. Instructional designers, curriculum developers, and educators should explore new ways to encourage students' use of the learner control offered by VLs, especially since learner control is linked to increased student achievement (Finkelstein et al., 2005; Swan & O' Donnell, 2009; Zacharia, 2007). Alternately, students in the PL group had the ability to control their learning through accessing available guidance from the instructor as necessary, however they only did so when the TA asked them questions and provided guidance to check for their understanding. This finding suggests that educators should actively support and encourage students' questing in PL environments as they may be hesitant to seek guidance own their own (NRC, 1996; NRC, 1997). Students in the VL groups expressed positive opinions of instructor guidance; but viewed it as more of a convenient supplement to their learning, and did not find it necessary. Instructional designers and educators should take into account the levels of guidance provided within VLs, yet clearly express the availability of the affordance to students. The provision of too much guidance, unclear guidance, and students' perception of limited guidance can negatively impact learning (Pedersen & Irby, 2014; Stuckey-Mickell & Stuckey-Danner, 2007). Still, further research is needed to explore students' experiences of accessing available guidance as needed in PLs and VLs (NRC, 2006; Humphries, 2007; Lee et al., 2010; Richardson et al., 2015). Finally, to inform the design and development of PLs and VLs, further studies exploring and encouraging students' use of learner control in these environments are necessary (Yaman, Nerdel, & Bayrhuber, 2008; Zacharia et al., 2015).

Implications for Future Research

The results of this study are in-line with many other studies which indicate that physical and virtual laboratory delivery modes produce similar or equivalent learning outcomes (Darrah et al., 2014; Tatli & Ayas, 2013; Triona & Klahr, 2003; Zacharia & Olympiou, 2011). This study served to further inform how physical and virtual laboratory delivery modes compare in the subject of biology, further studies are needed in the subject of biology, especially at the college level (Flowers, 2011; Ma & Nickerson, 2006). Additionally, further studies are needed to specifically determine how the affordance of instructor presence (Dixson, 2010; Richardson et al., 2015; Stuckey-Mickell & Stuckey-Danner, 2007; Watson, Watson, Richardson, & Loizzo, 2016) impacts students' achievement and learning experiences (Humphries, 2007; Richardson et al., 2015; Robinson, 2012; Stang & Roll, 2014). Insight is needed into specific types of instructor presence, including the levels of guidance provided by VLs to promote successful student learning and positive experiences in STEM subjects (Ahmed & Hasegawa, 2014; Chen et al., 2016; Pedersen & Irby, 2014; Smith, 2015; Zacharia et al., 2015). There is also a need to determine how instructor presence affects student learning in online and VL environments; specifically, how varying degrees of communication provided by instructors can facilitate increased learning of content knowledge (Flowers, 2011; Picciano, 2002; Stuckey-Mickell & Stuckey-Danner, 2007; Zacharia et al., 2015). Additionally, there is a need to explore instructor-student communication experiences (Humphries, 2007; Richardson et al., 2015). The affordance of learner control's influence on student achievement (Brown, Howardson, & Fisher, 2016; Chamberlain, Lancaster, Parson, & Perkins, 2014; Chang, Chen, Lin, & Sung, 2008; Zacharia et al., 2008) and learning experiences (Lee et al., 2010; NRC, 2006; Puttick et al., 2015) in PL and VL also requires further research. In the context of learner control, more research is needed into the effect that the affordance of repetition offered by VL environments has on student learning (Zacharia et al., 2015). Further research is needed to determine how the effect of students' time spent in PL and VL environments impacts achievement (Darrah et. al, 2014; Pedersen & Irby, 2014). Additionally, to provide proper levels of guidance in PL and VL and to ensure students make use of provided guidance, further research is needed into the specific presentation and types of guidance which promote learning and academic achievement (Yaman et al., 2008; Zacharia et al., 2015) and the impact of such guidance on students' learning experiences. Continued studies on how students use and describe their experiences of repetition, pacing, time spent, and accessing available guidance in PLs and VLs serves to inform educators, instructional designers, curriculum publishers, and institutions of higher learning in how they can more effectively design and implement virtual laboratories to maximize efficient use of learner control.

As stated in previous research, a constraint of many studies exploring virtual laboratory environments is that they are confined by small sample sizes. Studies on delivery involving larger sample sizes would be of benefit to the field of research (Ma & Nickerson, 2006). Finally, this study revealed that students did not take advantage of the provided affordances of instructor presence and learner control outside of laboratory sections, further study is needed to explore how educators, curriculum publishers, and research institutions can encourage students to use affordances provided by physical and virtual laboratories to assist in their learning (Dede, 2009; De Jong et al., 2013).

A longer duration of treatment is warranted to gain better insight into the impact that the four different modes of biology lab delivery and the affordances of instructor presence and learner control have on student achievement and their learning experiences. As previously mentioned the duration of each of the four laboratory treatments was only 50 minutes, due to time constraints and the necessity to keep with the established schedule on the course syllabus. Future studies might be designed to test the cumulative difference of the laboratory delivery modes and explore students' experiences over an entire semester of a course.

