Science and Mathematics Education Centre

Effectiveness of Virtual Laboratories in Terms of Achievement, Attitudes, and Learning Environment among High School Science Students

Rachel Rose Oser

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Declaration

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university. To the best of my knowledge and belief, this thesis contains no material previously published by any person except where due acknowledgement has been made.

Signature:

Date: Dec. 14, 2012

Abstract

As our society becomes increasingly technological, research suggests that students, too, benefit from technology-rich learning environments (Aldridge & Fraser, 2008; Borgman, Abelson, Dirks et al., 2008; Tamim, Bernard, Borokhovski et al., 2011). In an effort both to allow students laboratory experiences that would not otherwise be possible in high school settings and to augment the integration of technology within science classrooms, virtual laboratories can be used to simulate real laboratories and encourage students to engage in scientific inquiry.

This study investigated the effectiveness of such virtual laboratories in terms of students' perceptions of the learning environment, attitudes towards science, and achievement. Classes of students who utilized virtual laboratories were compared with classes of students who did not. The sample consisted of 322 high-school students in 21 science classes in the US. Data were obtained by administering the Laboratory Assessment in Genetics (LAG) containing selected scales from the Technology-Rich Outcomes-Focused Learning Environment Inventory (TROFLEI) (Aldridge & Fraser, 2008), the Science Laboratory Environment Inventory (SLEI) (Fraser, Giddings, & McRobbie, 1992), and the Test of Science-Related Attitudes (TOSRA) (Fraser, 1981), as well as some achievement items from previously-validated science examinations. Quantitative data were complemented by qualitative data from interviews with students and teachers.

Data analysis supported the LAG's factorial validity, internal consistency reliability, discriminant validity, and ability to differentiate between the perceptions of students in different classrooms. All six learning environment scales correlated significantly and positively with students' attitudes and some of those scales (Integration, Material Environment, Teacher Support, Differentiation) also correlated significantly with students' achievement. Most learning environment scales were also found to be independent predictors of attitudes.

No significant differences were found between instructional groups for any criteria of effectiveness, indicating that the promise of such technological interventions in the classroom might not be fulfilled. However, the use of virtual laboratories did not negatively impact on students. Significant interactions were found between instructional method and sex for three dependent variables (Material Environment, Teacher Support, and the Attitude to Inquiry), with virtual laboratories being more effective for males than females. The results of this study have the potential to inform educational practitioners, add to the body of knowledge in the field of learning environments, and stimulate further investigations into the effectiveness of virtual laboratories as an instructional method.

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“Appreciation is a wonderful thing. It makes what is excellent in others belong to us as well.” — Voltaire

They say that the process to become a Doctor of Philosophy (PhD) is 10% intelligence and 90% persistence. While persistence might be internal, my persistence to complete this dissertation was catalyzed by the support, advice, and encouragement from others. First and foremost, I’d like to thank all the participants in my study: the students who responded to the questionnaire, and some of whom allowed me to interview them over their summer break, the students’ parents who offered their consent and many of whom expressed their support for my endeavor, and, of course, the teachers who volunteered their precious time implementing this study in their classrooms. Additionally, these teachers cooperated gracefully with my onerous instructions and numerous requests for feedback. Their insight and encouragement throughout this process has really made a difference to me – thank you! The administration in each of these schools also deserves my appreciation for allowing this study to take place under their auspices. In particular, the administration of the school in which I was based was helpful and encouraging.

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All along the dissertation writing process, I kept envisioning what it would look like at the end and I would often find myself composing the 'Acknowledgments' in my head. However, now that I have to put words on paper, I am at a loss. All I can muster is: thank you from the bottom of my heart to the love of my life, Asher, who pushed me to always pursue further and tolerated my unavailability, and thank you the miniature loves of my life, Mordechai, Aryeh, and Mira, who have egged me on and have had the patience to wait until 'Mommy has finished working'.

Abbreviations

CES	Classroom Environment Scale
CCEI	Computerized Classroom Ergonomic Inventory
CLES	Constructivist Learning Environment Survey
COLES	Constructivist-Orientated Learning Environment Survey
CUCEI	College and University Classroom Environment Inventory
DOLES	Distance and Open Learning Environment Scale
DELES	Distance Education Learning Environments Survey
ICEQ	Individualized Classroom Environment Questionnaire
LAG	Laboratory Assessment in Genetics
LEI	Learning Environment Inventory
MCI	My Class Inventory
OLLES	Online Learning Environment Survey
QTI	Questionnaire on Teacher Interaction
SAI	Scientific Attitude Inventory
SLEI	Science Laboratory Environment Inventory
TOSRA	Test of Science-Related Attitudes
TROFLEI	Technology-Rich Outcomes-Focused Learning Environment Inventory
VL	Virtual Laboratory
WEBLEI	Web-Based Learning Environment Instrument
WIHIC	What Is Happening In this Class? Questionnaire

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Chapter 1

Introduction

"If we knew what it was we were doing, it would not be called research, would it?"
– Albert Einstein

1.1 Introduction

In order to compete globally, students require a strong foundation in science, technology, engineering, and mathematics (STEM). To this end, the development and evaluation of educational innovations in science classes have become increasingly significant. One such educational innovation – virtual laboratories – was evaluated in my study.

Intended to simulate real experiments, virtual laboratories, available through the Internet, can utilize less instructional time, reduce reliance on complex, hazardous, and costly equipment, and allow students to experience high-level investigations that might not otherwise be possible in a high school classroom setting. In response to urging to adopt more educational technology in science classrooms, the use of virtual laboratories also can offer an engaging instructional medium, one to which many students of the digital age are well-accustomed. However, evidence is required about whether this instructional tool is indeed effective and whether virtual laboratories should continue to be developed and utilized in classrooms.

Because students spend approximately 20,000 hours in a classroom setting during the period extending from pre-school to university (Fraser, 2001), the learning environment has a strong impact on students, and students' perceptions of that environment are an important measure of the effectiveness of any educational intervention. Therefore, the effectiveness of virtual laboratories was investigated in this study in terms of students' perceptions of the learning environment, as well as the student outcomes of attitudes and achievement.

This chapter introduces the components of this study. The rationale for this study is explained in Section 1.2. The research questions, design, and method are described in Section 1.3. The context, which describes the setting in which the study was implemented, and also the curriculum on which the study was based, are explored in

Section 1.4. Limitations and boundaries regarding this study are delineated in Section 1.5. This chapter concludes with an overview of the remaining chapters that review relevant literature, discuss an appropriate framework, explain the methods of the study, describe methods for analyzing the data, report the results, and provide implications for practical applications and future research.

1.2 Rationale

Achievement scores in the sciences for American students have raised alarms about the abilities, skills, and knowledge base of the nation's future work force (see Section 1.4.1). As decried by Thomas Friedman in *The World is Flat* (2006), the US has entered an era of 'outsourcing' low-skilled jobs to developing countries because the cost is less. Outsourcing also occurs for high-skilled jobs involving Science, Technology, Engineering, and/or Mathematics (STEM) for which the American workforce is ill-equipped; this is referred to as the 'brain drain' or "the chronic decline in homegrown STEM talent" (Dugger, 2010). A 2005 report of the US Bureau of Labor Statistics predicted that, by 2012, the number of jobs in STEM occupations would grow by 47%, which is three times the rate for all other occupations (Russell & Siley, 2005). Fortunately, Friedman argues, educational systems are dynamic and can be enhanced to better train American youth and prevent such outsourcing (Friedman, 2006).

In response to this phenomenon, a number of initiatives to improve science education have been launched. Examples include the *Educate to Innovate* campaign that focuses on activities outside the classroom and *National Lab Day* that matches scientists willing to volunteer their time with local science classes. Challenges to design video games that incorporate scientific concepts and skills, online directories for local science activities (www.connectamillionminds.com), and an emphasis on science in popular children's television programming are also some of the innovative plans offered by various organizations and corporations (Chang, 2009, November 23).

The National Science Foundation's Task Force on Cyberlearning also proposed upgrading the state of Science, Technology, Engineering, and Mathematics (STEM) education by incorporating interactive technology, with one of the examples offered being virtual laboratories (Borgman et al., 2008). The integration of technology into science laboratories has begun, but several researchers note the lack of empirical evidence concerning its effectiveness in general (Russell, 1999), and the effectiveness of using virtual laboratories in particular (Harms, 2000; Hofstein & Lunetta, 2004; Javidi & Sheybani, 2006). Ma and Nickerson (2006) acknowledge the necessity to further evaluate the educational effectiveness of laboratory simulations by conducting controlled studies. While there are a number of studies that have assessed such educational innovations from the field of Information Technology, there is hardly any evaluative research on virtual laboratories from an educational perspective. The purpose of this study, then, was to evaluate the effectiveness of the use of such virtual laboratories in science classes.

Virtual laboratories are essentially simulated experiments conducted using computer software (often through the Internet), that offer numerous advantages for both student learning and the logistics of educational experiences, as discussed in Section 2.5.2. The author's initial motivation to conduct this study was based on a teaching experience in which under-performing male students seemed to be engaged by this technology, which seemed to lead to increased understanding and task completion. However, because these initial observations were purely anecdotal, further evidence was needed about the effectiveness of such virtual laboratories.

The researcher chose the field of learning environments as the foundation for the current study. Classroom learning environment research focuses on interactions that take place within a classroom, between students, and between teachers and students (Fraser, 2012). Learning environment instruments can be used to assess student perceptions of what is taking place in the classroom and these assessments can guide future directions to improve the learning environment. Because associations have been established between the learning environment and student attitudes towards science, as well as with achievement in science (Fraser, 2012), enhancing the learning environment through an educational innovation (such as virtual laboratories) might also improve students' attitudes and achievement levels.

Attitudes towards science amongst middle to early high school students have been found to decline relative to their earlier schooling experiences (Oliver & Venville, 2011). Students who lose interest in the sciences are less likely to further explore the field in higher education and tend not to pursue such lines of work (Tytler & Osborne, 2012). If educational researchers can uncover evidence for the effectiveness of instructional media that engage students in science at this critical age of development, it might inform current and future practices for improving attitudes towards science and science-related careers. Therefore, in addition to assessing students' perceptions of the learning environment, this study also examined students' attitudes towards science, especially because robust and economical instruments are available to assess such attitudes.

While achievement is traditionally a measure of the effectiveness of educational innovations, this study focused mainly on how the psychosocial aspects of the classroom were impacted. However, the effect of virtual laboratories on achievement was also taken into account in order to check students' understanding of the material and to confirm previously-established links between achievement and such psychosocial aspects of education. If both students' perceptions of the classroom environment and their attitudes towards science improved as a result of an intervention, but their conceptual understanding was unchanged, then the intervention could not be considered to be truly effective.

Additionally, because learning environment instruments have been honed to detect differences between subgroups (such as different sexes) within a classroom setting, they could be applied in this study to examine differences between males and females in perceptions of the learning environment, attitudes, and achievement. This is a significant area of research in science education and there is much controversy over whether such gender differences exist (Scantlebury, 2012). Therefore, this study also explored gender differences, especially whether virtual laboratories are a gender-inclusive instructional technique.

Ideally, an evaluation of any intervention should include a comparison group without the intervention so that data from both groups can be compared. The current study adopted a quasi-experimental design for this purpose, with data from students in classes that engaged in virtual laboratories being compared with data from students in traditional classes. However, quantitative data cannot provide the whole picture of the effect of virtual laboratories, especially because students cannot indicate their opinions outside of the specific questions about which they are asked on an instrument. For this reason, the collection of qualitative data through semi-structured interviews was an important element in this study. A triangulation of quantitative and qualitative methods of data collection in learning environment research has been recommended by Tobin and Fraser (1998). Elaboration of the research design is described in Section 1.3 and further details are furnished in Chapter 3.

This is the first study of its kind to evaluate the effectiveness of virtual laboratories in science education in terms of students' perceptions of the learning environment and the student outcomes of attitudes and achievement. Therefore, findings have the potential to usefully inform future researchers in science education, practitioners such as administrators and teachers, and policy-makers, and eventually impact on students.

1.3 Research Questions, Design and Method

Once the purpose of this study was conceived, it was further divided into four separate aims for exploring various aspects of the educational intervention. Each aspect of my investigation was guided by a research question, as appears below.

To check whether the instruments used in this study were valid and reliable, the first research question was constructed:

Research Question 1:

> Are scales from the Test Of Science Related Attitudes (TOSRA), Science Laboratory Environment Inventory (SLEI), and Technology-Rich Outcomes-Focused Learning Environment Inventory (TROFLEI), as well as achievement items, valid and reliable when used with a sample of high school students taking biology in the US?

To uncover associations between the three criteria used to assess the effectiveness of virtual laboratories, the second research question was written:

Research Question 2:

> Are there associations between the perceived classroom learning environment and student outcomes of attitudes towards and achievement in science?

To examine the effectiveness of virtual laboratories in terms of the three measures of criteria, the third research question was formed:

Research Question 3:

> Is the use of virtual laboratories in high school science classes effective in terms of students':
>
> a. perceptions of their learning environment,
> b. attitudes towards science, and
> c. academic achievement?

To examine whether using virtual laboratories was differentially effective for different sexes, the final research question was asked:

Research Question 4:

> Is the use of virtual laboratories differentially effective for males and females in terms of students':
>
> a. perceptions of their learning environment,
> b. attitudes towards science, and
> c. academic achievement?

Chapter 3 describes the research design and method in detail; the following is a brief overview of Chapter 3. This study used a quasi-experimental design to compare students in 11 high school classes who engaged in virtual laboratories with students in 10 high school classes who did not (they continued learning and experimenting in their normal fashion). Eight different virtual laboratories related to the topic of genetics were chosen by the researcher for their design and use of inquiry. Teachers used at least four of these virtual laboratories. The treatment period lasted from two to twelve weeks.

This study involved a questionnaire called the Laboratory Assessment in Genetics (LAG) that was administered to a sample of 322 students at the end of the treatment period. As well, semi-structured interviews were conducted with six self-selected students from the same sample and three of their teachers. The scales for the LAG were adopted from previously validated questionnaires that measure students' perceptions of the learning environment, such as the Science Laboratory Environment Inventory (SLEI) and the Technology-Rich Outcomes-Focused Learning Environment Inventory (TROFLEI), in addition to scales measuring students' attitudes towards science from the Test Of Science Related Attitudes (TOSRA), and an achievement scale with items borrowed from standardized biology examinations. The learning environment and attitude scales were first checked for validity and reliability, and then associations between the variables — perceived classroom learning environment and student outcomes of achievement and attitudes towards science — were explored. Finally, the effectiveness of using virtual laboratories, as well as the differential effectiveness for males and females, in terms of perceptions of the learning environment, attitudes towards science, and academic achievement, were investigated. Effect sizes were also calculated for each of these analyses to determine the magnitude of any differences.

1.4 Context

The field of science education provided the general context for this study. This section surveys the landscape of science education today regarding recent trends and future directions on a national scale, with respect to global circumstance (Section 1.4.1). Next, Section 1.4.2 delves into the particulars of the science curriculum, on which the content of the virtual laboratories used in this study was based. The role of the science laboratory is also explored because it provided the setting for the intervention evaluated in this study (Section 1.4.3).

1.4.1 The State of Science Education Today on a National Scale

This study took place in the United States of America and involved public high school students from four different states along the eastern coast. The sciences are considered a 'high need' area in education because there is a shortage of qualified teachers and because students have been losing interest in this area (Baird, 2012).

The subject of science is part of a larger area of learning commonly referred to as STEM, which stands for Science, Technology, Engineering, and Mathematics. *Science* seeks to understand the natural world; *technology* aims to modify the natural environment through innovation in order to satisfy perceived human wants or needs; *engineering* is about developing ways to economically use the materials and forces of nature for the benefit of mankind; and *mathematics* refers to the study of patterns and relationships to provide models for the natural world (National Research Council (NRC), 1996). Because one is a sub-section of the other, the terms 'science education' and 'STEM education' are used interchangeably throughout this chapter.

With the globalization of the economy as well as other aspects of society and culture, STEM education must involve global collaboration as it prepares the future workforce (Friedman, 2006). In the last decade or two, several international assessments were developed to compare the achievement of students in different countries. The most notable are the Third (or, renamed 'Trends in') International Mathematics and Science Study (TIMSS) and the Programme for International Student Assessment (PISA) for reading, mathematics, and science literacy. Data for TIMSS have been collected from 4th and 8th graders every four years since 1995 and data for PISA have been collected from 15 year-olds every three years since 2000 (Programme for International Student Assessment (PISA), 2009; Trends in International Science and Mathematics Study (TIMSS), 2007).

How does the US compare to other countries in terms of student competency in science? According to the most recent PISA (2009) results, about 18% of American students did not score proficiently in science (level one and below). The PISA report states: "Students whose proficiency in science is limited to Level 1 will find it difficult to participate fully in society at a time when science and technology play a large role in daily life" (Organization for Economic Co-operation and Development (OECD), 2010, p. 24). Similar findings were reported from the TIMSS (Gonzales, Williams, Jocelyn et al., 2008).