Additionally, this study focused specifically on a sample of non-major biology students. Previous studies on virtual laboratory delivery modes have been similarly confined to using non-major or introductory classes in order to gain large sample sizes (Brinson 2015; Ma & Nickerson, 2006) or because of resistance from college faculty and staff to alter the traditional laboratory format of majors science courses (Crippen, Archambault, & Kern, 2013; Hallyburton & Lunsford, 2013; Zacharia, 2007). Future studies exploring how the modes of lab delivery and their affordances impact student achievement in majors biology courses are of particular interest (Hallyburton & Lunsford, 2013), specifically those which simultaneously measure and compare the effects of laboratory delivery modes in both majors and non-majors biology courses. Future studies exploring students' experiences in the modes of lab delivery and how they use provided affordances are needed (NRC, 2006; Humphries, 2007; Lee et al., 2010; Richardson et al., 2015), specifically those which simultaneously measure and compare laboratory delivery mode experiences in both majors and non-majors biology courses.

This study did not assign grades for students' use of the affordances of instructor presence and learner control presented by the laboratory delivery modes, additionally; use of the affordances outside of the scheduled laboratory sections was non-existent. Further study is needed to investigate how students use the affordances of instructor presence and learner control offered by the laboratory delivery modes and their impact on achievement. Also, studies are needed to investigate students' experiences using the affordances of instructor presence and learner control offered by the laboratory delivery modes. To accomplish these research goals, it is recommended that future studies integrate instructor presence and learner control as part of an actual graded assignment. Incorporating study designs where students must actively communicate with the instructor about laboratory content either in-person or online; or log back in to repeat and review a virtual lab may increase students' use of these affordances and provide better measurable outcomes.

Limitations and Delimitations

The study was limited by small sample sizes due to the fact there was only one non-majors biology course offered at the university during the fall 2016 semester. While overall participation in the quantitative portion was high, with (n=92) out of (N=98) students completing the study, participants were dropped due to absence during the lecture or laboratory treatments. For the qualitative phase, 63 students initially consented to participate in the focus groups; however data was only collected from 15 students. The focus group participation numbers were so low that the VLIP focus group had only one participant and resulted in an interview.

Time was an additional constraint of the study; the lecture and physical and virtual laboratories delivered were a part of course instruction and had to follow the scope and sequencing identified within the course syllabus. As a result, student delayed learning outcomes were measured after only a one week delay. Additionally, many of the participants who initially consented to the focus groups did not show up due to schedule conflicts. Future studies with less rigid scheduling structure and greater allotment of time would be able to measure the delayed effects of mode of laboratory delivery and students' experiences of instructor presence and learner control over a greater period of time.

An additional limitation of the study was the short duration of each of the four biology delivery mode treatments; each treatment lasted for only 50 minutes. To provide a more thorough measurement of the effects of the four different modes of biology on student achievement and students' learning experiences, future studies might be designed to test the cumulative differences and explore the impact of the delivery modes over an entire course.

Implications for Practice

An interesting question pertaining to educational practice is raised by this study, "How can instructors further encourage students to take advantage of the affordances of instructor presence and learner control?" While this question has been examined in depth in physical learning environments, there is a need for further study in online virtual lab environments (Campen, 2013; Flowers, 2011; Reese, 2013; Stuckey-Mickell & Stuckey-Danner, 2007) to establish their effectiveness as a learning tool and to inform potential adopters, instructional designers, and curriculum or academic researchers. The provision of instructor presence (Dixson, 2010) and learner control (Lee et al., 2010; Brown et al., 2016) has been shown to promote achievement when used; however, there is a need for further practice to actively ensure that students are taking advantage of the benefits.

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APPENDIX A
STUDENT DEMOGRAPHIC SURVEY

Pre-Study Demographic Survey

Directions: Please complete all of the questions on this brief demographic survey prior to beginning your pre-test. Your provided information will remain confidential and will be reported anonymously in the final research publication to describe the population of study participants.

1. Circle the **LETTER** that describes your age range.
   A. 18-24 years
   B. 25-34 years
   C. 35-44 years
   D. 45-54 years
   E. 55-64 years
   F. Age 65 or older

2. Circle the **LETTER** that best describes the gender with which you identify.
   A. Male
   B. Female
   C. Other:___________________________________(fill in the blank)

3. Circle the **LETTER** that describes your racial and ethnic background.
   A. African-American
   B. Asian
   C. Caucasian/White
   D. Hispanic/Latino
   E. Middle Eastern
   F. Native American
   G. Pacific Islander
   H. More than one race
   I. Other:__________________________(fill in the blank)

4. Circle the **LETTER** that describes your college grade level.
   A. Freshman
   B. Sophomore
   C. Junior
   D. Senior
   E. Graduate Student
   F. Professional Student
   G. Continuing education student
   H. High School (Earning college credit)

5. Circle the **LETTER** that describes your major.
    A. Business
    B. Computer Science
    C. Education
    D. Engineering
    E. GIS / Geological Sciences
    F. Liberal Arts
    G. Life Sciences (Non-Biology Major)
    H. Nursing / Health Sciences
    I. Physical Sciences
    J. Undecided
    K. Other:___________________________(fill in the blank)

APPENDIX B
PRE-TEST AND POST-TEST INSTRUMENTS

Mitosis and Meiosis Test
Form A

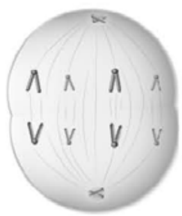
Student Name: ________________________

1. Select the function of the centromere in the transmission of genetic information

A. The formation of the mitotic spindle
B. The replication of chromosomes
C. The production of ribosomal subunits
D. The attachment point for the mitotic spindle
E. The production of energy to drive cell division

2. Which phase of mitosis is shown in the image on the right?

A. Metaphase
B. Anaphase
C. Telophase and cytokinesis
D. Prophase



3. Which of the following are products of cell division by mitosis?

A. Cells that have different forms of the same gene
B. Four genetically similar daughter cells
C. Two daughter cells with identical chromosomes
D. Daughter cells with half the number of chromosomes

4. Select the choice that correctly fills in the blanks to complete the order of the cell cycle stages, from earliest to latest**:** Interphase, _________, _________, metaphase, _________, telophase, cytokinesis

A. Prophase, prometaphase, anaphase

B. Prometaphase, prophase, anaphase

C. Anaphase, prophase, prometaphase

D. Prophase, anaphase, prometaphase

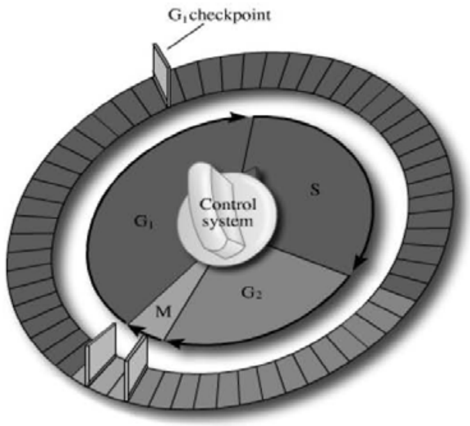
5. Human non-reproductive cells contain 46 total chromosomes. How many chromosomes would a human egg cell contain?

A. 92 total
B. 46 pairs
C. 46 total
D. 23 pairs
E. 23 total

6. Which phrase best describes chromatin?

A. Single-stranded DNA that cannot undergo replication
B. The region of DNA that joins chromatids together
C. A fiber composed of DNA and protein molecules
D. DNA in its duplicated, tightly condensed form

7. Which cellular event takes place at the cell cycle checkpoint identified in the image below?



A. The cell determines whether resources are sufficient to proceed with the cell cycle

B. All chromatids are checked for proper attachment to spindle fibers

C. Proper replication of all chromosomes is verified

8. When does a cell use apoptosis?

A. If a cell is damaged or no longer needed, apoptosis may be initiated.

B. After a cell has become cancerous, it will rapidly begin the process of apoptosis.

C. When new cells are needed for growth or repair, apoptosis produces the cells.

D. Antibodies produced by the immune system use apoptosis to destroy foreign organisms.

9. The _____________ phase of mitosis is shown in the image on the right.

A. Telophase and cytokinesis
B. Prophase
C. Anaphase
D. Metaphase

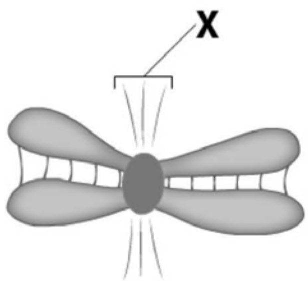
10. What is the term used to describe the area where two sister chromatids are linked?

A. Chromatin
B. Centromere
C. Centrosome
D. Centriole

11. The mitotic spindle serves which of the following functions?

A. Keeping sister chromatids connected
B. Pinching a cell into two daughter cells
C. Condensing chromosomes
D. Separating sister chromatids

12. Which chromosomal part involved in mitosis is represented by the 'x' in the diagram below?



A. Centromere
B. Spindle fibers
C. Cohesin
D. Sister chromatids

13. Select the function of the centrioles in the transmission of genetic information.

A. Swelling of the cell in preparation for division
B. Production of ribosomal subunits
C. Assisting in chromosomal movement
D. Replication of chromosomes

14. Which phase of mitosis is shown in the image on the right?

A. Metaphase
B. Anaphase
C. Telophase and cytokinesis
D. Prophase

15. Select the function of the mitochondria in the transmission of genetic information.

A. The production of energy to drive cell division
B. The production of ribosomal subunits
C. The duplication of DNA
D. The formation of the mitotic spindle

16. An organism has 24 chromosomes in its diploid non-sex cells. How many chromosomes are in its gametes?

A. 48
B. 24
C. 6
D. 12

17. Which of the following best describes the function of chromosomes?

A. Allow genes from both parents to combine during fertilization

B. Provide genetic variation that is acted upon by natural selection

C. Enable more efficient packing and transport of genetic material in mitosis

D. Form hydrogen bonds with other chromosomes that make up DNA

18. Select the definition of a sister chromatid.

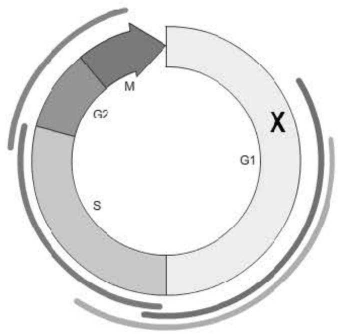
A. The second, noncoding strand of double-stranded DNA

B. One copy of a duplicated chromosome

C. mRNA that is being copied and still in complex with DNA

D. The second copy of a homologous chromosome

19. Which cell cycle process occurs at the position indicated by the 'x' in the diagram below?



A. Cell prepares to replicate DNA
B. Mitosis occurs
C. Sister chromatids are present
D. DNA is synthesized

20. The image on the right shows which phase of mitosis?

A. Prophase
B. Metaphase
C. Anaphase
D. Telophase and cytokinesis

21. What is apoptosis?

A. A process used by cancer cells to migrate through the body
B. A means of initiating DNA replication during growth
C. A means of removing unneeded proteins from a cell
D. A process in which cells direct their own destruction