To improve education in general, the US government launched a number of efforts with the aim of increasing educational opportunities for all learners. Such efforts in general education included A Nation at Risk (Gardner, 1983), that focused on students, and President Bush's No Child Left Behind Act (NCLB, 2001), that focused on schools' Adequate Yearly Progress (AYP). Currently, the Obama administration has been granting more and more waivers to schools that have not met their AYP, indicating the lack of the NCLB's success (Rich, 2012). A new initiative launched by President Obama is the Race to the Top (Westendarp & Westendarp, 2009) that pits states against each other to infuse a sense of competition and urgency regarding the nation's educational status. As part of reforming general education, the US Department of Education continually seeks to improve science education by investing in efforts to implement programs that aim towards higher standards, such as the examples cited in Section 1.4.2.

1.4.2 Reforming Science Curricula

While the examples offered in Section 1.4.1 refer to the *how* of engaging students in science, *what* science content is being delivered also requires upgrading. As the US became aware of how poorly its students were achieving in science relative to other developed countries, it sought to establish clear learning statements as goals for its students to attain. Historical examples of such science learning goals include *Benchmarks for Science Literacy* (American Association for the Advancement of Science (AAAS), 1989), the *National Science Education Standards* (National Research Council (NRC), 1996, 2005), and a *New Generation of Science Standards* (NGSS, 2011). In accordance with the new framework's scientific practices to promote scientific inquiry, to focus on cross-cutting concepts (concepts fundamental to different disciplines of science), and to deepen core content, virtual laboratories (the intervention in the current study) are one medium through which such scientific inquiry can be practiced and enable a greater emphasis on cross-cutting concepts, without the distraction of time-consuming hands-on tasks.

The specific topic on which the virtual laboratories in this study were based was genetics, the study of inheritance. Disciplinary core ideas introduced by the NGSS are addressed by such virtual laboratories, including 'LS1: From molecules to organisms: Structures and processes', 'LS3: Heredity: Inheritance and variation of traits', and 'LS4: Biological evolution: Unity and diversity' (National Research Council (NRC), 2011, pp. ES-3). Such ideas are considered to be difficult to learn (Bahar, Johnstone, & Hansell, 1999) because they require multilevel thinking: an organism is at the macro-level, while cells, chromosomes and DNA are at the micro- and molecular level, and genotypes are at the symbolic level (Johnstone, 1991). For instance, to master the topic of genetics at the high school level, students must be able to discuss the structure and function of key molecules in the cell, explain the process and purpose of DNA replication, meiosis, gene expression, cellular regulation, and mutations, predict the impact of environmental factors on these processes, discuss how they lead to diversity, and the identify role of genetics in evolution. The teaching of genetics proves to be complex, as well. Controversy exists over what order in which the sub-topics should be taught and at which point in the curriculum genetics should be presented (Redfield, 2012) in order to maximize understanding.

Since Watson and Crick's (1953) discovery of the structure of DNA, the area of genetics, one that began in the mid-1800's as classic 'Mendelian genetics', took on a new direction and was renamed 'molecular genetics'. From this historic event, entire new fields within molecular genetics were borne (Marbach-Ad, Rotbain, & Stavy, 2008), including genetic engineering, which is the intentional modification of an organism's characteristics by manipulating its genetic material. From an economic perspective, the burgeoning pharmaceutical industry provides the impetus to raise standards in the learning of genetics because it relies on a skilled workforce, which will be drawn from today's students.

Unfortunately, current genetics instruction leaves many students ill-prepared to understand, discuss, and engage in debates about the benefits and detriments of technological advances in genetic engineering, such as genetically-modified (GM) foods, cloning, gene therapy, personalized medicine, and genetic screening and counseling (Toth, Morrow, & Ludvico, 2009). Enhancing such instruction through the use of models and visualization might prove to be helpful, especially at the molecular level at which students have difficulty understanding this topic simply based on textual presentations (Marbach-Ad, Rotbain, & Stavy, 2008). A number of researchers note the potential of computer animations/simulations to facilitate the visualization of abstract concepts and processes at the molecular level (Marbach-Ad, Rotbain, & Stavy, 2008; Tsui & Treagust, 2004; Wu, Krajcik, & Soloway, 2001). Virtual laboratories, which are such examples of computer-based simulations, are capable of reducing the logistic load required in both the classroom and laboratory when learning molecular genetics, so that students might better focus on its demanding cognitive aspects.

To assess whether learning goals are achieved and whether interventions are beneficial, the *National Assessment of Educational Progress* (NAEP), colloquially referred to as the 'Nation's Report Card', showed that science scores improved between 2009 and 2011, and that the achievement gap for minorities also narrowed (National Center for Educational Statistics (NCES), 2012a). Another study revealed that, over the course of a decade (from 2000–2010), more high school students were enrolled in science and mathematics courses but that achievement had not improved (Aud, 2012). However, the stagnancy of these scores might even be commended because it indicates that standards have not been artificially lowered in order to entice students to engage in more science and mathematics (Campbell, 2012). These findings suggest that the interventions aimed at improving science education in the last decade might hold promise. Therefore, one of the aims of this study was to investigate whether using an intervention (i.e. virtual laboratories) would lead to increased student science achievement.

1.4.3 Science Laboratories

The laboratory has been a prominent feature of science education since the inception of teaching science systematically in the 19th century. A laboratory refers to "experiences in school settings in which students interact with equipment and materials or secondary sources of data to observe and understand the natural world" (Hofstein & Kind, 2012, p. 190). However, in the early years of science experimentation in school, laboratories were simply environments in which to practice or confirm information learned during lectures or from textbooks. The evolution of laboratories as being the environment through which exploration and inquiry occur took decades, and is a process that is still ongoing.

Going back to the 1960s–1970s, the contributions of psychologists to the field of science education, and specifically experimentation, cannot be underestimated. Also, it was anticipated that science teaching could also help to develop the sort of thinking processes in youngsters that psychologists espoused. Based on Piaget (1970) and cognitive psychology, educational researchers developed the learning cycle to emphasize the *process* of science: 1) *exploration*, involving students in manipulating concrete materials, 2) *concept introduction* in which the teacher introduces new concepts, and 3) *concept application* when the student applies the learned concept to novel situations. In this way, work with concrete objects, as afforded by the laboratory part of science classes, was considered to be an essential component of the development of thought processes, especially as a prerequisite to the 'formal operations' period (Hofstein & Kind, 2012; Karplus & Butts, 1977).

The development of an inquiry-based model for scientific experimentation continued throughout and beyond this period (Kempa & Ward, 1975; Tamir, 1974). However, it was argued that an overemphasis was placed on the 'scientific method' as a simplified, empiricist approach that included following instructions, getting the correct answer, and manipulating equipment. Therefore, the 1980s–1990s saw an increase of science as *craftsmanship* (i.e. inquiry with a trained scientist/teacher to become better problem solvers) and a focus on *procedural knowledge* (i.e. learning how to do science), in addition to conceptual development, which formed a new perspective on science education referred to as 'constructivism' (Hofstein & Kind, 2012). In the field of psychology, developmental constructivism refers to the idea that children learn by doing (Piaget, 1963). In line with this theory, the science laboratory was considered the ideal setting for such construction of knowledge.

Later, constructivists further expanded their ideas by incorporating Vygotsky's (1978) socio-cultural view of learning, which dictates that the construction of concepts originates from socially-mediated activities, especially through language. Therefore, learning that takes place in a laboratory was seen as a socialization into scientific culture. This process requires students to engage in metacognition in that they must internalize the their own thought processes as well as those of their peers (Hofstein & Kind, 2012).

Despite all of these reform efforts over the years, challenges still remain; Hofstein and Lunetta (2004) pose serious questions about the efficiency and benefits of the science laboratory. The laboratory in science education has been shown to be effective in the development of practical, manipulative skills related to handling equipment, but it has failed to enhance concept-building, critical thinking, and an understanding of the nature of science; in essence, the laboratory has become a place for "manipulating equipment and materials, but not ideas" (Hofstein & Kind, 2012, p. 192).

Some reasons for the lack of evidence regarding the effectiveness of laboratories include inadequate assessment and research procedures (Lazarowitz & Tamir, 1994), such as insufficient control over laboratory procedures (e.g. laboratory manuals, teacher behavior, teachers' assessments of student achievement), inappropriate samples, and the use of measures that were not sensitive to the laboratory learning environment (Hofstein & Lunetta, 1982). Since then, a number of instruments to measure dimensions specific to the science laboratory were developed, such as the Science Laboratory Environment Inventory (SLEI) discussed further in Section 2.3.2.

In practice, the inclusion of concepts such as inquiry and constructivism were difficult to implement. Teachers preferred the safer 'cookbook' approach, in which students perform investigations as if they are following a recipe; teachers underestimated learners' capabilities to handle the high cognitive demand required by true investigations (Hofstein & Kind, 2012). In fact, when Sere (2002) conducted a comprehensive and long-term study of the use of laboratories in several EU countries, based on 23 case studies, she found that, although laboratory work was perceived as an essential component of the experimental sciences, the objectives stated for practical work in the laboratory were too numerous and demanding to be implemented by the average science teacher.

Hofstein and Kind (2012) highlight a number of possible solutions to these challenges about the role of the laboratory in science classrooms. They stress the importance of incorporating *metacognition* into all activities; this is also considered to be a way to develop *independent learners* (NRC, 1996, 2005, 2011). Four conditions are necessary in order to foster an environment of inquiry, in which *metacognition* can occur: time, opportunity, guidance, and support (Baird & White, 1996). *Time* can be afforded by reducing the amount of time spent on tasks that can be handled by technology. Similarly, Hofstein and Lunetta (2004) present a way to overcome the challenges of a lack of inquiry in science laboratories: investing in the training and use of 'inquiry empowering technologies'. Already in the early 1980s, digital technologies were recognized as important tools for the science laboratory (further discussion about the history of educational technology is found in Section 2.5). Essentially, such technologies can be used to perform time-consuming tasks such as gathering and analyzing data. This allows students more *time* to observe, reflect and construct conceptual knowledge; conduct, interpret, and report more accurate and relevant data; and focus on student collaboration, development of a community of inquirers, and engagement in argumentation (Hofstein & Kind, 2012). All of these features are outcomes of laboratory investigation steeped in the concepts of inquiry, constructivism, and social learning.

Hofstein and Kind (2012) note some improvements in students' conceptual understanding of science with the integration of information and communication technology (ICT) in the laboratory, but the level at which ICT is utilized in various school laboratories varies. They surmise that ICT will be used to achieve a greater synthesis between laboratory work and computer-based simulations and conclude that this is an area that requires more research regarding its educational effectiveness.

Hence, the current study evaluated the educational effectiveness of virtual laboratories, which are computer-based simulations of real investigations. In line with the aforementioned advantages for technology integration, the virtual laboratories were anticipated to save time on menial laboratory tasks and allow students to focus on the theory behind the investigation, as well as its connection to the design of the experiment.

1.5 Limitations

The intention of this study was to compare the instructional effectiveness of virtual laboratories relative to instruction without virtual laboratories. Therefore, virtual laboratories, in the context of this study, were meant to *supplement* current methods of instruction, rather than *substitute* traditional methods (i.e. hands-on experiments) with more innovative and technological ones. In other words, the intention of this study was not to compare virtual laboratories with their hands-on counterparts. The researcher was not interested in investigating whether virtual laboratories were more effective than hands-on laboratories for the same experiment because research (Bredderman, 1982; Johnson, Wardlow, & Franklin, 1997; Ma & Nickerson, 2006) already has indicated the effectiveness of hands-on experiences with regard to experimentation. In fact, the small body of past research on physical (hands-on) versus virtual laboratories is inconclusive regarding which method is more beneficial for students (de Jong, Linn, & Zacharia, 2013). This point is further expanded upon in Section 2.5 where the literature regarding the effectiveness of virtual laboratories, and educational technology in general, is reviewed.

Rather, the researcher simply noted a lack of opportunities for students to engage in complex experimentation and techniques with which they are expected to become familiar, according to newer standards of science education (see Section 1.4.1). Therefore, the hypothesis of my study was that the introduction of virtual laboratories would help students in this regard more than current instructional methods that only involve verbal explanations or textbook illustrations. Essentially, the researcher did not wish to run similar physical experiments with the comparison group because such experiments are not usually possible in a high school setting. High school laboratories simply do not have the safety precautions in place for conducting such experiments; nor do high schools have the resources, such as costly equipment and long periods of time for conducting these experiments.

Thus, this study was limited to high school classrooms that do not have the capability to conduct complex experiments; the comparison of virtual experiments with similar physical ones was beyond the scope of this investigation. As long as the results of this study do not suggest a negative impact of virtual laboratories on students' educational experience (including perceptions of their learning environment, attitudes, and achievement), then they suggest the effectiveness of virtual laboratories as an instructional method.

1.6 Overview of Thesis

Background information about this study, its implementation, and its results are presented in five chapters. Chapter 1 introduced the background (Section 1.1), rationale and purpose (Section 1.2), research questions and research design (Section 1.3), educational context (Section 1.4), and limitations (Section 1.5) of the study, as well as an overview of the rest of the thesis (Section 1.6).

Chapter 2 reviews the literature relevant to the current study, and is organized into several sections and sub-sections. Section 2.2 describes the theoretical framework for the evaluation of the intervention, namely, learning environments, including its history and development, instruments used to assess the learning environment, and the application of learning environment scales to current educational research. Section 2.3 deals with students' attitudes towards science, another measure of the effectiveness of virtual laboratories in my study, by defining the term 'attitude', describing how attitudes are assessed, and reviewing research on the impact of educational interventions on attitudes. Gender differences in science education are also considered in Section 2.4. The intervention in this study, virtual laboratories, is discussed in Section 2.5, including its definition, history, and benefits, and the possibility that educational technology might not offer any advantages. Finally, Section 2.6 examines various aspects of achievement, another measure of effectiveness, in science education.

The methodological aspects of this study are depicted in Chapter 3. Section 3.2 delineates the research questions that guided the methods, while Section 3.3 describes the sample selection, and Section 3.4 discusses the assessment instruments and other resources. The procedures for the study's implementation are elucidated in Section 3.5, and a description of how the data were collected, entered, and analyzed is presented in Section 3.6. Errors and other general limitations are pointed out in Section 3.7

The next chapter, Chapter 4, reports results for validation of the various parts of the LAG instrument in Section 4.2, for associations between perceptions of the learning environment (SLEI, TROFLEI) and attitudes (TOSRA) and achievement in Section 4.3, and for the effectiveness of virtual laboratories in Section 4.4, including results for the differential effectiveness of virtual laboratories for males and females.

The final chapter summarizes the earlier chapters regarding research methods and results (Section 5.2), explicates the significance of the results and implications for educational research and practice (Section 5.3), points out the limitations of this study as well as suggesting directions for further research (Section 5.4), and provides a conclusion for the study (5.5).

Chapter 2

Literature Review

"If I have seen further it is by standing on the shoulders of giants." – Isaac Newton

2.1 Introduction

This chapter reviews literature that supports the various aspects of this study. The aim of this study was to investigate the effectiveness of virtual laboratories in terms of students' perceptions of the learning environment, their attitudes towards science, and their achievement in science. Additionally, it examined the differential effectiveness of virtual laboratories for different sexes using the same measures.

First, Section 2.2 focuses on the literature that provided the theoretical framework for the evaluation of the intervention: the field of learning environments provided a framework for evaluating the effectiveness of virtual laboratories. Included in this section is a review of the literature regarding the historical background for the development of the field (Section 2.2.1), the instruments used to assess the learning environment (Section 2.2.2), and the application of learning environment scales to current research in classrooms (Section 2.2.3).

Next, Section 2.3 reviews the literature that deals with students' attitudes towards science, another measure of the effectiveness of virtual laboratories. The term 'attitude' is defined in Section 2.3.1, methods of assessment are presented in Section 2.3.2, and literature concerning the impact of educational interventions on students' attitudes is reviewed in Section 2.3.3.

Historically, many studies in science education have examined gender differences when assessing the learning environment of a classroom. Therefore, in my study, gender differences were considered when evaluating the effectiveness of virtual laboratories. The literature that discusses whether such gender differences are perceived by society or whether they are real and innate is examined in Section 2.4.

Finally, literature about the subject of the intervention in this study, virtual laboratories, is reviewed in Section 2.5. More specifically, this section reviews literature that describes the history of as well as the rationale for integrating educational technology into classrooms (Section 2.5.1), that defines virtual laboratories and portrays their advantages and application (Section 2.5.2), and literature that provides a critical voice against such interventions (Section 2.5.3).

2.2 Theoretical Framework: Learning Environments Research

This study was couched in an area of educational research that has grown from its infancy to premiership over the last 40 years. How does one measure the effects of educational reform? Traditionally, educational research has focused on the learning outcomes, especially achievement scores, of students experiencing an educational intervention. However, evidence for the effectiveness of education is broader than a mean score on achievement tests. This is the focus of the learning environments framework; ‘learning environments’ is an area of research that involves not only the learning outcome of achievement, but also a complex web of psychosocial factors that impact on students, classrooms, and schools. More specifically, it explores intangible aspects that give the classroom a characteristic tone (Fraser, 2001).

In fact, Fraser (2001, 2012) claims that the students, in contrast to external observers, are the best evaluators of the classroom setting because they have been observers in a multitude of classrooms during their entire lives. He states that, by the time a student graduates from university, s/he will have been experiencing classrooms for over 20,000 hours! Therefore, the perspective that is taken into account in the field of learning environments is that of the student. That is, the field uses students’ perceptions of the classroom environment, assessed by quantitative surveys (Fraser, Giddings, & McRobbie, 1995), as criteria of effectiveness and predictors of students’ cognitive and affective outcomes (Walberg & Anderson, 1968). Because these perceptions might in turn impact upon their attitudes and achievement, the field of learning environments indirectly involves learning outcomes, even though the real focus is the student’s perception of the classroom environment.