22. Which phrase best describes homologous chromosomes?

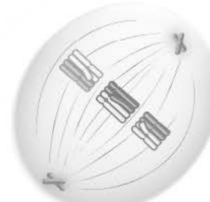
A. Any two chromosomes that enter the same gamete after the final meiotic division
B. A pair of identical chromosome copies that result after duplication during meiosis
C. A maternal and paternal chromosome that have the same genes
D. A pair of X and Y chromosomes that determine male gender when inherited

23. The _____________ phase of meiosis I is shown in the image on the right.

A. Metaphase I
B. Telophase I
C. Anaphase I
D. Prophase I

24. The image on the right shows which phase of meiosis I?

A. Telophase I
B. Anaphase I
C. Prophase I
D. Metaphase I



25. Which phase of meiosis I is shown in the image on the right?

A. Anaphase I
B. Metaphase I
C. Prophase I
D. Telophase I

26. The ____________ phase of meiosis II is shown in the image on the right.

A. Anaphase II
B. Prophase II
C. Metaphase II
D. Telophase II and cytokinesis

27. Identify the phase of meiosis II demonstrated in the image.

A. Telophase II and cytokinesis
B. Anaphase II
C. Prophase II
D. Metaphase II

28. Identify the phase of meiosis II demonstrated in the image.

A. Telophase II and cytokinesis
B. Prophase II
C. Anaphase II
D. Metaphase II

29. The ____________ phase of meiosis I is shown in the image on the right

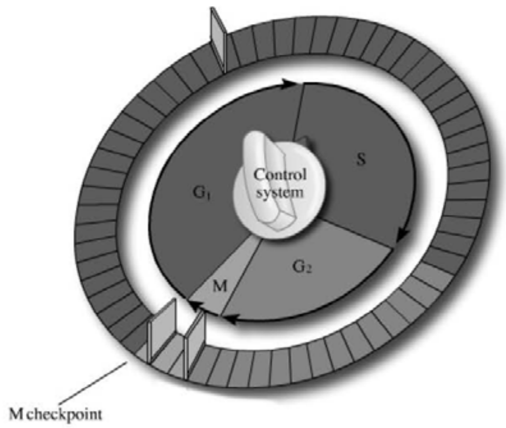
A. Anaphase I
B. Prophase I
C. Metaphase I
D. Telophase I

30. Which phase of meiosis II is shown in the image on the right?

A. Prophase II
B. Metaphase II
C. Telophase II and cytokinesis
D. Anaphase II

Student Name: ________________________

1. Which cellular event takes place at the cell cycle checkpoint identified in the image below?



A. The cell determines whether resources are sufficient to proceed with the cell cycle

B. All chromatids are checked for proper attachment to spindle fibers

C. Proper replication of all chromosomes is verified

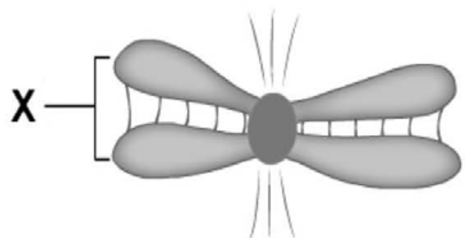
2. A sister chromatid is______________?

A. The second copy of a homologous chromosome
B. RNA that is copied directly from the original DNA template
C. One copy of a duplicated chromosome
D. The second, noncoding strand of double-stranded DNA

3. The _____________ phase of mitosis is shown in the image on the right.

A. Anaphase
B. Prophase
C. Telophase and cytokinesis
D. Metaphase

4. Which chromosomal part involved in mitosis is represented by the 'x' in the diagram below?



A. Sister chromatids
B. Centromere
C. Cohesin
D. Spindle fibers

5. What is the role of the mitochondria in cell division?

A. The production of ribosomal subunits
B. The formation of the mitotic spindle
C. The production of ATP to fuel cell growth
D. The replication of chromosomes

6. Which is an example of the process of cell apoptosis?

A. After a cell has become cancerous, it will rapidly begin the process of apoptosis.
B. If a cell is damaged or no longer needed, apoptosis may be initiated.
C. Antibodies produced by the immune system use apoptosis to destroy foreign organisms.
D. When new cells are needed for growth or repair, apoptosis produces the cells.

7. What is the function of the mitotic spindle?

A. Keeping sister chromatids connected
B. Pinching a cell into two daughter cells
C. Separating sister chromatids
D. Replicating chromosomes

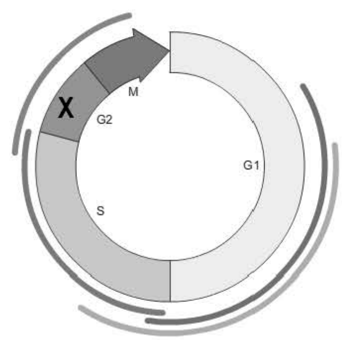
8. What is the role of the centrioles in cell division?

A. Formation of the mitotic spindle
B. Production of energy to drive cell division
C. Replication of chromosomes
D. Production of ribosomal subunits

9. Apoptosis is defined as______________?

A. A process used by cancer cells to migrate through the body
B. A process in which cells direct their own destruction
C. A means of stimulating rapid cell division during growth
D. A means of removing unneeded proteins from a cell

10. Which cell cycle process occurs at the position indicated by the 'x' in the diagram below?



A. Cell prepares to replicate DNA

B. Mitosis occurs

C. DNA is synthesized

D. Sister chromatids are present

11. Cell division through mitosis results in which of the following?

A. Two daughter cells with identical chromosomes
B. Cells that have different forms of the same gene
C. Daughter cells with half the number of chromosomes
D. Four genetically similar daughter cells

12. Select the choice that correctly fills in the blanks to complete the order of the cell cycle stages, from earliest to latest:

___________, prophase, prometaphase, _____________, anaphase, telophase, ___________.

A. Interphase, cytokinesis, metaphase
B. Metaphase, interphase, cytokinesis
C. Cytokinesis, metaphase, interphase
D. Interphase, metaphase, cytokinesis

13. Homologous chromosomes are defined as______________?

A. A maternal and paternal chromosome that have the same genes
B. Any two chromosomes that enter the same gamete after the final meiotic division
C. A paternal Y and a maternal X chromosome present together in males
D. A pair of identical chromosome copies that result after duplication during meiosis

14. Chromatin is defined as______________?

A. DNA in its duplicated, tightly condensed form
B. The region of DNA that joins chromatids together
C. Single-stranded DNA that cannot undergo replication
D. A fiber composed of DNA and protein molecules

15. The_________ is the area where two sister chromatids are linked.

A. Centrosome
B. Centriole
C. Chromatin
D. Centromere

16. An organism has 48 chromosomes in its diploid non-sex cells. How many chromosomes are in its gametes?

A. 48
B. 12
C. 24
D. 96

17. What is the role of the centromere in cell division?

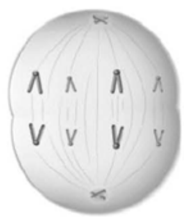
A. The swelling of the cell in preparation for division
B. The production of ribosomal subunits
C. The attachment point for the mitotic spindle
D. The replication of chromosomes
E. The formation of the mitotic spindle

18. The image on the right shows which phase of mitosis?

A. Metaphase
B. Prophase
C. Telophase and cytokinesis
D. Anaphase

19. The__________ phase of mitosis is shown in the image on the right.

A. Anaphase
B. Metaphase
C. Prophase
D. Telophase



20. The _____________ phase of mitosis is shown in the image on the right.

A. Telophase and cytokinesis
B. Anaphase
C. prophase
D. Metaphase

21. Dog non-reproductive cells contain 78 total chromosomes. How many chromosomes would a dog sperm cell contain?

A. 39 total
B. 78 total
C. 39 pairs
D. 78 pairs
E. 156 total

22. Chromosomes serve which of the following functions?

A. Allow genes from both parents to combine during fertilization
B. Compact DNA, facilitating proper distribution during cell division
C. Hold the strands of the DNA double helix together
D. Provide genetic variation that is acted upon by natural selection

23. Which phase of meiosis I is shown in the image on the right?

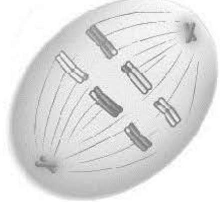
A. Metaphase I
B. Telophase I
C. Anaphase I
D. Prophase I

24. The _____________ phase of meiosis I is shown in the image on the right.

A. Telophase I
B. Metaphase I
C. Anaphase I
D. Prophase I

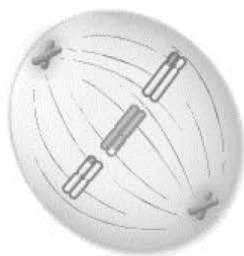
25. The image on the right shows which phase of meiosis I?

A. Metaphase I
B. Telophase I
C. Prophase I
D. Anaphase I



26. Identify the phase of meiosis II demonstrated in the image.

A. Metaphase II
B. Anaphase II
C. Prophase II
D. Telophase II and cytokinesis



27. The _____________ phase of meiosis II is shown in the image on the right.

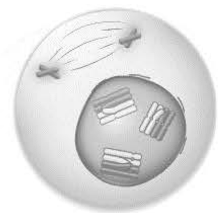
A. Anaphase II
B. Metaphase II
C. Prophase II
D. Telophase II and cytokinesis

28. Which phase of meiosis II is shown in the image on the right?

A. Anaphase II
B. Telophase II and cytokinesis
C. Metaphase II
D. Prophase II

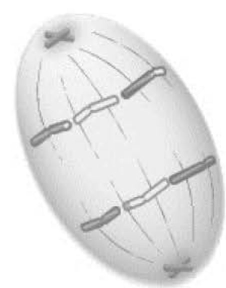
29. Which phase of meiosis I is shown in the image on the right?

A. Metaphase I
B. Prophase I
C. Telophase I
D. Anaphase I



30. The _____________ phase of meiosis II is shown in the image on the right.

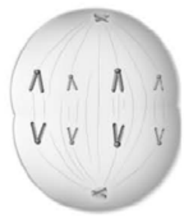
A. Metaphase II
B. Prophase II
C. Anaphase II
D. Telophase II and cytokinesis



Mitosis and Meiosis Test
Form C

Student Name: ________________________

1. Identify the phase of mitosis shown in the image on the right.



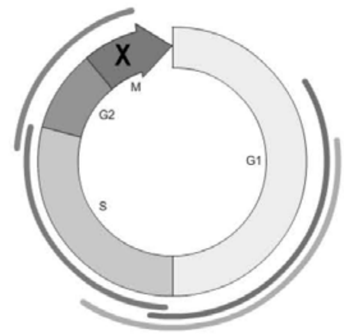
A. Prophase
B. Telophase and cytokinesis
C. Metaphase
D. Anaphase

2. Select the choice that correctly fills in the blanks to complete the order of the cell cycle stages, from earliest to latest:

Interphase, __________, prometaphase, _____________, anaphase, ___________, cytokinesis.