This section reviews literature concerning various aspects of the field of learning environments. First, Section 2.2.1 provides the historical background of the development of the field. Next, instruments used to assess the learning environment are explored in Section 2.2.2. Finally, Section 2.2.3 reviews how learning environment scales have been applied in research in classrooms.

2.2.1 History and Development of Learning Environments Research

The field of learning environments has foundations that date back to Lewin's (1936) seminal study in a business setting that led to the formula, Behavior = f(Person, Environment), in which behavior is defined as a function of the person and the environment; this idea was applied to human behavior in any setting. His work was followed by Murray (1938) who advocated a needs–press model in which personal needs are either supported or frustrated by the environmental press. In line with this model, Murray also coined the terms 'alpha press', referring to the perspective of an objective observer, and 'beta press', which is the perspective of the participant of the environment. Furthermore, Stern, Stein, and Bloom (1956) delineated between the individual's perception of the environment (private beta press) and the shared group's perception of the environment (consensual beta press), a distinction important to researchers when deciding upon the perception scores of the individual, the group, or an external observer. Work in learning environments was furthered by Stern (1970) who expanded upon the notion of person–environment fit.

Soon, research on environmental influences was extended to educational settings. The founding studies in America that involved classroom environment assessments began simultaneously with Walberg's (1968) evaluation of the Harvard Physics Project, resulting in the development of the Learning Environment Inventory (LEI), and Moos' (1974) study which used social climate scales that were initially applied in evaluating psychiatric programs but later were adapted for use in classrooms with the creation of the Classroom Environment Scale (CES). The development of both of these widely-used instruments was based upon the Getzels and Thelen (1960) model that learning outcomes are a result of the interaction of personality needs, role expectations, and classroom climate. This founding work was significant to the growth of the field of learning environments as reviewed in numerous books (Fisher & Khine, 2006; Goh & Khine, 2002; Khine & Fisher, 2003) and book chapters (Fraser, 1998a, 2007, 2012).

Within a decade, the pioneering research on learning environments that began in the US soon became international. Wubbels and Levy (1993) in the Netherlands developed the Questionnaire on Teacher Interaction (QTI) to assess student–teacher interactions. This work with the QTI was furthered by others in countries such as Brunei Darussalam (Scott & Fisher, 2004), Singapore (Quek, Wong, & Fraser, 2005), Korea (Lee, Fraser, & Fisher, 2003), and Indonesia (Fraser, Aldridge, & Soerjaningsih, 2010). Barry Fraser and his colleagues established Australia as a center of research for learning environments and initially constructed the Individualized Classroom Environment Questionnaire (ICEQ), which differed from previous questionnaires that assessed teacher-centered classrooms to focus on classrooms that were more student-centered (Fraser & Butts, 1982). He was also involved in the development and cross-validation of numerous other instruments applied to learning environments around the world as described in this and the next section.

The field was further established by the creation of specific research groups, journals, and books devoted to learning environments, in addition to the accumulation of studies conducted by individual researchers. In the mid-1980s, the American Educational Research Association formed a Special Interest Group (SIG) on Learning Environments. The launch of the *Learning Environments Research: An International Journal* (Fraser, 1998a) carried the field of learning environments to the next echelon in its rich history and development spanning the last few decades. As well, new book series, Advances in Learning Environments Research (Aldridge & Fraser, 2008), that has emerged to cater for topics in greater depth and breadth than that allowed in journals.

Research in the burgeoning field of learning environments still continues and new instruments to assess the student's perspective are currently being conceived at the same time that scales from historically-significant questionnaires are still being adapted to new circumstances. While designing studies that evaluate classroom environments, researchers must select the appropriate instrument that best fits the scope of the intended study, while also taking care to choose the appropriate unit of analysis (e.g. the student, the class, the teacher) for scores from the questionnaire responses to ensure statistically-accurate results (Dorman, 2012). A review of the historically-significant instruments to assess learning environments ensues, with a focus on the relevant questionnaires from which scales were selected and adapted for my study.

2.2.2 Instruments for Assessing the Learning Environment

In his review of classroom environment instruments, Fraser declares: "Few fields of educational research have such a rich diversity of valid, economical, and widely-applicable assessment instruments as does the field of learning environments" (Fraser, 1998a, p. 7). This section reviews this array of learning environment instruments after first noting some general issues regarding the structure of these questionnaires. Following this introduction, an overview of the questionnaires used to assess learning environments is presented in Section 2.2.2.1, and a focus on the questionnaires from which scales were adapted for this study are found in Sections 2.2.2.2 and 2.2.2.3.

Debates abound regarding the most appropriate method to evaluate a classroom environment. Should data be collected quantitatively through the use of questionnaires that assess students' perceptions, or should data be qualitative in nature and involve an external researcher observing the natural climate of the classroom and/or interviewing students?

There are several advantages in the use of quantitative questionnaires to collect data. In general, gathering data through the administration of questionnaires provides a snapshot of the classroom environment (Fraser, 1998a, 1998b). The nature of these quantitative instruments allows for data collection from several large groups at one time and for comparisons to made across these groups and between subgroups (Fraser, Fisher, & McRobbie, 1996); it is therefore an efficient method for gathering a large data set in a short amount of time, in contrast to the amount of time required to collect, record, transcribe, and organize qualitative data. This is particularly relevant to classrooms where research-based improvements need to be implemented swiftly before the environment changes. Additionally, questionnaires enable an examination of multiple aspects of a learning environment to be assessed at a single time (Fraser, 1998a, 1998b), as opposed to the limited field of view of an external observer. Fraser (2012) also notes that gleaning perspectives from the participants in the environment, namely, the students and teachers, can capture information which an external observer can miss or consider insignificant. Naturally, gathering data through quantitative measures introduces less bias than a researcher observing the classroom environment or interviewing students himself or herself (Anderson & Arsenault, 1998). Finally, in comparison with the effort required to train an external agent in observation or interviewing techniques, teachers who administer quantitative surveys do not require specialized training, ensuring greater efficiency in data collection (Fraser, 1998a, 1998b).

Needless to say, while quantitative data collection through the use of surveys allows all of the aforementioned benefits in the research process, it also lacks the ability to grasp the nuances in students' perceptions of the environment. In particular, the researcher could be unable to understand the rationale behind students' perceptions and lack the information necessary to explain anomalies in the data (Duit & Confrey, 1996). For this reason, while quantitative data collection via questionnaires dominated the field of learning environments in the past, the method of triangulation in which the productive combination of quantitative and qualitative approaches to data collection characterizes the field today (Aldridge, Fraser, & Huang, 1999; Fraser & Tobin, 1991; Mathison, 1988; Tobin & Fraser, 1998).

Some brief explanations are in order regarding the general structure of such questionnaires. The scales within a questionnaire (e.g. Student Cohesiveness and Independence) are the dimensions by which the learning environment can be quantitatively measured. The scales comprise specific items that address the particularities of that dimension; for example, an item under Student Cohesiveness might ask respondents to indicate their agreement with the statement "I know other students in this class". Most questionnaires contain a Likert or frequency scale where responses range from 'strongly disagree' to 'strongly agree' or from 'almost never' to 'almost always', respectively.

According to Moos' (1974) scheme, there are three general dimensions that characterize all human environments. Scales within any specific instrument can be classified under the *relationship* dimension (i.e. the strength and type of personal relationships within the environments, and the extent to which people are involved in the environment and support one another), the *personal development* dimension (i.e. the extent to which self-reflection and personal growth occur), or sys*tem maintenance and change* dimensions (i.e. the extent to which the environment is orderly, clear in expectations, maintains control, and is responsive to change) (Moos, 1974).

Table 2.1 Overview of Scales used in some Learning Environment Instruments (CUCEI, MCI, QTI, SLEI, CLES, WIHIC, and COLES)

			Scales classified according to Moos' dimensions		
Instrument	Level	Items per scale	Relationship	Personal development	System maintenance and change
College and University Classroom Environment Inventory (CUCEI)	Higher Education	7	Personalisation Involvement Student Cohesiveness Satisfaction	Task Orientation	Innovation Individualisation
My Class Inventory (MCI)	Elementary	6–9	Cohesiveness Friction Satisfaction	Difficulty Competitiveness	
Questionnaire on Teacher Interaction (QTI)	Secondary/ Primary	8–10	Leadership Helpful/Friendly Understanding Student responsibility and freedom Uncertain Dissatisfied Admonishing Strict		
Science Laboratory Environment Inventory (SLEI)	Upper Secondary/ Higher Education	7	Student cohesiveness	Open-endedness Integration	Rule clarity Material Environment
Constructivist Learning Environment Survey (CLES)	Secondary	7	Personal relevance Uncertainty	Critical voice Shared control	Student negotiation
What Is Happening In this Class (WIHIC)	Secondary	8	Student cohesiveness Teacher support Involvement	Investigation Task orientation Cooperation	Equity
Constructivist-Oriented Learning Environment Survey (COLES)	Secondary	11	Student cohesiveness Teacher support Involvement Young adult ethos Personal relevance	Task orientation Cooperation	Equity Differentiation Formative assessment Assessment criteria

Adapted from Fraser (2012)

Table 2.1 displays important questionnaires used in the learning environments field, and categorizes the scales of these questionnaires according to Moos' three dimensions. More dated questionnaires, as well as less commonly used questionnaires, are not included in this table. Additionally, the TROFLEI is omitted because it is described in a separate table (see Table 2.2).

Issues to consider in the design and administration of such questionnaires include the convenience of the survey in terms of its length, low reading level, and absence of negative wording, which could confuse respondents and invalidate the results. Many of the historically-significant questionnaires are quite lengthy, containing around 100 items and potentially creating fatigue for both respondents. Fraser (1982) reduced the number of items in several instruments while still maintaining the instruments' reliability, thereby creating a short form. Consequently, most of the more contemporary classroom environment questionnaires are relatively short and have scales containing 6–8 items.

As these instruments were developed, numerous different versions emerged. Lewin (1936) distinguished between beta press (subjective observation of a participant) and alpha press (objective observation by a detached observer) in advocating the consideration of teachers' and students' perspectives about their own educational processes. To accommodate further discrepancies in perceptions, many instruments include a personal form as opposed to a whole-class form (Fraser, Fisher, & McRobbie, 1996) so that, instead of generalized statements such as "Students learn from each other in this class", students are first asked to consider a more relevant statement based on their personal experiences, such as "I learn from other students in this class". The first such variation of this form was tested using the Science Laboratory Environment Inventory (see Section 2.3.2.2) for which item and factor analyses confirmed that the personal form had a similar factor structure and comparable statistical characteristics (e.g. internal consistency, discriminant validity) to the class form when either the individual student or the class mean was used as the unit of analysis. This study also revealed that students might have a more detached and often more positive view of the environment when perceiving it as a whole class rather than as an individual. According to the study, gender differences in perceptions of the environment were somewhat larger on the personal form than on the class form (Fraser, Giddings, & McRobbie, 1995). Therefore, the major advantage of the personal form is the increased sensitivity of the perceptions of subgroups (eg. gender) within the classroom, in contrast to the traditional class form to which students could respond inconsistently. For instance, when asked about whether the work in the class is difficult, some students might consider whether the whole class thinks that the work is difficult, while others perhaps perceive that certain students think that the work is difficult, and still others reflect on whether the work is difficult for themselves. In this confusion, it would be difficult to extract the perspectives of subgroups. This distinction between personal and class forms accommodates the distinction between 'private' beta press and 'consensual' beta press (Section 2.3.1).

To broaden understanding of a classroom environment from different perspectives, some forms are for students and others are for teachers, and yet others are for administrators; some forms are intended for a classroom setting and some for a whole-school setting (Fraser & Rentoul, 1982). There are even forms to distinguish between the 'actual' and the 'preferred' environment because students' perceptions of what actually occurs can differ from their perceptions of what they would have liked to occur in their classrooms; the wording for these actual and preferred forms differs somewhat (Fraser, 1998a). Often these actual and preferred forms are utilized to evaluate programs in terms of bridging the gap between what is actually occurring and what students would prefer. These distinctions between forms of questionnaires are considered further when reviewing instruments in Section 2.2.2.1 –2.2.2.11 and learning environment studies in Section 2.2.3.

The following sections review the learning environment instruments that have been developed in the field (including the instruments from which scales have been adapted for this study): the Learning Environment Inventory (LEI) and My Class Inventory (MCI) (Section 2.2.2.1), the Classroom Environment Scales (CES) (Section 2.2.2.2), the Individualized Classroom Environment Questionnaire (ICEQ) (Section 2.2.2.3), the College and University Classroom Environment Inventory (CUCEI) (Section 2.2.2.4), the Questionnaire on Teacher Interaction (QTI) (Section 2.2.2.5), the Constructivist Learning Environment Survey (CLES) (Section 2.2.2.6), the Science Laboratory Environment Inventory (SLEI) (Section 2.2.2.7), the What Is

Happening In this Class? (WIHIC) survey (Section 2.2.2.8), the Technology-Rich Outcomes-Focused Learning Environment Inventory (TROFLEI) (Section 2.2.2.9), the Constructivist-Orientated Learning Environment Survey (COLES) (Section 2.2.2.10), and a few other questionnaires (Section 2.2.2.11). The summaries in these sections provide a more detailed description of the learning environment questionnaires outlined in Table 2.1. Each instrument's synopsis below includes information about the number of scales and items within each scale, the age level for which the questionnaire is designed, past studies that have validated the questionnaire, and the fit or lack thereof with the current study.

2.2.2.1 Learning Environment Inventory (LEI) and My Class Inventory (MCI)

As part of an evaluation of the Harvard Physics Project in the late 1960s, Walberg formulated the Learning Environment Inventory (LEI), which was widely used in the United States for secondary classrooms (Walberg & Anderson, 1968). The LEI includes 15 scales (Cohesiveness, Friction, Favoritism, Cliqueness, Satisfaction, Apathy, Speed, Difficulty, Competitiveness, Diversity, Formality, Material Environment, Goal Direction, Disorganization, Democracy) each containing 7 items that are responded to in four gradations of agreement with some reverse–scored items. Because this instrument is geared towards a teacher-centered style of classroom and is quite lengthy, it is better suited to traditional educational environments at the secondary level. Furthermore, its length and complexity was not found suitable for students involved in this study.

Later, the LEI was adapted to be used with younger students (ages 8–12 years) as its item wording is simplified, its number of scales are trimmed to just 5 containing 25 items in the short form (Cohesiveness, Friction, Satisfaction, Difficulty, Competitiveness), and responses are reduced to a Yes–No format; this instrument became known as the My Class Inventory (MCI) (Fisher & Fraser, 1981; Fraser, Anderson, & Walberg, 1982). Swee Chiew Goh and Barry Fraser (1998) expanded the MCI's response option to include a three-point frequency scale (Seldom, Sometimes and Most of the Time) and included a Task Orientation scale, and then used the revised MCI in research in Singapore among primary mathematics students. The MCI has also been successfully employed in Brunei Darussalam with just three scales (Cohesiveness, Difficulty and Competition) to reveal sex differences in students' perceptions (Majeed, Fraser, & Aldridge, 2002). In the US, the MCI has been used in Florida to evaluate a K–5 mathematics program that integrates children's literature called Project SMILE (Science and Mathematics Integrated with Literature Experiences) (Mink & Fraser, 2005), in Texas to evaluate the use of science kits in primary school (Houston, Fraser, & Ledbetter, 2008), and in Washington as an accountability tool for elementary-school counselors (Sink & Spencer, 2005). Because this instrument is geared towards primary school students and the response options are limited, it was not considered relevant for this study.

2.2.2.2 Classroom Environment Scales (CES)

Moos (1974) developed the Classroom Environment Scales (CES) after evaluating and researching diverse human environments such as psychiatric hospitals, prisons, universities, and work settings in the US. The CES includes 9 scales (Involvement, Affiliation, Teacher Support, Task Orientation, Competition, Order and Organization, Rule Clarity, Teacher Control, Innovation) each containing 10 items answered in a True–False response format (Trickett & Moos, 1973). While some of the CES's scales were used in the current study, as they have been integrated into more contemporary questionnaires (i.e. Teacher Support and Task Orientation), the instrument in its entirety was not appropriate for use my study because it is geared towards a teacher-centered setting, and is lengthy and complex, and its response format is limited.

2.2.2.3 Individualized Classroom Environment Questionnaire (ICEQ)

In 1979, the Individualized Classroom Environment Questionnaire (ICEQ) was created to assess secondary individualized classrooms in Australia that differed from traditional classrooms in their openness and focus on inquiry-based education (Rentoul & Fraser, 1979). The final version (Fraser, 1990) includes 10 items for each of five scales (Personalization, Participation, Independence, Investigation, Differentiation) with a 5-point frequency response scale ranging from Almost Never to Very Often. Many items are reverse scored. Because of its reverse scoring and the fact that its factorial validity was never properly established (McKavanagh & Stevenson, 1992), the application of this instrument to the current study would have presented challenges, even though the scale of Investigation was used because it was borrowed from more recent questionnaires.