A. Metaphase, prophase, telophase
B. Prophase, metaphase, telophase
C. Telophase, prophase, metaphase
D. Prophase, telophase, metaphase

3. Which cell cycle process occurs at the position indicated by the 'x' in the diagram below?



A. Sister chromatids are present
B. Cell prepares to replicate DNA
C. Mitosis occurs
D. DNA is synthesized

4. Which phase of mitosis is shown in the image on the right?

A. Prophase
B. Telophase and cytokinesis
C. Metaphase
D. Anaphase

5. The mitotic spindle assists cell division by _____________.

A. Separating sister chromatids
B. Keeping sister chromatids connected
C. Pinching a cell into two daughter cells
D. Replicating chromosomes

6. Which of the following best describes apoptosis?

A. A means of removing unneeded proteins from a cell

B. A means of stimulating rapid cell division during growth

C. A process in which cells direct their own destruction

D. A process used by cancer cells to migrate through the body

7. If a Bottle-nosed dolphin's non-reproductive cells each contained 44 total chromosomes, how many chromosomes would each of the dolphin's sperm cells contain?

A. 88 total
B. 22 total
C. 44 total
D. 22 pairs
E. 44 pairs

8. The image on the right shows which phase of mitosis?

A. Prophase
B. Telophase and cytokinesis
C. Metaphase
D. Anaphase

9. Which choice is a description of how a cell would use apoptosis?

A. When new cells are needed for growth or repair, apoptosis produces the cells.

B. Antibodies produced by the immune system use apoptosis to destroy foreign organisms.

C. If a cell is damaged or no longer needed, apoptosis may be initiated.

D. After a cell has become cancerous, it will rapidly begin the process of apoptosis.

10. The function of chromosomes is to ________________________?

A. Allow genes from both parents to combine during fertilization

B. Hold the strands of the DNA double helix together

C. Provide genetic variation that is acted upon by natural selection

D. Enable more efficient packing and transport of genetic material in mitosis

11. _____________ is the definition that best describes homologous chromosomes.

A. Any two chromosomes that enter the same gamete after the final meiotic division

B. A pair of X and Y chromosomes that determine male gender when inherited

C. Two copies of the same chromosome that result after replication during meiosis

D. A maternal and paternal chromosome that have the same genes

12. How does the centromere assist the process of cell division?

A. Serves as the attachment point for sister chromatids
B. Forms the mitotic spindle
C. Assembles 50S and 30S ribosomal subunits
D. Duplicates DNA
E. Produces energy to drive cell division

13. An organism has 44 chromosomes in its diploid non-sex cells. How many chromosomes are in its gametes?

A. 22
B. 88
C. 44
D. 11

14. Which phase of mitosis is shown in the image on the right?

A. Anaphase
B. Metaphase
C. Telophase and cytokinesis
D. Prophase

15. ______________ is the definition that best describes chromatin

A. A fiber composed of DNA and protein molecules
B. Uncoiled, single-stranded DNA before replication
C. DNA in its duplicated, tightly condensed form
D. A constricted area of the condensed form of DNA

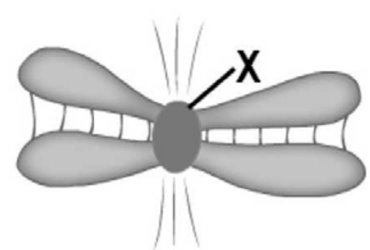
16. How do the mitochondria assist the process of cell division?

A. The formation of the mitotic spindle
B. The production of ATP to fuel cell growth
C. The synthesis of ribosomal RNA
D. The duplication of DNA

17. _______________ occur after cellular division by mitosis

A. Four genetically similar daughter cells
B. Two daughter cells with identical chromosomes
C. Daughter cells with half the number of chromosomes
D. Cells that have different forms of the same gene

18. Which chromosomal part involved in mitosis is represented by the 'x' in the diagram below?



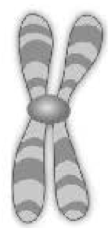
A. Spindle fibers
B. Sister chromatids
C. Centromere
D. Cohesin

19. Which phrase describes a sister chromatid?

A. The second, noncoding strand of double-stranded DNA
B. The second copy of a homologous chromosome
C. RNA that is copied directly from the original DNA template
D. The exact copy of a single chromosome

20. The area where two sister chromatids are linked is known as?

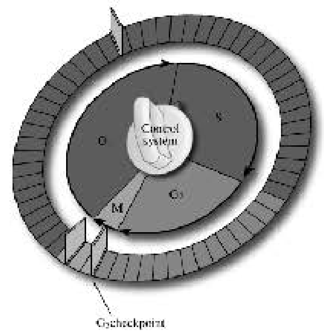
A. Centromere
B. Centrosome
C. Centriole
D. Chromatin



21. How do the centrioles assist the process of cell division?

A. Replication of chromosomes
B. Swelling of the cell in preparation for division
C. Production of ribosomal subunits
D. Formation of the mitotic spindle

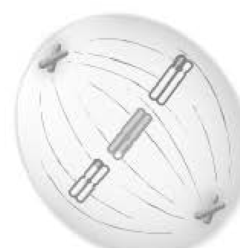
22. Which cellular event takes place at the cell cycle checkpoint identified in the image below?



A. All chromatids are checked for proper attachment to spindle fibers
B. The cell determines whether resources are sufficient to proceed with the cell cycle
C. Proper replication of all chromosomes is verified

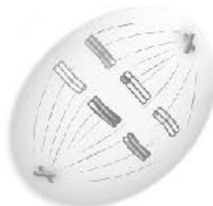
23. Which phase of meiosis II is shown in the image on the right?