2.2.2.4 College and University Classroom Environment Inventory (CUCEI)

A similar questionnaire, called the College and University Classroom Environment Inventory (CUCEI), was developed for small-sized university classrooms. The CUCEI contains seven items in each of seven scales (Personalization, Involvement, Student Cohesiveness, Satisfaction, Task Orientation, Innovation, Individualization). The response style is a 4–point Likert scale of agreement and approximately half of the items are reverse scored (Fraser & Treagust, 1986). The CUCEI has been used to evaluate an alternative high school classroom in order to determine the presence of more student-centered features such as involvement, satisfaction, innovation and individualization (Fraser & Tobin, 1987) and in computing classrooms in New Zealand, where its psychometric performance had limitations (Logan, Crump, & Rennie, 2006). Therefore, the CUCEI was considered of limited use for this study.

2.2.2.5 Questionnaire on Teacher Interaction (QTI.

Another aspect of learning environments is the interpersonal relationship between teachers and students, which inspired the creation of the Questionnaire on Teacher Interaction (QTI) in the Netherlands for senior high school students (Wubbels, Brekelmans, & Hooymayers, 1991), as noted above. This survey assesses eight aspects of behavior drawing upon a theoretical model that considers proximity (cooperation–opposition) and influence (dominance–submission) between teachers and students. Each scale contains 8-10 items and responses are on a five-point frequency scale. The QTI has been cross-validated in many other countries and languages including the USA (Wubbels & Levy, 1993), Australia (Fisher, Henderson, & Fraser, 1995), Brunei Darussalam (Scott & Fisher, 2004), Singapore (Goh & Fraser, 1996; Quek, Wong, & Fraser, 2005), Korea (Kim, Fisher, & Fraser, 2000; Lee, Fraser, & Fisher, 2003), and Indonesia (Fraser, Aldridge, & Soerjaningsih, 2010). It has been adapted to relationships between principals and teachers in the Principal Interaction Questionnaire (PIQ) (Fisher & Cresswell, 1998). These important interactions between teacher and student have led to the inclusion in other learning environment instruments of scales such as Teacher

Support. While Teacher Support is a relevant dimension to assess in the current study, a more economical and current version of this scale was adopted from another, more current questionnaire (see Section 2.2.2.9).

2.2.2.6 Constructivist Learning Environment Survey (CLES)

A growing trend since the early part of this century has been the constructivist learning theory which postulates that learning is a proactive, cognitive process in which the learner makes sense of the world in relation to prior constructed knowledge through negotiation and consensus building. To assess the degree to which constructivist epistemology is reflected in the learning environment, including the teachers' epistemological assumptions and the students' awareness of the invisible forces that affect their thinking, the Constructivist Learning Environment Survey (CLES) was developed (Taylor, Fraser, & Fisher, 1997).

Large-scale quantitative and qualitative studies were conducted to validate the CLES with over 2,000 students in US and Australian classes (Taylor, Fraser, & Fisher, 1997). Sound validity was also reported from a cross-national study of junior high-school science classroom learning environments, which involved administering the English version of the CLES to 1,081 students in Australia, and administering the Mandarin version of the CLES to 1,879 students in Taiwan. This study also revealed that Australian classes were perceived as being more constructivist than Taiwanese classes (Aldridge, Fraser, Taylor et al., 2000). The CLES was further cross-validated by administering it to 1,864 students in South Africa. The focus this study was action research for South African teachers to become more reflective practitioners in their classrooms, with some improvements in the constructivist orientation of classrooms being noted (Aldridge, Fraser, & Sebela, 2004).

The validated CLES has been used in the evaluation of educational innovations (see Section 2.2.3.2 for further detail). For instance, data from the CLES revealed the success of novel teaching strategies in middle-school mathematics classrooms (Ogbuehi & Fraser, 2007) and of a new mathematics program called the Class Banking System (Spinner & Fraser, 2005). Additionally, when a teacher professional development program based on the Integrated Science Learning

Environment (ISLE) was evaluated using the CLES, the results showed that changing teachers' learning environment at the university level enhanced their students' middle-school classroom environments (Nix, Fraser, & Ledbetter, 2005).

As well, smaller-scale studies tested the instrument in various countries and languages. In the US, the CLES was validated numerous times (Beck, Czerniak, & Lumpe, 2000; Cannon, 1995; Harwell, Gunter, Montgomery et al., 2001). The CLES has been successfully used in Mandarin in Taiwan (Aldridge, Fraser, & Fisher, 2000), in Spanish in Miami (Peiro & Fraser, 2009), in Korean in the US (Cho, Yager, Park et al., 1997) and Korea (Oh & Yager, 2004), and in English in South Africa (Aldridge, Fraser, & Sebela, 2004). In 2004, a shortened form of the CLES was shown to be equally valid and reliable as the long form (Johnson & McClure, 2004); Nix and Fraser (Nix & Fraser, 2011) used this short form in the US with 845 students and reported strong support for its validity.

The final version of the CLES was a revision of the original version (Taylor & Fraser, 1991) that focused on students as co-constructors of knowledge but ignored the cultural context of the classroom environment. It contains 7 items per scale (Personal Relevance, Uncertainty, Critical Voice, Shared Control, Student Negotiation) with responses on a 5-point frequency scale. Its advantages include an organizational arrangement of items in blocks for the respondent and minimal use of negative wording. While constructivism is a desirable dimension featured in virtual laboratories, none of the CLES scales seemed relevant for assessing their implementation and so this instrument was of limited use for this study.

2.2.2.7 Science Laboratory Environment Inventory (SLEI)

The Science Laboratory Environment Inventory (SLEI) was designed specifically to assess the unique role of the laboratory in a high school or university science class, which is also an important factor in the psychosocial makeup of the learning environment. In particular, this instrument can be used to address effectiveness of science laboratory classes and whether the associated costs are justified (Fraser, Giddings, & McRobbie, 1992). In developing the SLEI, relevant literature was reviewed to identify dimensions important in the unique environment of a science laboratory class and this was compared to dimensions in existing instruments. In addition, students and teachers were interviewed to provide comments to guide revisions to the survey during the various stages. Furthermore, student data collected using the SLEI were subjected to item and factor analysis, which resulted in the final version containing 7 items per scale (Student Cohesiveness, Open-Endedness, Integration, Rule Clarity, Material Environment) with responses on a 5-point frequency scale (Newby & Fisher, 1997).

Advantages of this instrument include its economical administration (in that it is short) and easy hand scoring, its cyclic design, and the availability of the personal and class versions and the actual and preferred forms, which were all shown to be equally valid and reliable (Fraser, Giddings, & McRobbie, 1992). One shortcoming of this instrument is that it contains some reverse items in the original version, although wording can be easily modified to include only positive statements.

A sample of over 5,447 students in 269 classes in the USA, Canada, England, Israel, Australia, and Nigeria was used to field test and validate the SLEI (Fraser & McRobbie, 1995). Simultaneous testing revealed consistent scores on internal consistency reliability and discriminant validity when used with 1,594 students in 92 classes (Fraser, Giddings, & McRobbie, 1995), as well as predictive validity when used along with attitude scales to predict the effect on student outcomes (Fraser, Giddings, & McRobbie, 1992). Further validation was accomplished through a study of 489 senior high-school biology students in Australia by Fisher, Henderson and Fraser (1997).

The SLEI was also translated into Korean for use in a study of differences between the classroom environments of three streams (science-independent, science-oriented and humanities), consisting of 439 high-school students in total. This version of the SLEI exhibited sound factorial validity and internal consistency reliability, and was able to differentiate between the perceptions of students in different classes. Generally students in the science-independent stream perceived their laboratory classroom environments more positively than did students in either of the other two streams (Fraser & Lee, 2009).

To illustrate its application in the evaluation of educational innovations, the SLEI, or adaptations, was employed in assessing an innovative science course for prospective elementary teachers (Martin-Dunlop & Fraser, 2007) and the effect of anthropometric activities on a classroom learning environment (Lightburn & Fraser, 2007). Each of these studies is explored in detail in Section 2.2.3.2.

The SLEI has also been adapted to more specific environments, such as the Chemistry Laboratory Environment Inventory (CLEI), which was found to be valid when used in Singapore to uncover associations between the learning environment and attitudes (Wong & Fraser, 1996) and to assess the differences in chemistry laboratory environments between streams (gifted versus non-gifted) and sexes (Quek, Wong, & Fraser, 2005).

At around the same time, adaptations were made to the SLEI for use for courses in which computing technology is a fundamental tool. The Computer Laboratory Environment Inventory (CLEI) was developed to assess the learning environment of a computer laboratory in higher education and was tested with 80 college-level students (Newby & Fisher, 1997). The survey contains 5 scales (Student Cohesiveness, Open-Endedness, Integration, Technology Adequacy, Material Environment) and responses are on a 5-point frequency scale.

As a whole, the SLEI, with its focus on laboratory classroom environments seemed to be an appropriate instrument for use in the current study of the effectiveness of an alternative laboratory. However, most of the scales are geared towards hands-on experimentation in a whole-class setting involving social aspects of the classroom (i.e. Student Cohesiveness, Open-Endedness, Rule Clarity) and therefore are irrelevant to the setting of the study, which focused on the individual student. Therefore, only the scales of Integration and Material Environment were borrowed from the SLEI for use in the current study's instrument because they pertain to various aspects of virtual laboratories.

The personal form of the SLEI was more appropriate for this study to ensure that students provided their own perspectives rather than their perspectives of the whole class. Also, the actual version of the SLEI scales was applicable to the circumstances because changing the environment in light of student preferences was not part of my study. For use among high-school science students, the language was modified to include only positively-worded items to avoid confusion. Also, an item was added to each SLEI scale to maintain consistency in the number of items in other scales in this study's instrument.

2.2.2.8 What Is Happening In this Class? (WIHIC)

The What Is Happening In this Class? (WIHIC) questionnaire is important in this literature review because it is the most frequently-used classroom environment instrument around the world today and because it formed the foundations for the development of the Technology-Rich Outcomes-Focused Learning Environment Inventory (TROFLEI), which was selected for use in my study.

The original What Is Happening In this Class? (WIHIC) was developed by Fraser, McRobbie, and Fisher (1996) to combine previous questionnaires and incorporate contemporary educational concerns such as equity and constructivism. It was found to be reliable and valid when tested with a sample of 50 high school classes each in Australia and Taiwan (in Chinese). Interestingly, even though Australian students viewed their learning environments more favorably, Taiwanese students had more positive attitudes towards science. Many of the studies employing the WIHIC investigated associations between perceptions of the learning environment and attitudes towards learning; for a more comprehensive description of these studies, see Fraser's review of Classroom Learning Environments (Fraser, 2012).

Originally consisting of 90 items in nine scales, the WIHIC was field tested with 355 middle school students. Factor analysis and interviews resulted in a revised form containing 56 items in 7 scales (Student Cohesiveness, Teacher Support, Involvement, Investigation, Task Orientation, Cooperation, Equity) with a 5-point frequency scale (Aldridge, Fraser, & Huang, 1999). In addition to its wide use and validity, the WIHIC's items are organized in blocks, there are no reverse-scored items (to minimize confusion), and there is a personal and class form available to accommodate differences in individualized perceptions of the classroom (Aldridge, Fraser, & Huang, 1999; Fraser, 1998a). This instrument has been extensively applied to various subject areas, age levels, and countries, and is available in many languages, as described below.

In a second round of field testing of the WIHIC with 1,081 students in Australia and 1,879 students in Taiwan using a Chinese version, Aldridge and colleagues reported strong factorial validity and internal consistency reliability and that each scale was capable of differentiating significantly between the perceptions of students in different classrooms (Aldridge, Fraser, & Fisher, 2000). In fact, these sound psychometric qualities have been replicated in every study using the WIHIC.

A comprehensive validation was conducted by Dorman using a cross-national sample of 3,980 high-school students from Australia, the UK, and Canada. The use of multi-sample analyses within structural equation modeling for the three grouping variables of country, grade level, and student sex supported "the wide international applicability of the WIHIC as a valid measure of classroom psychosocial environment" (Dorman, 2003, p. 231). Another such study validated both the actual and preferred forms of the WIHIC using multi-trait–multi-method modeling, with the seven scales as traits and the two forms of the instrument as methods; this study involved 978 secondary-school students from Australia (Dorman, 2008).

The WIHIC has been translated into Mandarin for use in Taiwan (Aldridge, Fraser, & Fisher, 2000; Aldridge, Fraser, & Huang, 1999), Indonesian for use in Indonesia (Fraser, Aldridge, & Adolphe, 2010; Wahyudi & Treagust, 2004), Korean for use in Korea (Kim, Fisher, & Fraser, 2000), Arabic for use in the UAE (Afari, Aldridge, Fraser et al., in press; MacLeod & Fraser, 2010), and Spanish for use in Miami in the US (Allen & Fraser, 2007; Helding & Fraser, in press; Robinson & Fraser, in press). Additionally, countries where the instrument has been validated in English, besides the aforementioned studies in Australia, include the US (Allen & Fraser, 2007; den Brok, 2006; Helding & Fraser, in press; Martin-Dunlop & Fraser, 2007; Ogbuehi & Fraser, 2007; Pickett & Fraser, 2009; Robinson & Fraser, in press; Wolf & Fraser, 2008), Canada (Zandvliet & Fraser, 2004, 2005), Singapore (Chionh & Fraser, 2009; Khoo & Fraser, 2008), India (Koul & Fisher, 2005), South Africa (Aldridge, Fraser, & Ntuli, 2009), and Turkey (den Brok, Telli, Cakiroglu et al., 2010).

Because of its robustness, the WIHIC's scales have been adapted for use with other instruments in particular environments in many different areas of research. For instance, 2,638 grade 8 science students from 50 schools in the Limpopo Province of South Africa were used as a sample to develop and validate a classroom environment instrument in the Sepedi language for monitoring the implementation of outcomes-based classroom environments. The Outcomes-Based Learning Environment Questionnaire (OBLEQ) contains four scales from the WIHIC, in addition to three other scales (Aldridge, Laugksch, Seopa et al., 2006).

Greek versions of two scales of the WIHIC, namely, Involvement and Teacher Support, were incorporated into a new questionnaire entitled How Chemistry Class is Working (HCCW), which was validated with over 1600 students in Greece and Cyprus. A more positive classroom environment was perceived among Cypriot students than among Greek students (Giallousi, Gialamas, Spyrellis et al., 2010).

The WIHIC's use (either in its entirety or in adaptations) in the evaluation of educational innovations is illustrated in the following studies, all of which are expanded upon in Section 2.2.3.2: inquiry laboratory teaching in middle schools (Wolf & Fraser, 2008); a new science course for prospective elementary school teachers (Martin-Dunlop & Fraser, 2007); innovative teaching strategies in middle-school mathematics classes (Ogbuehi & Fraser, 2007); computer-networked high school classrooms in Australia and Canada (Zandvliet & Fraser, 2005); the physical and psychosocial environments in internet classrooms in Canada (Zandvliet & Buker, 2003); and laptop use in science and mathematics classes in Canada (Raaflaub & Fraser, 2002).

Owing to its outstanding validity, widespread use, and ease of administration amongst students, the WIHIC would have been a sound choice for use in the current study. However, because the more-recent TROFLEI builds on the WIHIC and is more relevant to the technological aspects of this study, the TROFLEI provided a better choice for my study.

2.2.2.9 Technology-Rich Outcomes-Focused Learning Environment Inventory (TROFLEI)

Outcomes-focused education has been espoused by educational researchers and adopted in many countries as an approach to educational reform in which planning, delivery, and assessment all focus on the student outcomes that result from teaching rather than on content (Fraser, 2012); this approach is also often referred to as 'backward planning' (Wiggins & McTighe, 2005). Appropriate instruments are necessary in order to evaluate this approach to education. As well, the integration of technology into education is a contemporary dimension of classroom environments. This reflects the view that the classroom environment is dynamic rather than static and that instrumentation to evaluate new dimensions needs to be continually devised. Rather than using a generalized instrument 'off the shelf', it is now common to validate context-specific instruments when conducting classroom environment research (Dorman, Aldridge, & Fraser, 2006).

To this end, the Technology-Rich Outcomes-Focused Learning Environment Inventory (TROFLEI) was designed as an innovative, modern instrument by Aldridge and Fraser (2003) in Australia to meet these two growing trends of research. It draws upon the WIHIC and incorporates all of its seven scales (Student Cohesiveness, Teacher Support, Involvement, Investigation, Task Orientation, Cooperation, Equity), but includes three additional dimensions (Differentiation, Computer Usage, Young Adult Ethos) to permit investigation of learning environments that are outcomes-based and technology-rich. Each of the 10 scales consists of 8 items that are responded to using a five-point frequency scale (Almost Never, Seldom, Sometimes, Often and Almost Always).

The TROFLEI has been applied across all learning areas using both the personal and class forms and actual and preferred forms (Aldridge & Fraser, 2008). A unique aspect of the TROFLEI is that it employs a side-by-side response format, which enables students to provide their separate perceptions of actual and preferred classroom environment in an economical way. To provide contextual cues and to minimize confusion to students (Aldridge et al., 2000), TROFLEI items that belong to the same scale are grouped together instead of arranging them randomly or cyclically. Only positively-worded items are employed to ease students' understanding of the statements, as indicated in past studies (Barnette, 2000).

The TROFLEI was originally validated in a study of 1,035 students in grades 10 and 11 at Seven Oaks Senior College in Western Australia (Aldridge & Fraser, 2003), which has an emphasis on outcomes-focused education and the use of Information

Communication Technology (ICT). More extensive validation was carried out using a larger sample of 2,317 students from 166 grade 11 and 12 classes from Western Australia and Tasmania. During its first year of operation, the new school was subjected to formative and summative evaluation that included use of the TROFLEI. The study revealed strong factorial validity and internal consistency reliability for both the actual and preferred forms of the TROFLEI. As well, the actual form of each scale was capable of differentiating between the perceptions of students in different classrooms. Results after four years supported the efficacy of the school's educational programs and offered insights regarding differences in the classroom environment perceptions between males and females and between students enrolled in university-entrance examinations and in wholly school-assessed subjects (Aldridge & Fraser, 2008). Furthermore, Aldridge, Dorman and Fraser (2004) used multi-trait-multi-method modeling with a sub-sample of 1,249 students, of whom 772 were from Western Australia and 477 were from Tasmania, to support the TROFLEI's construct validity and sound psychometric properties, including that the actual and preferred forms share a common structure.

Employing structural equation modeling with a sample of 4,146 grade 8–13 students, Dorman and Fraser (2009) used the TROFLEI to establish associations between students' affective outcomes and their classroom environment perceptions. With the same sample, the authors also applied cluster analysis to the TROFLEI responses in order to identify five relatively homogeneous groups of classroom environments: exemplary, safe and conservative, non-technological teacher-centered, contested technological, and contested non-technological (Dorman, Aldridge, & Fraser, 2006).

In addition to validation studies in Australia and Tasmania, the TROFLEI, in its entirety, has been validated amongst secondary science students in a number of other countries. For secondary science students in both India (Gupta & Koul, 2007) and New Zealand (Koul, Fisher, & Shaw, 2011), the TROFLEI was shown to be a valid questionnaire to assess a technology-rich learning environment. Females perceived a more positive technology-rich learning environment than males, confirming previous findings regarding females' positive perceptions of the learning environment. As well, associations were found for scales of the TROFLEI and three affective outcomes scales (attitude to subject, attitude to computers, and academic efficacy) (Koul, Fisher, & Shaw, 2011).

Table 2.2 Scale Description, Moos' Dimension, and Sample Item for Each Technology-Rich Outcomes-Focused Learning Environment Inventory (TROFLEI) Scale

Environment Scale	Scale Description	Moos' Dimension	Sample Item
Student Cohesiveness	The extent to which students know, help, and are supportive of one another.	Relationship	I am friendly to members of this class.
Teacher Support	The extent to which the teacher helps, befriends, trusts, and is interested in students.	Relationship	The teacher takes an interest in me.
Involvement	The extent to which students have attentive interest, participate in discussions, do additional work and enjoy the class.	Relationship	I explain my ideas to other students.
Task Orientation	The extent to which it is important to complete activities planned and stay on the subject matter.	Personal Development	I know how much work I have to do.
Investigation	The extent to which skills and processes of enquiry and their use in problem solving and investigation are emphasized.	Personal Development	I carry out investigations to test my ideas.
Cooperation	The extent to which students cooperate rather than compete with one another on learning tasks.	Personal Development	I share my books and resources with other students when doing assignments.
Equity	The extent to which students are treated equally by the teacher.	System Maintenance and Change	I get the same opportunity to answer questions as other students.
Differentiation	The extent to which teachers cater for students differently on the basis of ability, rate of learning and interests.	System Maintenance and Change	I do work that is different from other students' work.
Computer Usage	The extent to which students use their computers as a tool to communicate with others and to access information.	System Maintenance and Change	I use the computer to take part in online discussion with other students.
Young Adult Ethos	The extent to which teachers give students responsibility and treat them as young adults.	Relationship	I am encouraged to take control of my own learning.

(Koul, Fisher, & Shaw, 2011)

Another validation study was conducted cross-culturally with 980 Turkish and 130 American high school science students in grades 9–12. This study revealed sound psychometric properties of the TROFLEI for use with both populations (Welch, Cakir, Peterson et al., 2012). The TROFLEI was also validated in Thailand involving tertiary-level students in electronics laboratories (Promratrak & Malone, 2006).

Table 2.2, adapted from Koul, Fisher, and Shaw (2011), displays for each of the 10 scales of the TROFLEI, a scale description, its categorization under Moos' dimensions, and a sample item. The scales chosen for use in the current study are discussed at greater length in Chapter 3.

Considered to be an instrument of choice for technology-integrated environments, this unique questionnaire has numerous applications. For instance, in their overview of instrumentation for virtual high schools, Black et al. (2008) consider that the TROFLEI is robust, especially for adult populations. Individual scales have been adopted in newly-created instruments for ICT around the world including in Taiwan (Wu, Chang, & Guo, 2009) and Belgium (Van Petegem, Deneire, & De Maeyer, 2008).

2.2.2.10 Constructivist-Orientated Learning Environment Survey (COLES)

As an outgrowth of the WIHIC and TROFLEI, the Constructivist-Orientated Learning Environment Survey (COLES) was recently designed to provide feedback as a basis for reflection in teacher action research. It differs from its predecessor instruments in that it addresses important aspects related to the assessment of student learning, a feature lacking in all existing classroom environment questionnaires. Therefore, Aldridge, Fraser, Bell and Dorman (2012) constructed two new COLES scales related to assessment: Formative Assessment (the extent to which students feel that the assessment tasks given to them make a positive contribution to their learning) and Assessment Criteria (the extent to which assessment criteria are explicit so that the basis for judgments is clear and public). As a foundation, the COLES incorporates six of the WIHIC's seven scales (namely, Student Cohesiveness, Teacher Support, Involvement, Task Orientation, Cooperation and Equity), while omitting the WIHIC's Investigation scale. Like the TROFLEI, the COLES also includes the scales of Differentiation and Young Adult Ethos. In addition, the Personal Relevance scale (the extent to which learning activities are relevant to the student's everyday out-of-school experiences) was also borrowed from the CLES for inclusion in the COLLES.

Data analysis supported the sound factorial validity and internal consistency reliability of both actual and preferred versions of the COLES for a sample of 2,043 grade 11 and 12 students in Western Australian schools. In addition, the actual form of the COLES was capable of differentiating between the perceptions of students in different classrooms. In order to provide feedback as a basis for reflection in teacher action, results from the COLES were also complemented by students' reflective journals, written feedback, discussion at a forum, and teacher interviews. The experiences of these teachers concerning the viability of using feedback from the COLES was considered as part of their action research aimed at improving their classroom environments (Aldridge et al., 2012).

2.2.2.11 Other Questionnaires

The evolution of learning environments reflects the changing values of society towards education; the follow ing illustrates how some instruments adapted to those changes. Fraser (2012) reviews a broader spectrum of these alternative questionnaires. Of particular interest to this study are measures to assess learning environments involving technological adaptations.

Instruments that have been developed to assess remote learning environments at the post-secondary level include the Distance and Open Learning Environment Scale (DOLES) for higher education (Jegede, Fraser, & Fisher, 1995) and the Distance Education Learning Environments Survey (DELES) (Walker & Fraser, 2005). The DOLES contains the five core scales of Student Cohesiveness, Teacher Support, Personal Involvement and Flexibility, Task Orientation and Material Environment, and Home Environment, as well as the two optional scales of Study Center Environment and Information Technology Resources. The DELES was constructed online and includes six scales (Instructor Support, Student Interaction and Collaboration, Personal Relevance, Authentic Learning, Active Learning and Student Autonomy).

The Web-Based Learning Environment Instrument (WEBLEI) was developed to assess students' perceptions of online learning environments for higher education. The online mode of education represents a paradigm shift in learning environments as it involves a separation of time and place between teacher and learner, between learners, and between learners and learning resources. A study conducted with university students in Australia, the majority of whom were new to the concept of an online mode for coursework, validated the questionnaire's four scales of Access, Interaction, Response, Results (Chandra & Fisher, 2009).

Another questionnaire, the Online Learning Environment Survey (OLLES), was designed to capture students' perceptions of their online learning environment and to assess new information and communication via technology-rich ways of teaching and learning. The validation was based on respondents from universities in New Zealand and Australia for various levels and course subjects. The survey is more individual-based as there is no real concept of a class. It includes 49 items in 7 scales: Computer Competence, Material Environment, Student Collaboration, Tutor Support, Active Learning, Information Design and Appeal, and Reflective Thinking (Clayton, 2007).

In the case of digitalized classrooms, the physical components of the learning environment grow increasingly important in addition to the psychosocial factors which can influence the learning outcomes. Therefore, the Computerized Classroom Ergonomic Inventory (CCEI), containing scales such as Workspace Environment, Computer Environment, Visual Environment, Spatial Environment, and Overall Air Quality (Kroemer & Grandjean, 1997), was used in a number of studies evaluating technology-rich learning environments (Zandvliet & Fraser, 2005). Maor and Fraser (1996) developed and validated a five-scale classroom environment instrument in Australia (assessing Investigation, Open-Endedness, Organization, Material Environment and Satisfaction) based on the LEI, ICEQ and SLEI. Teh and Fraser (1994) developed and validated a four-scale instrument in Singapore to assess Gender Equity, Investigation, Innovation and Resource Adequacy.

While such questionnaires to assess alternative classroom environments were somewhat relevant to the current study, each was too specific in the environment that it assesses. Therefore, they were used as a reference to modify wording of specific items within scales that were adopted from more generalized questionnaires as described in Sections 2.2.2.7 and 2.2.2.9. Specifically, the OLLES informed modifications necessary for the Material Environment scale adopted from the SLEI. In order to maximize validity and reliability of this study, the author chose to balance the need to customize instrumentation to the specific aspects of this study with the robustness of more standardized questionnaires such as the SLEI and TROFLEI detailed above.

2.2.3 Past Applications of Learning Environment Scales

The learning environment instruments described above have been used to pursue numerous lines of past research. Specific lines of past research within the field of learning environments, which are briefly reviewed below, are associations between student outcomes and the learning environment (Section 2.2.3.1), teachers' efforts to improve the classroom environment (Section 2.2.3.2), comparison of actual and preferred environments (Section 2.2.3.3), cross-national studies (Section 2.2.3.4), and other lines of research (Section 2.2.3.5). Finally, Section 2.2.3.6 singles out the line of research that pertains to this study, namely, using learning environment dimensions as criterion variables in the evaluation of educational innovations.

2.2.3.1 Associations Between Student Outcomes and Environment

Past research has consistently linked the nature of the learning environment with students' cognitive (i.e. achievement) and affective (eg. attitudes) learning outcomes. In fact, a multitude of factors have a multiplicative, diminishing-returns effect on educational productivity, as theorized by Walberg's (1981) economic model of agricultural, industrial, and cultural productivity: age, ability, motivation, quality and quantity of instruction, and the psychosocial environments of the home, classroom, per group, and mass media. The effect of these factors is multiplicative in that any factor at zero point (e.g. motivation) will result in zero learning, and therefore it is better to improve a limiting factor that is low rather than to improve a factor that is already functioning well. While there is this multitude of factors that affect educational productivity, the psychosocial learning environment has emerged as a strong predictor of both achievement and attitudes even when other factors are held constant (Fraser, 2007, 2012). In other words, students' perceptions of their classroom environments, relative to other influential forces such as students' backgrounds, are more closely associated with learning outcomes.

Associations of learning outcomes and students' perceptions of the psychosocial characteristics of their classrooms is a common and historic area of interest amongst learning environment investigations, and such associations have been replicated for a variety of measures, instruments, and sample populations in different countries and at different age levels (Fraser, 1994).

For instance, in evaluating computer-assisted instruction, Teh and Fraser (1994) established associations between classroom environment, achievement and attitudes among a sample of 671 high-school geography students in Singapore. Using the QTI, associations between student outcomes and perceived patterns of teacher–student interaction were reported for samples of 489 senior high-school biology students in Australia (Fisher, Henderson, & Fraser, 1995) and 1,512 primary-school mathematics students in Singapore (Goh, Young, & Fraser, 1995). The WIHIC has been employed in over a dozen different studies in various countries and languages, and amongst diverse populations, which also showed associations between classroom learning environment and student outcomes (Fraser, 2012).

A positive learning environment, specifically in science laboratories, has been found to lead to improved attitudes towards science (Hofstein & Walberg, 1995). Scales from the SLEI were found to be associated with students' cognitive and affective outcomes for a sample of approximately 80 senior high-school chemistry classes in Australia (Fraser, Giddings, & McRobbie, 1995; McRobbie & Fraser, 1993), 489 senior high-school biology students in Australia (Fisher, Henderson, & Fraser, 1997) and 1,592 grade 10 chemistry students in Singapore (Wong & Fraser, 1996).

Even though many past learning environment studies have employed techniques such as multiple regression analysis, oversight in this method results because classroom environment data are typically derived from students grouped in pre-formed classes, which are inherently hierarchical. Therefore, multilevel analysis is appropriate under such conditions to avoid aggregation bias and imprecision. Two studies of outcome-environment associations compared the results obtained from multiple regression analysis with those obtained from an analysis involving the hierarchical linear model (HLM). The multiple regression analyses were performed separately at the individual student level and the class mean level. In the HLM analyses, the environment variables were investigated at the individual level and also they were aggregated at the class level. In a study involving 1,592 grade 10 students in 56 chemistry classes in Singapore, associations were investigated between three student attitude measures and a modified version of the SLEI (Wong, Young, & Fraser, 1997). In Goh, Young and Fraser's (1995) study with 1,512 grade 5 mathematics students in 39 classes in Singapore, scores on a modified version of the MCI were related to student achievement and attitude. The two methods produced results that were consistent in strength and in direction.

Using a large sample of high school students in Turkey, a translated version of the QTI was administered in conjunction with an attitude questionnaire to explore associations between teacher–student interpersonal behavior and students' attitudes to science. The use of multilevel analysis revealed that the influence dimension of the QTI was related to student enjoyment, while proximity was associated with attitudes to inquiry (den Brok et al., 2010). In another study involving the TROFLEI, the classroom environment was investigated by applying structural equation modeling using LISREL, antecedent variables (gender, grade level, and home computer and Internet access), and student affective outcomes (attitude to the subject, attitude to computer use and academic efficacy) among 4,146 high-school students from Western Australia and Tasmania. Results revealed that: improving classroom environment had the potential to improve student outcomes; antecedents did not have any significant direct effect on outcomes; and academic efficacy mediated the effect of several classroom environment dimensions on attitude to subject and attitude to computer use (Dorman & Fraser, 2009).

Table 2.3 Some Studies of Associations Between the Learning Environment and Student Outcomes

Study	Outcome Measures	Sample
Studies Involving the MCI		
Fraser & Fisher (1982b)	Inquiry skills; understanding of nature of science; attitudes	2,305 Grade 7 science students in 100 classes in Tasmania, Australia
Goh, Young, & Fraser (1995)	Attitudes	1,512 primary school students in Singapore
Majeed, Fraser, & Aldridge (2002)	Attitudes	1,565 mathematics students in 81 classes in Brunei Darussalam
Studies Involving the SLEI		
Fraser & McRobbie (1995); McRobbie & Fraser (1993)	Attitudes	Approximately 80 senior high school chemistry classes in Australia
Fisher, Henderson, & Fraser (1997)	Attitudes	489 senior high school biology students in Australia
Wong & Fraser (1996)	Attitudes	1,592 Grade 10 chemistry students in Singapore
Lightburn & Fraser (2007)	Attitudes	761 high-school students in the US
Quek, Wong, & Fraser (2005)	Attitudes	497 secondary school students in Singapore (using an adaptation, the CLEI)
Studies Involving the CLES		
Kim, Fisher, & Fraser (1999)	Attitudes	1,083 Grade 10 and 11 science students in 24 classes in Korea
Aldridge, Fraser, Taylor, & Chen (2000)	Attitudes	1,081 Grade 8–9 science students in Taiwan and 1,879 Grade 7–9 science students in Australia
Aldridge, Fraser, & Sebela (2004)	Attitudes	1,843 Grade 4–9 students in 29 mathematics classes in South Africa
Nix, Fraser, & Ledbetter (2005)	Attitudes	1,079 high school students in 59 classes in Texas, USA
Studies Involving the WIHIC		
Aldridge et al. (1999); Aldridge & Fraser (2000)	Enjoyment	1,081 junior high school students in Australia and 1,879 such students in Taiwan
Kim, Fisher, & Fraser (2000)	Attitudes	543 Grade 8 students in 12 schools in Korea
Telli, Çakıroğlu, & Brok (2006)	Attitudes	1,983 students in 57 classrooms in Turkey
Wolf (2008)	Attitudes	1,434 middle-school science students in 71 classes in the US
Fraser & Chionh (2009)	Achievement, Attitudes, and Self-esteem	2,310 grade 10 geography and mathematics students in Singapore
Fraser, Aldridge, & Adolphe (2010)	Attitudes	567 high-school science students in Australia and 594 such students in Indonesia
Studies Involving the TROFLEI		
Dorman & Fraser (2009)	Attitudes	4,146 grade 8–13 students in Western Australia and Tasmania
Koul, Fisher, & Shaw (2011)	Attitude to subject, Attitude to Computers, and Academic Efficacy	1,027 high-school students in New Zealand

A meta-analysis conducted by Haertel, Walberg and Haertel (1981) involving 734 correlations from 12 studies involving 823 classes, eight subject areas, 17,805 students and four nations revealed associations between various dimensions of the learning environment and student outcomes. Additionally, correlations were generally higher in samples of older students and in studies employing collectivities such as classes and schools (in contrast to individual students) as the units of statistical analysis. In particular, higher achievement on a variety of outcome measures was found consistently in classes perceived as having greater Cohesiveness, Satisfaction and Goal Direction and less Disorganization and Friction. Other meta-analyses also provide further evidence supporting the link between educational environments and student outcomes (Fraser, Walberg, Welch et al., 1987).