A. Prophase II
B. Anaphase II
C. Telophase II and cytokinesis
D. Metaphase II



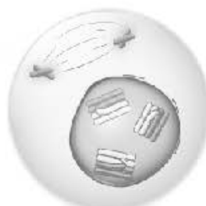
24. Which phase of meiosis I is shown in the image on the right?

A. Telophase I
B. Anaphase I
C. Metaphase I
D. Prophase I



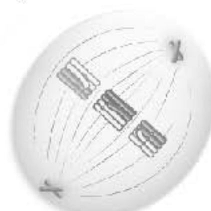
25. The image on the right shows which phase of meiosis I?

A. Prophase I
B. Anaphase I
C. Telophase I
D. Metaphase I



26. The _____________ phase of meiosis I is shown in the image on the right.

A. Anaphase I
B. Metaphase I
C. Telophase I
D. Prophase I



27. The image on the right shows which phase of meiosis II?

A. Anaphase II
B. Metaphase II
C. Prophase II
D. Telophase II and cytokinesis

28. Identify the phase of meiosis II demonstrated in the image.

A. Telophase II and cytokinesis
B. Anaphase II
C. Metaphase II
D. Prophase II

29. The image on the right shows which phase of meiosis I?

A. Prophase I
B. Anaphase I
C. Telophase I
D. Metaphase I

30. Which phase of meiosis II is shown in the image on the right?

A. Prophase II
B. Metaphase II
C. Telophase II and cytokinesis
D. Anaphase II

APPENDIX C

INSTRUCTOR CONTACT AND AFFORDANCES SHEETS

BIOL 1308.003 R 12:00pm-2:00pm

In-Person Mitosis and Meiosis Lab Affordances & Instructor Contact Sheet

Today, you will be completing the scheduled lab from Chapter 6 of your course lab manual, *Exploring Biology in the Laboratory*. The readings and lab activities in Chapter 6 are meant to reinforce and provide 'real-world' examples of “Mitosis and Meiosis". Additionally, today's lab activity serves to reinforce what you have learned through your course text book readings and lecture.

Affordances of completing a 'Hands On' physical based lab

Instructor Presence

By completing the physical in-person lab in the laboratory today, you will have an instructor present to help guide you by giving directions on laboratory procedures, answering questions on lab content, and providing assistance in using lab equipment. You are able to ask the instructor questions and receive answers and help during lab time.

Hands-On Learning Experience

By completing the physical in-person lab in the laboratory today, you will get a 'real world' example of how to use lab equipment such as microscopes and slides to view real-life examples of cells during Mitosis and Meiosis. You will also have the chance to go through the actual physical steps of how scientists and students work in the science lab environment.

Instructor Contact

Terri Nicolau

In Person: EN 310B during office hours or by appointment
e-mail: Terri.Nicolau@tamucc.edu
Blackboard: Using your course blackboard

Jaime McQueen
e-mail: jmcqueen@islander.tamucc.edu
phone:361-236-9159

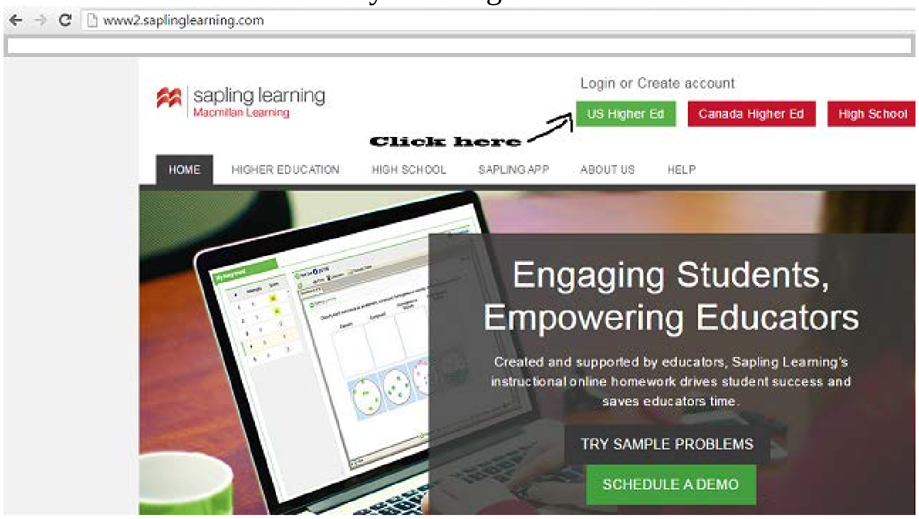
Lindsay Ramirez
In person: During standard lab hours

VL-Sapling Learning Login Instructions

An interactive virtual lab on "Mitosis and Meiosis" and a short set of related questions have been provided to students by *Sapling Learning*. These resources will help you to learn the mitosis and meiosis concepts covered in BIOL 1308.002, I hope you enjoy using the virtual lab and find it helpful.

How to access the virtual lab/ questions:

1. Go to http://www2.saplinglearning.com/
2. Click on the button that says US Higher Ed



3. Login with the Username and Password provided to you
4. Once you are inside the "TAMUCC Research Study Fall 2016 002" Course, you can:
   a. Complete a brief tutorial on how to use Sapling Learning
   b. Use the interactive virtual lab on "Mitosis and Meiosis" by clicking the Mitosis and Meiosis Virtual lab Link and access a short set of questions to help you make the most of the virtual lab

You can access the Sapling Learning Virtual Mitosis and Meiosis Lab anywhere you have internet.