In summary, classroom and school environment dimensions consistently have been found to be strong predictors of both achievement and attitudes even when a comprehensive set of other factors are held constant. Consequently, the rationale for investigating associations between learning environments and learner outcomes in my study was that an educational innovation (i.e. virtual laboratories) influences the learning environment which, in turn, is likely to be linked to improved attitudes and achievement.

Table 2.3 displays details of some of the well-known studies that have established associations between learning environment scales and various measures of student outcomes. These studies are organized in the table below according to which specific learning environment instrument was employed in the study. Other information about each study, such as the sample size, grade level, and location, is also shown.

2.2.3.2 Action Research: Teachers' Efforts to Improve Classroom Environments

Because the study of educational environments is ultimately intended to lead to implementing changes beneficial for students, the evaluation of reform efforts should include classroom environment dimensions to provide process measures of effectiveness. However, much of the research specific to the field of learning environments has remained unfamiliar to teachers. Fraser (1986) describes how feedback information based on student or teacher perceptions can be employed as a basis for reflection upon, discussion of, and systematic attempts to improve classroom and school environments. Therefore, this section reviews this specific line of research involving teachers' use of learning environment perceptions in guiding practical attempts to improve their own classrooms and schools.

Fraser and Fisher's (1986) case studies of teachers attempting to improve their classroom environment involved five steps: assessment when students were given the preferred form of the CES and one week later the actual form; feedback to the teachers from students' responses regarding the gap between the preferred and the actual environment; private reflection and informal discussion that helped the teacher to consider which dimensions require intervention; intervention for about a two-month period during which specific strategies to address dimensions of concern were implemented; and reassessment at which point students again responded to the actual form of the CES to determine whether the changes they preferred indeed had occurred. Some changes in the actual environment did occur as a result, and two of the dimensions on which significant changes were recorded were those on which the teacher had specifically attempted to change.

This practical approach to learning environments research has been used with pre-service teacher education students in their own university settings and in their students' school classrooms (Yarrow, Millwater, & Fraser, 1997), as well as with in-service teachers (Aldridge, Fraser, & Ntuli, 2009). For instance, in South Africa, two such studies were conducted using action research in an attempt to improve teachers' classroom learning environments. In Aldridge, Fraser and Ntuli's (2009) study, 31 in-service teachers undertaking a distance-education program administered an adapted version of the WIHIC in the IsiZulu language to 1077 primary school students, which enabled some of the teachers to use feedback from the questionnaire to improve their classroom environments with varying degrees of success. In Aldridge, Fraser and Sebela's (2004) study, a group of 29 mathematics teachers in South Africa administered the English version of the CLES to their primary-level students and some of the teachers were able to improve the constructivist orientation of their classrooms.

In the US, Sinclair and Fraser (2002) used the actual and preferred forms of a questionnaire based on the WIHIC to guide changes in their classrooms' learning environments. Results generally supported the success of teachers' attempts to change their classroom environments based on feedback from the students, but they also indicated that efforts to change the learning environment should involve different interventions for students of different genders.

Most recently, the COLES was used as a basis for reflection for teachers' attempts to bridge the gap between preferred and actual classroom environments over a six-week period. The COLES was administered as a pre-test and post-test with the aim being for teachers to use the feedback from the pre-test to reduce the actual–preferred discrepancies on selected COLES scales by the time of the post-test. In this particular study, the authors created a novel method, using circular profiles, to communicate to the teachers feedback information based on students' responses to the COLES. Qualitative data were also collected from reflective journals, written feedback, forum discussions and teacher interviews. Teachers felt that this process enabled them to reflect on their teaching practices and ultimately to help them to improve their classroom environments (Aldridge et al., 2012).

2.2.3.3 Comparison of Actual and Preferred Environments

As described in Section 2.3.2, different versions of learning environment instruments are available to distinguish between students' perception of the actual environment and their preferred environment. Interestingly, a number of studies showed that students preferred a more positive classroom environment than was actually present on all dimensions within a survey, and teachers perceived a more positive actual classroom environment than did their students in the same classrooms on most of the dimensions on that same survey (Fisher & Fraser, 1983; Fraser, Giddings, & McRobbie, 1995; Moos, 1974). Subsequently, the question arises as to whether students would perform better in their preferred environments. To this end, Fraser and Fisher (1983) used the CES and ICEQ with a sample of 116 class means and found that actual–preferred congruence (or person–environment fit) could be as important as the actual classroom environment in predicting student achievement of cognitive and affective learner outcomes. Therefore, outcomes might be enhanced by attempting to change the actual classroom environment in order to increase congruence with student preferences.

2.2.3.4 Cross-National Studies

With the recent globalization of the economy, new vistas open for education in the international arena as well. Approaching educational environments from a cross-national perspective is advantageous in that variation (such as teaching methods, student attitudes, new nationalities) is increased within the sample for a study, and in that standard practices in one country can be called into questioned in an unbiased manner in another country (Fraser, 2012).

A landmark cross-national learning environment study (Aldridge, Fraser, & Huang, 1999) involving a collaboration between six Australian and seven Taiwanese researchers involved the administration of the WIHIC to 50 junior high-school science classes in each of Taiwan (1,879 students) and Australia (1,081 students). The questionnaire was available in both English and Mandarin, and the translation was double-checked by external translators. In addition to students' scores from the questionnaires, qualitative data, involving interviews with teachers and students and classroom observations, were also collected. The largest differences in the means between the two countries were found for the scales of Involvement and Equity, with Australian students perceiving each scale more positively than students from Taiwan. The qualitative data provided valuable insights into the perceptions of students cross-nationally, helped to explain some of the differences in the means between countries, and highlighted the need for caution in the interpretation of differences between the questionnaire results from two countries with cultural differences. A similar study was conducted at the cross-national level involving the use of the CLES in Taiwan and Australia (Aldridge et al., 2000).

In a separate study, the WIHIC was validated in two languages in Indonesia (in Bahasa) and in Australia (in English) and some differences were found between countries, as well as for different sexes. This study also confirmed associations between the learning environment and several attitude scales (Fraser, Aldridge, & Adolphe, 2010).

In designing new instruments, it is important to validate them across nations simultaneously, and many such questionnaires were developed in this way. For instance, the SLEI was validated across the USA, Canada, Australia, England, Israel, and Nigeria (Fraser, Giddings, & McRobbie, 1992) and the WIHIC was validated using students in Australia, England, and Canada (Dorman, 2003). As well, the TROFLEI was cross-culturally validated in the US and Turkey for high school (grades 9–12) students. Differences were noted across national borders in each study, suggesting the role of culture in perceptions of the learning environment.

2.2.3.5 Other Lines of Learning Environments Research

Other lines of research involve the use of triangulation or, combining quantitative and qualitative methods, which permeates the field today (Aldridge, Fraser, & Huang, 1999; Fraser & Tobin, 1991; Mathison, 1988; Tobin & Fraser, 1998). Quantitative data collection is accomplished most often through the use of a questionnaire while qualitative data usually encompasses student and teacher interviews (and perhaps sometimes interviews of administrators and parents), classroom observations, and students' written work. Unique contributions to learning environments that use a mixed-methods approach within the same study include the complementation of qualitative data to quantitative results that clarified patterns in Taiwanese and Australian classrooms and identified the differences between them (Aldridge, Fraser, & Huang, 1999), the investigation of higher-level cognitive learning in US classrooms (Tobin, Kahle, & Fraser, 1990), and a multilevel exploration of the learning environment to judge whether a certain teacher was typical of other teachers within her school and of other schools within the state in Australia (Fraser, 1999). In a mostly qualitative study comparing exemplary teachers with non-exemplary teachers, data from questionnaires were also obtained and the merging of these two methods helped to shed light on the differences between classrooms of such teachers (Fraser & Tobin, 1989). Currently, many evaluations of educational innovations using a learning environment framework include the use of at least semi-structured interviews in their design, in addition to the main method of questionnaires as data collection.

As well, learning environments research has started to play a significant role in informing school psychologists and counselors about how to guide changes in classroom environments (Burden & Fraser, 1993) and in evaluating the efficacy of their own counseling programs in education (using the MCI) (Sink & Spencer, 2005).

Recently, a trend has re-emerged to extend the research on learning environments in classrooms to its links between other environments such as the home (Marjoribanks, 1991), the home and the parents' workplace (Moos, 1991), and the home and peer environments (Fraser & Kahle, 2007). Findings from a three-year study involving 7,000 US science and mathematics students showed that the environments of the classroom, home, and peer group all accounted for statistically significant amounts of unique variance in student attitudes, but only the classroom environment accounted for statistically significant amounts of unique variance in student achievement scores (Fraser & Kahle, 2007). Numerous studies also considered whether the ethos of the whole school environment has an impact on the classroom environment (Aldridge, Fraser, & Laugksch, 2011; Dorman, Fraser, & McRobbie, 1997; Fraser & Rentoul, 1982). A new scale was even developed to assess links between multiple settings in a unique African milieu: the Socio-Cultural Environment Scale (Jegede, Fraser, & Okebukola, 1994).

A learning environments framework is also applied to studies of transitions from primary to high school, where the environment often changes. Most of these studies identify a deterioration of the classroom environment as students move from the more personal primary classrooms to high school classrooms (Ferguson & Fraser, 1998; Midgley, Eccles, & Feldlaufer, 1991).

Finally, typologies of classroom environments have also been identified through learning environments research. Five clusters of learning environment orientations that emerged from a study using the CES in the US are control, innovation, affiliation, task completion, and competition (Moos, 1978). Using the QTI in the Netherlands and US researchers identified eight distinct interpersonal profiles: directive; authoritative; tolerant-authoritative; tolerant; uncertain-tolerant; uncertain-aggressive; repressive; and drudging (Brekelmans, Levy, & Rodriguez, 1993), although some of these typologies were considered to be unique to certain countries (Rickards, den Brok, & Fisher, 2005). Six distinct classroom profiles that emerged from a study employing a Turkish translation of the WIHIC in Turkey were: self-directed learning; task-orientated cooperative learning; mainstream; task-orientated individualized; low-effective learning; and high-effective learning (den Brok et al., 2010). As well, using cluster analysis for results from the TROFLEI on a large Australian sample of students, five relatively homogeneous groups of classes became apparent: exemplary; safe and conservative; non-technological teacher centered; contested technological; and contested non-technological (Dorman, Aldridge, & Fraser, 2006).

2.2.3.6 Evaluating Educational Innovations using Learning Environment Scales

This section discusses another line of past and current research involving learning environment scales that is relevant to my study and therefore deserves this separate section to allow for greater depth. More recently, educational innovations have changed the dynamic of traditional classrooms and their evaluation has created a new subgenre of the learning environment framework. Learning environment scales have been useful in providing criteria of effectiveness for evaluating educational innovations in the numerous past studies described below. Thus, in my study, learning environment variables were used both as criteria of instructional effectiveness and as predictors of student outcomes such as attitudes and achievement. In this manner, educational innovations influence learning environments, which in turn influences attitudes and achievement. This constitutes the specific research approach for my study because the use of virtual laboratories is considered an educational innovation that requires evaluation.

Studies that have used learning environment scales to evaluate educational innovations are presented below in a chronological manner. They include historical studies (Section 2.2.3.6.1), and studies that evaluate inquiry-based learning and constructivism (Section 2.2.3.6.2), new programs in mathematics (Section 2.2.3.6.3), teacher professional development programs (Section 2.2.3.6.4), and technology integration (Section 2.2.3.6.5).

2.2.3.6.1 Historical evaluation studies

The focus on using learning environment scales to evaluate educational innovations has evolved only recently but, since its inception, the development of learning environment questionnaires has often been within the context of a need to evaluate a particular educational evaluation. An evaluation of Harvard Project Physics, a national curriculum introduced in the late 1960s to utilize new instructional media that emphasize the philosophical, historical, and humanistic aspects of physics, resulted in the development of the first learning environment questionnaire, the LEI, as described in Section 2.2.21. In one particular study, which was part of a series of investigations about the classroom as a social system, according to the Getzels and Thelen's (1960) theory, 1,700 US high school students who completed the project were surveyed (within-class design) with a questionnaire that was based on the Physics Achievement Test, the Science Process Inventory, the Semantic Differential for Science Students, the Pupil Activity Inventory, and the Classroom Climate Questionnaire. The study showed that there were significant and complex relations between climate measures (18 structural and affective) and learning criteria (9); for instance, characteristics such as 'isomorphism', 'organization', and 'synergism' predicted learning variables more frequently than 'coaction' and 'syntality' (Walberg & Anderson, 1968).

Another seminal study was the evaluation of the Australian Science Education Project (ASEP) that, during 1969 to 1974, produced learning materials for high school science classes. The sample involved 300 schools and used case studies as well as questionnaires (Owen, 1979). At that time, because few instruments existed, half of the LEI scales that were relevant were selected and some new scales were developed, including a new scale of Individualization. ASEP students perceived their classroom as being more satisfying, individualized, and having a better material environment compared to a control group (Fraser, 1979).

The difference between these historical and founding studies and more recent evaluations of educational innovations is the evolution of learning environment variables – whether they serves as independent variables or dependent variables (i.e. criteria of effectiveness).

2.2.3.6.2 Evaluation of inquiry-based learning and constructivism in science

Inquiry-based learning encourages students to ask questions, share ideas, and engage in dialogue to investigate information. A key component is whole-group collaboration, although individuals participate equally and are held accountable. Many studies have supported the effectiveness of inquiry-based programs (Wolf & Fraser, 2008). For example, evaluation of a computer-assisted learning course in which students used a database to explore birds of Antarctica, a study which is described in the section on Technology Integration below, revealed positive student perceptions of dimensions such as Investigation and Open-Endedness, which both are hallmarks of inquiry-based learning (Maor & Fraser, 1996). In another study, which differed from prior evaluations of inquiry-based learning in that it utilized a control group, inquiry-based laboratory teaching was evaluated in terms of perceptions of the class learning environment, students' attitudes towards science, and cognitive achievement. The data from 1,434 middle-school physical science students in the US were collected using the WIHIC to measure the perceptions of the learning environment, selected items from the TOSRA to measure attitudes towards science, a 9-item scale to assess achievement based on a standardized state test, and interviews. The instructional method was differentially effective for males (higher with inquiry) and females (higher with non-inquiry) (Wolf & Fraser, 2008).

In two separate studies, the CLES was used in Korean high schools to assess novel constructivist approaches. One study involved longitudinal action research with 136 earth science students and revealed that students' perceptions became increasingly positive over time (changes on the Personal Relevance scale were also associated with improved attitudes towards science) (Oh & Yager, 2004). Another study involved teachers who attended a professional development program at the University of Iowa involving the implementation of constructivist approaches (Cho et al., 1997).

2.2.3.6.3 Evaluation of new programs in mathematics

Although many studies reviewed in Section 2.2.3.2 involved the school subject of science, many instruments have been adapted for mathematics classes as the two subjects are often related. For instance, one particular innovation relies on mathematics media (numbers and measurements) within an innovative science course that uses anthropometric activities. This innovation was evaluated using four scales from the SLEI, TOSRA and Fennema-Sherman attitude scales, together with an achievement test and report card grades, respectively. This study was carried out on 761 biology high school students in the US, including a control group for learning environment perceptions and attitudes (Lightburn & Fraser, 2007).

A number of studies have evaluated educational innovations such as the Class Banking System (CBS), which uses constructivist approaches. In this study, 119 fifth grade students were split into two control groups and one experimental group to evaluate the CBS in terms of perceptions of the classroom environment, students' attitudes towards mathematics, and conceptual development in mathematics. However, the relatively small sample size decreased the statistical power. Learning environment data included scales from the actual forms of the ICEQ to assess Individualization and CLES to assess constructivism. The TOMRA was used to measure attitudes towards mathematics, concept map tests were used to measure the conceptual development, and some case studies were conducted (Spinner & Fraser, 2005).

In another attempt to improve the mathematics classroom environment and attitudes towards reading, writing, and arithmetic, teachers who participated in project SMILE (Science and Mathematics Integrated with Literary Experiences) implemented this innovative program in their classrooms. This program was evaluated by surveying 120 fifth grade students in the US whose teachers completed in-service training. In addition to qualitative data, scales from the actual and preferred forms of the MCI were used to measure perceptions of the learning environment, and scales from the NEAP attitude inventory were used to measure attitudes towards reading, writing, and arithmetic. The results showed improved congruence between the actual and preferred environment and improved reading and attitudes towards mathematics (Mink & Fraser, 2005).

Ogbuehi and Fraser (2007) evaluated innovative teaching strategies in middle-school mathematics in terms of the classroom environment, students' attitudes towards mathematics, and students' conceptual development of mathematics. For this study, 661 students from inner-city classes in the US were surveyed with questionnaires containing scales adapted from the CLES and WIHIC to measure perceptions of the learning environment, and scales from the TOMRA to measure attitudes towards mathematics. For each dimension, the efficacy of the innovative teaching model was supported (Ogbuehi & Fraser, 2007).

2.2.3.6.4 Evaluation of teacher professional development programs

A number of innovative programs have been aimed at teachers, who are responsible for transmitting science content and promoting positive attitudes towards science, and who have an important role in the learning environment. An evaluation of a long-term, teacher professional development program in the US, based on the Integrated Science Learning Environment (ISLE), involved a combination of methods: constructivist concept-mapping, psychosocial cognition, and Information Technology (IT). The evaluation of this program was novel in that the researchers assessed the effectiveness of the teacher-training program using a new form of the CLES (Comparative Student or CLES-CS) which has the same scales as the original CLES but includes two, separate, side-by-side frequency scales for each item to rate this class and another class (whose teachers have not been trained through the ISLE program). For a sample size of 1,079, students whose teachers participated in the ISLE program perceived higher levels of Personal Relevance and Uncertainty in their classes compared with other science and non-science classes in the same school (Nix, Fraser, & Ledbetter, 2005; Nix & Fraser, 2011).

Another evaluation of the effectiveness of a science course for prospective elementary school teachers, who are usually intimidated by teaching science involved these teachers' perceptions of laboratory learning environments and attitudes towards science. A sample of 525 females at an American urban university responded to scales from WIHIC, SLEI, and TOSRA. There were large and statistically significant differences between pre-course and post-course responses for both attitudes towards science and perceptions of the learning environment (Martin-Dunlop & Fraser, 2007).

A third such study investigated the success of a two-year mentoring program in science for beginning elementary-school teachers in terms of participants' classroom teaching behavior as assessed by their school students' perceptions of their classroom learning environments. The sample consisted of seven novice primary school teachers in the US and their 573 students. A modified version of the WIHIC was used to assess student perceptions of classroom learning environment as a pretest and as a posttest. The use of MANOVA and effect sizes supported the efficacy of the mentoring program in terms of some improvements over time in the learning environment, as well as in students' attitudes and achievement (Pickett & Fraser, 2009).

2.2.3.6.5 Evaluation of technology integration

Since the advent of the computer and the Internet, there has been much pressure to incorporate information technology into science classrooms; as well, there is an increasing interest in evaluating the effects of this technology on students in terms of learning environments. An evaluation of a micro-PROLOG-based Computer-Assisted Learning (CAL) involved developing and validating a new instrument, called the Geography Class Environment Inventory (GCEI). 671 high school students in Singapore were given the GCEI, which includes four scales (Gender Equity, Investigation, Innovation, and Resource Adequacy) to measure perceptions of the learning environment, the Semantic Differential Inventory (SDI) to measure attitudes towards the subject, and a Geography Aptitude Test (GAT) to measure achievement. Relative to non-CAL students, CAL students had higher scores for achievement, attitudes, and perceptions of classroom environment (Teh & Fraser, 1994).

As well, Maor and Fraser (1996) evaluated inquiry-based CAL with 120 high-school students in Western Australia who interacted with a computerized database associated with a program entitled The Birds of Antarctica. A new questionnaire based on the LEI, ICEQ, and SLEI, called the Computerized Classroom Environment Inventory (CCEI), was developed to include five scales (Investigation, Open-Endedness, Organization, Material Environment, Satisfaction). Questionnaire items were re-worded for whole-class observations from 'I' statements to 'students' statements. The results showed increased student-perceived Investigation and Open-Endedness, whereas the teachers' perceptions were more positive.

In an investigation of whether using laptop computers in science and mathematics classes affects students' perceptions of the learning environment, 1,173 high school students in Canada were given a new version of the WIHIC (the personal form and actual and preferred forms), one scale from the Computer Aptitude Survey (CAS) to measure attitudes towards computers, and one scale from the TOSRA (Enjoyment of Lessons). While there were positive associations between perceptions of the learning environment and students' attitudes towards science and mathematics, there were statistically significant differences between perceptions of the actual and preferred environments, differences for males and females, and differences between science and mathematics (Raaflaub & Fraser, 2002).

Regarding networked use of computers, Zandvliet and Buker (2003) considered the relationship between technology and instruction as they evaluated Internet classrooms in terms of the physical and psychosocial environments and student satisfaction. They argued that technology brings more diversity to the factors that influence the learning environment; these factors are divided into three major categories that comprise the person's learning experience and thus satisfaction: the ecosphere (physical surroundings for example, lighting and space); the sociosphere (the person's net interactions with all other people within that environment (e.g. autonomy and cohesion); and the technosphere (includes all the man-made objects available). In one of their studies, 358 high school students in B.C., Canada, responded to the actual form of the WIHIC, items from the TOSRA, and the Computer Classroom Environment Checklist (CCEC) for physical factors (for which the unit of analysis was the classroom and the scales included Workspace Environment, Computer Environment, Visual Environment, Spatial Environment, and Air Quality Rating). In another study, the physical and psychosocial learning environments of computer-networked classrooms were evaluated for their effects on student satisfaction. Scores from the CCEI, WIHIC (actual and personal forms), and TOSRA, as well as systematic observation and case studies, comprised the data collected from 1,404 students in Australian and Canadian high schools, which indicated that the psychosocial environment (specifically Independence and Task Orientation) was significantly associated with satisfaction with learning, although learning satisfaction was not associated with the physical classroom environment. However, there were statistically significant associations between the physical and psychosocial learning environment variables in classes using new informational technology and, thus, the physical environment indirectly impacted students' satisfaction with learning (Zandvliet & Fraser, 2005).

Aldridge and Fraser's (2003, 2008, 2012) longitudinal study, which also involved the TROFLEI's development and validation, evaluated a technology-rich environment that focused on outcomes-based learning. The four-year investigation involving 1918 students led to more positive student perceptions of seven out of the ten TROFLEI scales, but the degree of change in the learning environment varied for different learning areas.

Adult students undertaking computer application courses in Singapore were also involved in an evaluation of the program's effectiveness. The WIHIC was adapted for the sample of 250 working adults and it proved to be valid and reliable. Generally, students perceived their classroom environment in a positive manner, but with some variation for students of different genders and ages (Khoo & Fraser, 2008).

In another study, students' perceptions of a blended learning environment, in which online technology is integrated into class lessons, were investigated. Getsmart, a teacher-designed website, was blended into science and physics lessons at an Australian high school. The Web-Based Learning Environment Instrument (WEBLEI) (Section 2.2.2.11) was found to be valid for this sample of 302 students in year 10–12 classes, even though the original questionnaire was intended for university students. The data generated through the WEBLEI, in addition to qualitative data extracted from written surveys and emails, suggested that students had positive perceptions of their web-based learning environment (Chandra & Fisher, 2009).

2.3 Student Attitudes

In this study, the effectiveness of virtual laboratories was evaluated in terms of not only students' perceptions of their learning environment (see Section 2.2) but also students' attitudes towards science. Below, I consider aspects of the affective domain of learning and its relationship to the cognitive domain of learning. First, the term 'attitude' is defined in Section 2.3.1. Then methods of assessment are presented in Section 2.3.2, and this is followed by a review of the literature about the impact of educational interventions on students' attitudes (Section 2.3.3).

2.3.1 Definition of Attitude

For decades, the attempt to clarify the term 'attitude' has engendered much controversy because it incorporates a broad range of dimensions that are loosely defined with vague references. Examples of such dimensions are interest, engagement, motivation, mindfulness, flow, self-efficacy, identity, perceived ability, the degree of fun, personal relevance, and the like. This haziness is further clouded by the inclusion of sub-topics under the all-encompassing 'science' umbrella, such as various careers, formal and informal education, perceptions of scientists and science media (Aldridge & Fraser, 2008; Olitsky & Milne, 2012; Oliver & Venville, 2011; Tytler & Osborne, 2012). More recently, Koballa and Glynn (2007) define an attitude as "a general and enduring positive *or* negative feeling about some person, object, or issue", in this case, science (p. 78). This definition maintains the neutrality of the term 'attitude', whereas many of the aforementioned dimensions refer to only the positive form of the affective domain; for instance, 'interest' denotes a positive feeling about the subject.

Because of the lack of clarity concerning the term attitude, Klopfer (1971) began to distinguish between 'attitudes towards science', the subject of this section, and 'scientific attitudes', a mindset committed to evaluating evidence, harboring skepticism, and requiring rational explanations for phenomena. However, 'attitudes towards science' can still encompass attitudes towards scientists, school science, science learning experiences and activities, as well as the pursuit of science-related careers (Tytler & Osborne, 2012). Later, Klopfer (1976) further classified the affective domain, specific to science education, into four categories of attitudes: towards events in the natural world (awareness and emotional responses to experiences), towards activities (school science and informal science), towards science in general (the nature of science as a means of knowing about the world), and towards inquiry (the adoption of inquiry processes including methodical assessment of phenomena).

OECD's (2009) Programme for International Student Assessment (PISA) assesses students every three years in a variety of subject areas. Their definition for attitudes towards science is based on the belief that a student's scientific literacy includes certain attitudes, beliefs, motivational orientations, sense of self-efficacy, values, and ultimate actions, which builds upon Klopfer's (1976) structure for the affective domain in science education as well as other reviews of attitudinal research (Gardner, 1975; Osborne, Simon, & Collins, 2003).

Considering other definitions for the affective domain, some educational researchers refer to 'engagement', a positive feeling or a passion, as an indicator for attitudes (Olitsky & Milne, 2012). Engagement can be further broken down into its various components, such as behavioral engagement (e.g. on-task actions in a science classroom or participation in extra-curricular activities), emotional engagement (interests and values evident from students' reactions to their environment), and cognitive engagement (motivation, self-efficacy, and behavior) (Fredricks, Blumenfeld, & Paris, 2004; McCarty, Hope, & Polman, 2010). A corollary of 'engagement' is the concept of 'flow', defined as "the feeling generated by total engagement with an activity" (Tytler & Osborne, 2012, p. 605). According to a pioneering study by Csikszentmihalyi and Schneider (2001), tests, quizzes, and concrete tasks, including laboratory work, all produced above-average levels of 'flow' while the presentation of lectures and video clips produced little 'flow'. The current study involved virtual laboratories, whose use was anticipated to produce greater 'flow'.

'Motivation' is a key term often used by educational researchers in relation to students' attitudes towards a subject. In a case study of 10th grade biology students in Australia concerning whether the incorporation of Biologica, a digital genetics activity, would increase their motivation, Tsui and Treagust (2004) identified some salient features that elicited student's motivation to learn: instant feedback, flexibility, and visualization. These features are also prominent in virtual laboratories, the subject of the current study. In Tsui and Treagust's study, student motivation, which increased as a result of exposure to Biologica, was interpreted by the intrinsic dimensions of curiosity, control, fantasy, and challenge. The researchers concluded that new complex topics, such as genetics, should be introduced to students by embedding them into supportive learning conditions including student motivation and interests, as well as the beliefs of learners and teachers. Furthermore, the authors asserted the need for students to be engaged in mindful learning. According to Salomon and Globerson (1987), mindfulness involves "volitional, meta-cognitively guided employment of non-automatic, usually effort-demanding processes" (p. 623). Accordingly, the learning benefits of being motivated and mindful are expected to be long-term because they are related to higher levels of learning that engage all faculties and produce stronger impressions in the minds of learners.

This section attempted to define the concept of attitudes towards science by exploring the various dimensions associated with the affective domain of learning. A longitudinal study by Oliver and Simpson (1988) showed a strong relationship between three such affective variables – attitude towards science, motivation to achieve, and the self-concept that the individual has of their own ability – and their achievement in science. This relationship is further explored in Section 2.2.3.1 on associations between perceptions of the learning environment and attitudes towards science.

2.3.2 Assessment of Student Attitudes

Students' attitudes towards science can be assessed using questionnaires, open-ended questions, interviews, preference rankings, and the like. The earliest, most notable instrument was developed by Perrodin (1966), who assessed the attitudes of over 500 fourth, sixth, and eighth graders in the US using qualitative methods. Later, Moore and Sutman (1970) created the Scientific Attitude Inventory to assess emotional and intellectual attitudes toward science among secondary school students. The development of a number of other similar attitude instruments ensued over the past few decades, but many of them fail to meet the sound psychometric standards, according to a comprehensive review of 66 instruments for measuring attitudes (Blalock, Lichtenstein, Owen et al., 2008) and many other critics who question their conceptual and empirical quality (Gardner, 1975; Munby, 1997; Shibeci, 1984).

Similarly, Fraser (1978) noted three major limitations of existing instruments used to assess attitudes toward science: low statistical reliability, a lack of economy of items, and the combination of different attitude dimensions into a single scale which creates a mixture of variables. In response, Fraser (1981) developed the Test of Science-Related Attitudes (TOSRA). This is the instrument that was selected for the current study because some of its scales were deemed highly suitable for the investigation of how students' attitudes towards science changed as a result of using virtual laboratories.

Because the TOSRA is based on Klopfer's (1976) classification of the affective domain, its scales correspond to Klopfer's attitudinal categories (see Table 2.4) with some modifications. In constructing the specific items, Fraser sought the expertise of science teachers and researchers involved in educational measurement.

Table 2.4 Fraser's (1981) TOSRA Scales and Klopfer's (1971) Classification

TOSRA Scale Name	Klopfer Classification
Social Implications of Science Normality of Scientists	H.1 Manifestation of favorable attitude towards science and scientists
Attitude to Scientific Inquiry	H.2 Acceptance of scientific enquiry as a way of thought
Adoption of Scientific Attitudes	H.3 Adoption of scientific attitudes
Enjoyment of Science Lessons	H.4 Enjoyment of science learning experiences
Leisure Interest in Science	H.5 Development of interest in science and science related activities
Career Interest in Science	H.6 Development of interest in pursuing a career in science

The TOSRA is a widely-used questionnaire for assessing attitudes of science (Aldridge & Fraser, 2003, 2008; Fisher, Henderson, & Fraser, 1995; Fraser, Giddings, & McRobbie, 1995; Koul, Fisher, & Shaw, 2011; Ogbuehi & Fraser, 2007; Quek, Wong, & Fraser, 2005), and it is intended to be used by teachers or researchers with grades 7–10 science students. Its attitude scales were originally validated in Australia with a total of 1,337 students from 11 schools that varied socioeconomically. The final version contains 10 items in each of the seven scales (Social Implications of Science, Normality of Scientists, Attitude to Scientific Inquiry, Adoption of Scientific Attitudes, Enjoyment of Science Lessons, Leisure Interest in Science, and Career Interest in Science) (Fraser, 1981). Each item is arranged on a Likert scale with the responses of Strongly Agree, Agree, Undecided, Disagree, and Strongly Disagree. Approximately half of the items in the TOSRA are negatively worded, thus challenging the respondent to think carefully about each statement.

The questionnaire was further validated in a cross-national study between Australia and Indonesia with 1,161 students (Fraser, Aldridge, & Adolphe, 2010), 1,592 Grade 10 chemistry students in Singapore (Wong & Fraser, 1996), and 1,110 high school students in Turkey and the US (Welch et al., 2012).

Modifications have been made to adapt the TOSRA scales to mathematics classrooms to form the Test of Mathematics-Related Attitudes (TOMRA), that has been employed in evaluating educational innovations (Ogbuehi & Fraser, 2007; Spinner & Fraser, 2005), as well as to college computer courses to form the Attitudes towards Computers and Computer Courses (ACCC) survey that added the scales of Lack of Anxiety, Enjoyment, Usefulness of Computers, and Usefulness of the Course (Newby & Fisher, 1997). Moreover, sometimes the TOSRA is used in a modified form, generally consisting of one or a few scales rather than all seven scales, or in a form with a lower reading level for younger students.

For the current study, attitudes were assessed using a modified version of the Enjoyment of Science Lessons scale as well as the Attitude to Scientific Inquiry scale. Sample items of the former include “I look forward to this class” and “This class is among the most interesting at this school”, whereas examples of the latter scale are “I would prefer to do experiments than to read about them” and “It is better to create my own hypothesis than to be given a hypothesis to test out”. To avoid confusion in responses, the items were all worded positively, as recommended by Barnette (2000). As well, because each TOSRA scale contains 10 items, items that were highly similar to other items in the same scale were removed to enable consistency with all other scales that had eight items in my study’s questionnaire.

2.3.3 Impact of Educational Interventions on Students’ Attitudes

Recently, research about students’ science-related attitudes has been on the rise because of a decrease in student enrolment in the sciences at the secondary and tertiary levels of education, especially in Western countries (Osborne, Simon, & Collins, 2003). In fact, there seems to be an inverse relationship between the economic advancement of a country and their students' interest in school science. In general, attitudes towards science tend to decline with age so that students in the younger grade levels report enjoyment of science lessons, while middle-school students begin to lose interest and high school students enjoy science the least out of all school ages. Similarly, gender differences in attitudes are less apparent in the younger years and emerge during middle school, especially in relation to the compartmentalization of the sub-topics within science, such as physical science and chemistry (Oliver & Venville, 2011; Tytler & Osborne, 2012). Nevertheless, despite the decrease seen in science attitudes, the overall interest in science remains predominantly positive (Tytler & Osborne, 2012).

However, the decline in attitudes towards science is also disturbing because attitudes correlate with achievement. The Trends in International Mathematics and Science Study (TIMSS) showed a consistent relationship between attitudes and achievement over the years, with students with more positive attitudes having higher achievement in science than those with medium or low attitudes in science (Nasr & Soltani, 2011; Neuendorf, 2002). The PISA study in 2006 reported that most students agree that science is important to learn and that science and technology improve living conditions, but that fewer students found science personally relevant and that even fewer students expressed an interest in pursuing a science-related career. The study also showed a correlation between socio-economic status and interest in science-related careers (Organization for Economic Co-operation and Development (OECD), 2009).