<u>Affordances of using Sapling Learning during this lab</u>

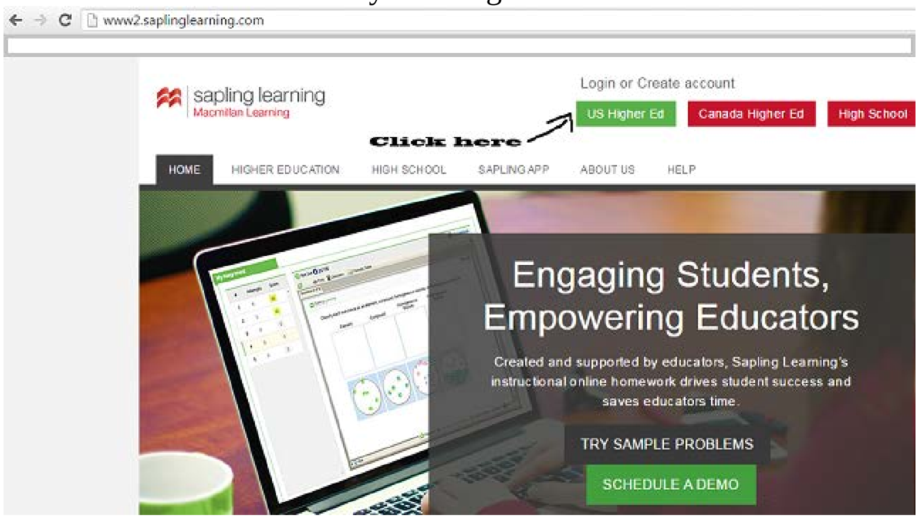
Remember that Sapling Learning is accessible on any computer with internet access. You can log in with the username and password provided.

VLIP-Sapling Learning Login Instructions

An interactive virtual lab on "Mitosis and Meiosis" and a short set of related questions have been provided to students by *Sapling Learning*. These resources will help you to learn the mitosis and meiosis concepts covered in BIOL 1308.001, I hope you enjoy using the virtual lab and find it helpful.

How to access the virtual lab/ questions:

1. Go to http://www2.saplinglearning.com/
2. Click on the button that says US Higher Ed



3. Login with the Username and Password provided to you
4. Once you are inside the "TAMUCC Research Study Fall 2016 001" Course, you can:
    a. Complete a brief tutorial on how to use Sapling Learning
    b. Use the interactive virtual lab on "Mitosis and Meiosis" by clicking the Mitosis and Meiosis Virtual lab Link and access a short set of questions to help you make the most of the virtual lab

You can access the Sapling Learning Virtual Mitosis and Meiosis Lab anywhere you have internet.

Affordances of using Sapling Learning during this lab

Instructor presence- You get to use the virtual lab and ask questions and communicate with an instructor

Please be sure to ask me any questions you have about the 'mitosis and meiosis' VL before you begin, during the lab, and after the lab. I am here to help you learn about 'mitosis and meiosis' with the Sapling Virtual Lab.

I also encourage you to contact your course instructor, your TA, or myself if you have any questions about the lab or related content over this next week. Please take the provided contact sheet with you; you may contact us via phone, e-mail, or on blackboard.

VLIPLC-Sapling Learning Login Instructions

An interactive virtual lab on “Mitosis and Meiosis” and a short set of related questions have been provided to students by *Sapling Learning*. These resources will help you to learn the mitosis and meiosis concepts covered in BIOL 1308.004, I hope you enjoy using the virtual lab and find it helpful.

How to access the virtual lab/ questions:

1. Go to http://www2.saplinglearning.com/
2. Click on the button that says US Higher Ed

3. Login with the Username and Password provided to you
4. Once you are inside the “TAMUCC Research Study Fall 2016 004” Course, you can:
    a. Complete a brief tutorial on how to use Sapling Learning
    b. Use the interactive virtual lab on “Mitosis and Meiosis” by clicking the Mitosis and Meiosis Virtual lab Link and access a short set of questions to help you make the most of the virtual lab

You can access the Sapling Learning Virtual Mitosis and Meiosis Lab anywhere you have internet.

<u>Affordances of using Sapling Learning during this lab</u>

Instructor presence- You get to use the virtual lab and ask questions and communicate with an instructor

Please be sure to ask me any questions you have about the 'mitosis and meiosis' VL before you begin, during the lab, and after the lab. I am here to help you learn about 'mitosis and meiosis' with the Sapling Virtual Lab.

I also encourage you to contact your course instructor, your TA, or myself if you have any questions about the lab or related content over this next week. Please take the provided contact sheet with you; you may contact us via phone, e-mail, or on blackboard.

Learner Control- You can control the amount of time you spend in the virtual lab, the pacing of the lab, the sequence and order of content you want to review, and how many times you repeat the virtual lab!

Using a Virtual Lab to learn about 'Mitosis and Meiosis' provides you greater control over your own learning. You can access the virtual lab on any computer with internet access. You can repeat the virtual lab as many times as you want after our class today: you can use it as a review tool for your Biology class, decide how much time you want to spend on it while you study, and decide which questions and sections you would like to review. The virtual lab also has many useful tools to help you control how you learn: the optional hint tool will help you to answer questions and will provide you with guidance. If you answer a question wrong, the virtual lab will give you helpful feedback and information so that you learn. The virtual lab animation also will feature labels and quick information on 'Mitosis and Meiosis'.

I encourage you to log back in to the 'mitosis and meiosis' lab after today's class. You can repeat and use the lab and its questions as a review tool for your class.