In searching for an answer to why attitudes to science decline relative to attitudes to other school subjects, a number of causes emerge based on students' responses. Students often complain that school science lacks relevance, the curriculum is riddled with repetition across primary to middle to high school classes, there aren't enough opportunities to discuss the implications of science, and there is an overemphasis on copying notes from the teacher or textbook as the standard form of writing (Tytler & Osborne, 2012). To generalize, there are actually many factors that determine students' interest in school science: gender, the quality of teaching, and pre-adolescent experiences are the most notable determinants, but others include self-evaluation of science ability, parental expectation and level of guidance, exposure to career guidance and goals, exposure to inspirational teachers, and teacher expectation of success (Osborne, Simon, & Collins, 2003; Shibeci, 1984; Tytler & Osborne, 2012).

Once such determinants are identified, researchers and educators can implement proactive strategies that address such issues in order to improve students' interest in science. For instance, enrichment experiences in school science have been shown to be effective in raising students' positive attitudes towards science (Quek, Wong, & Fraser, 2005; Tytler & Osborne, 2012). Olitsky and Milne (2012) propose the development of programs that focus on engagement in science, provide opportunities for students to construct their own meanings in science through direct experience, and engage students at an emotional level. In exploring Olympiad (honors-level) students' attitudes towards and passion for science, more positive attitudes were observed as a result of this enrichment program, even though school science originally had decreased their interest in science (Oliver & Venville, 2011).

Nasr and Soltani (2011) conducted a longitudinal study to examine the relationship between attitudes towards science and achievement in science in a grade 10 biology course in Isfahan, Iran. They found no statistically significant differences between the sexes. However, using the Simpson–Troost Attitude Questionnaire–revised (STAQ–R), meaningful positive associations were uncovered between achievement and the dimension of 'biology is fun for me'. The other dimensions, which lacked significant associations with achievement, included Motivating Biology Class, Self-Directed Efforts, Family Models, and Peer Models.

In the evaluation of a unique image-processing course that integrates STEM subjects with students' personal worlds and digital culture, Israeli middle-school learners' motivation to engage in the subject increased as a result of the intervention. In fact, the increase was greater for girls than for boys. This study used both quantitative methods, through the use of the Interest in Computers (IiC) questionnaire, and qualitative methods, through documenting learners' comments throughout the course, observing their levels of motivation, and through photographs and videotapes (Barak & Asad, 2012).

In a similar attempt to use computer animation and illustration activities to improve high school achievement in molecular genetics, the authors designed an attitude item ("Do you find molecular genetics more difficult than other topics in biology?") to determine if the type of activity influenced attitude and thus achievement. Indeed, 58% of the control group reported that molecular genetics was very difficult, indicating a negative attitude, compared with 24–38% of the experimental group. Accordingly, the experimental group showed greater knowledge in this topic than the control group, although interview responses revealed that the animation activity was significantly more effective than the illustration activity (Marbach-Ad, Rotbain, & Stavy, 2008).

Many studies using a learning environments framework also investigated whether students' attitudes improve as a result of an intervention. Often, associations are found between students' attitudes towards the subject and learning environment scales (Fraser, 2012). In this way, both attitudes and perceptions of the environment might be linked to achievement and can better inform educators about how to improve achievement in science.

Educational innovations that have resulted in improved student attitudes towards STEM subjects include a technology-rich environment (Aldridge & Fraser, 2003; Koul & Fisher, 2005), the introduction of inquiry laboratories (Wolf & Fraser, 2008), the integration of children's literature into mathematics (Mink & Fraser, 2005), a unique science course for prospective teachers of elementary students (Martin-Dunlop & Fraser, 2007), the introduction of an innovative mathematics program called the Class Banking System (Spinner & Fraser, 2005), the use of anthropometric activities with biology students (Lightburn & Fraser, 2007), computer-assisted learning environments (Teh & Fraser, 1994), the use of laptop computers (Raaflaub & Fraser, 2002), and adult computer application courses (Khoo & Fraser, 2008).

Many of these studies also revealed positive associations between attitudes, measured by the TOSRA, and learning environment scales from questionnaires such as the SLEI (Fraser, Giddings, & McRobbie, 1995; Kijkosol, 2005; Martin-Dunlop & Fraser, 2007), the QTI (Fisher, Henderson, & Fraser, 1995; Kijkosol, 2005; Quek, Wong, & Fraser, 2005), the WIHIC (Khoo & Fraser, 2008; Martin-Dunlop & Fraser, 2007; Raaflaub & Fraser, 2002; Wolf & Fraser, 2008), and the TROFLEI (Aldridge & Fraser, 2003, 2008; Koul, Fisher, & Shaw, 2011; Koul & Fisher, 2005). Adaptations of the TOSRA to mathematics classes, called the TOMRA, also showed positive associations with learning environment scales from the CLES, WIHIC, ICEQ, and MCI (Mink & Fraser, 2005; Ogbuehi & Fraser, 2007; Spinner & Fraser, 2005).

My study investigated whether virtual laboratories affect students' attitudes towards science and it also explored associations between dimensions of the learning environment and the student outcomes of attitude and achievement. If such associations exist, then virtual laboratories might possibly not only directly affect the learning environment, but also indirectly affect students' attitudes and achievement.

2.4 Gender Differences in Science Education

The current study investigated the effectiveness of virtual laboratories (the third research question) as well as their differential effectiveness for males and females (the fourth research question). While a full review of literature on gender issues in science education is beyond the scope of this thesis, a review of the perceptions, attitudes, and achievement of the different sexes in science education is necessary to provide a context for this investigation of whether virtual laboratories assist or hinder gender equity. If virtual laboratories assist in closing the gender gap in science education, they could be utilized in the classroom with greater confidence about their many benefits. On the other hand, if virtual laboratories are differentially beneficial for one sex over another, such differences would have to be taken into account when implementing their use in the classroom.

For decades, educational research has pointed to differences in attitudes and achievement between boys and girls in the sciences. Even today, a strong perception that males are inherently better at mathematics and science still remains (Hill, Corbett, & St. Rose, 2010; Scantlebury, 2012). In fact, the National

Assessment of Educational Progress (NAEP) reported in 2011 that American males in grade eight scored on average five points higher than females in science achievement examinations, which is consistent with the same study conducted in 2009 (National Center for Educational Statistics (NCES), 2012a). However, recent research has pointed to the absence of such a gender gap in the sciences (Koul, Fisher, & Shaw, 2011; Scantlebury, 2012). Whether the absence of a gender gap naturally exists or whether it exists as a result of interventions intended to create equality between the sexes is reviewed below.

In 2009, the Programme for International Student Assessment (PISA) revealed small gender differences amongst 15 year-old science students regarding attitudes and achievement, but the results were inconsistent in that they varied with different countries, types of schools, and socio-economic levels (Organization for Economic Co-operation and Development (OECD), 2009). A Trends in International Mathematics and Science Study (Trends in International Science and Mathematics Study (TIMSS), 2007) reported gender differences in favor of girls at the fourth and eighth grade levels. As well, female students in grades 4, 8, and 10 scored higher than males on hands-on science tasks, though males scored higher on the traditional paper-and-pencil science assessment. In the same study, there was no gender gap in interactive computer tasks in science (National Center for Educational Statistics (NCES), 2012b). In an individual study of grade 10 biology students in Isfahan, Iran, no significant differences between males and females were reported for attitudes, but females scored higher in achievement (Nasr & Soltani, 2011).

Regarding students' perceptions of their learning environments, the framework for the current study, gender differences also have been reported. Fraser and Tobin (1991) argue that the personal form of a learning environment questionnaire, in which students respond to statements in the first person (e.g. "I pay attention during this class"), is more sensitive to within-class sub-group differences, such as gender, than the class form which presents statements as facts which with students agree or disagree, or indicate the frequency of their occurrence in the classroom. For the personal, actual form of the Science Laboratory Environment Inventory (SLEI), females reported greater Student Cohesiveness, Integration, and Material Environment than males (Fraser, Giddings, & McRobbie, 1992, 1995).

Numerous studies using various learning environment questionnaires have replicated a pattern in which females scored more highly than males on scales such as Rule Clarity, Task Orientation, Cooperation, Equity, and Teacher Support. However, for scales such as Involvement, Investigation, Differentiation, and Young Adult Ethos, variable results have been reported for differences between the sexes (Aldridge & Fraser, 2008; Khoo & Fraser, 2008; Kijkosol, 2005; Koul, Fisher, & Shaw, 2011; Quek, Wong, & Fraser, 2005; Raaflaub & Fraser, 2002; Wolf & Fraser, 2008). In conclusion, females tend to perceive most aspects of their science learning environment more favorably than their male counterparts. Furthermore, a number of these same studies showed more positive attitudes towards science for males relative to females (Khoo & Fraser, 2008; Raaflaub & Fraser, 2002; Wolf & Fraser, 2008).

In response to such inconsistent findings about gender differences in science classes, Scantlebury (2012) points out that differences within genders can be greater than differences between genders. Differences include race/ethnicity, religion, class, socio-economic status, and sexual orientation. For instance, socio-economic status has been shown to have a greater impact on achievement than gender. Therefore, Scantlebury notes a disinterest in continued gender studies in science education (Scantlebury, 2012). Kahle (2004) also points out that it is currently optional to report achievement scores by gender for many state examinations in the US because gender differences are no longer considered an issue.

To further understand gender differences that were found in past research, it is necessary to dissect the various aspects of such differences. It seems that, even within the sciences, gender variation exists. Girls tend to prefer the life sciences because they are interested in humans and animals (e.g. activities involving collecting and cataloging seashells). Boys, on the other hand, tend to choose activities in the physical sciences, perhaps because of exposure to games that involve physical sciences such as shooting firearms. These gender-specific preferences have been consistent throughout the literature for over 40 years (Brotman & Moore, 2008; Farenga & Joyce, 1997; Hanson, 2009).

Similarly, gender differences found for interest in science-related careers have also been consistent. Females tend to perceive a lack of relevance of the physical sciences to their personal lives and often avoid choosing careers that are heavily based on such a subject. Instead, they tend to show interest in science careers that involve nurturing (e.g. nursing). As well, life demands have a larger impact on women than on men, which ultimately might cause women to neglect or underachieve in science-related careers. The opposite is generally true for males who show more interest in demanding science-related careers (Beede, Julian, Langdon et al., 2011; Oakes, 1990; Scantlebury, 2012).

In general, students' attitudes towards science decline as they go through the science 'pipeline' from preschool to their careers, but this decline is greater for girls than for boys. Female interest in science typically begins to decrease in the middle school years (Scantlebury, 2012).

Caleon and Subraminian (2008) found a positive correlation between intellectual ability and attitudes towards science amongst fifth graders in Singapore. The boys in the study reported more positive attitudes towards science than the girls, but boys were more likely to achieve higher scores than girls. Because attitudes are linked to achievement (also see Section 2.2.3.1), and attitudes amongst females tend to decline with grade level, female achievement in science is also negatively correlated with grade level (Oakes, 1990; Scantlebury, 2012). This phenomenon might explain why results from gender studies in science education are so inconsistent; more insightful results could be obtained if the grade level of students in a study's sample is considered.

Why is the extent of the decline in interest in science with grade level unbalanced between the sexes? One contribution might be teachers' preconceived notions about the difference in abilities between males and females. For instance, some research has revealed that some teachers call on boys to answer more-challenging questions and encourage them towards science-related careers (Oakes, 1990; Scantlebury, 2012). Huang and Fraser (2009) conducted a study involving 818 Taiwanese male and female science teachers' perceptions of the school environment. A critical finding from this study was that male science teachers reported that science is a subject more suitable for boys and that they encouraged boys more than girls in this area, while female teachers viewed science as equally important for boys and girls.

If teachers instill more confidence in males than in females in the sciences, then males are more likely to excel. In fact, Thompson (2008) claims that gender differences in science are due to differences in levels of self-confidence in learning science, rather than intellectual ability, and, because males have more self-confidence, they tend to outperform females.

Thus, it seems that, naturally, little difference exists between the sexes regarding their attitudes and achievement in science, but that these gender differences could be created by teachers or other educational interventions that tip the scale in favor of male interest and achievement in science. This also explains why traditional classrooms could have a narrower gender gap than classrooms with an innovative intervention (Wolf & Fraser, 2008).

If such gender differences, whether natural or contrived, exist, how might education be reformed to encourage more female interest in the sciences in order to reduce or eliminate the gender gap? This question was addressed in the early 1980s with the rise of feminism by the introduction of 'girl-friendly' curricula that highlight women's contributions to science and other female-focused themes (Scantlebury, 2012).

In another study, grade nine Israeli Arabs were exposed to an integrative Science, Technology, Engineering and Mathematics (STEM) intervention about image processing using computers. In this case, the pretest for interest in learning computers in school showed sex differences, with males outperforming females, but no significant differences were found between the sexes for the posttest (Barak & Asad, 2012). An intervention such as this can help to decrease the gender gap in science education.

Therefore, ideally, the evaluation of any intervention in science education today would also evaluate whether the intervention is differentially effective for males and females. Consequently, this study also included a research question about the differential effectiveness of virtual laboratories for different sexes.

2.5 Virtual Laboratories in Science Education

Section 2.2 reviewed literature concerning the main measure of effectiveness in my study (i.e. perceptions of the learning environment). Section 2.3 surveyed the literature regarding another measure of effectiveness (i.e. attitudes), and Section 2.4 provided a literature review of gender issues in science education because that was an additional aspect considered in my study. However, the actual intervention in my study (i.e. virtual laboratories) still requires elucidation. Therefore, this section reviews literature about virtual laboratories as well as the larger context of educational technology.

The literature outlining the advantages of integrating technology into science classrooms is presented in Section 2.5.1. Then Section 2.5.2 reviews literature detailing the definition, history, and particular benefits of virtual laboratories. Section 2.5.3 examines the literature describing virtual learning environments and the context for virtual laboratories, and this is followed by an overview of studies that evaluated virtual laboratories (Section 2.5.4). To provide a balance, Section 2.5.5 concludes with a review of the literature that is skeptical about the overall effectiveness of integrating educational technology into classrooms.

2.5.1 The Proponents: Rationale for Integrating Educational Technology

The use of technology for instruction is not a new idea. In reality, the reference to the term 'technology' changes with time. In the early part of the 20th century, 'technology' might have referred to phonographs and transistor radios, progressed to sound recordings, television and computers (Russell, 1999), and more recently included interactive whiteboards (Moss, Jewitt, Levaaic et al., 2007), Personal Response Systems (Herrmann, 2012), iPads (Nooriafshar, 2011), and other mobile devices (Milrad & Spikol, 2007). Naturally, these technologies have been adapted to the educational realm and, alongside, their educational effectiveness was evaluated. A full review of the integration of technology in education is beyond the scope of the current study; this section merely examines the general role of technology in science education.

Many technological advances are quickly revolutionizing the rate of discovery and youngsters are expected to be familiar with such innovations. As Javidi (Javidi,

1999) notes: “To allow educational tools to fall behind the pace of technological advance is to sell out a generation of learners” (p. 1). Because students learn better from processes which are sensory, visual, inductive, and active (Felder & Silverman, 1988), they benefit from lessons that are interspersed with technology-rich activities that contain digital images and animations, activities that involve the use of simulations and databases, and research via the internet (Beichner, Bernold, Burniston et al., 1999; Trindade, Fiolhais, & Almeida, 2002).

Whether or not the evidence supports its use (see Section 2.5.5), technology is the comfort zone for many students today. This idea is most eloquently summarized by the terms ‘digital natives’, referring to those born into an era surrounded by technology and are thus conferred with the ability to manage it, and ‘digital immigrants’, referring to those who need to adjust to technological innovation; it is argued that the thought processes of the former are fundamentally different from those of the latter (Prensky, 2001). Therefore, the modernization of presentation modes in education might be of benefit to students and to teachers who could use more tools to reach the young minds that have been trained by popular entertainment media to seek constant stimulation.

In studies on integrating Information and Communication Technologies (ICT) in four different countries, results showed that students perceived most aspects of the learning environment to be positive, thus influencing students’ overall perceptions of the science classroom, which are linked to improvements in achievement (Zandvliet & Buker, 2003; Zandvliet & Fraser, 2004). A meta-analysis of 25 studies that integrated technology into classrooms (mostly computer-based) resulted in a positive, but small to moderate, effect favoring the use of technology over traditional instruction without technology, and showed that computer technology used to support instruction was more effective than technology applications that provide direct instruction (Tamim et al., 2011). Norton et al. (2007) focused on robotics in middle school science classes and also indicated that integrating technology into these classes allowed students to think for themselves, apply logical thinking, be creative, and be autonomous.

As applied to the natural sciences, specifically regarding the topic of genetics, one study showed that the use of multiple representations dynamically linked in an interactive multimedia program called *BioLogica*, enhanced students' learning of introductory genetics. In this case, the intervention enabled teachers "to increase the use of visual-graphical representations, thus making genetics more interesting and easier to learn and understand" (p. 285). The authors underscore the role of the teacher in encouraging students to engage with such multimedia programs (Tsui & Treagust, 2004).

In a similar attempt to use computer animation and illustration activities to improve high school achievement in molecular genetics, the authors used an attitude item, "Do you find molecular genetics more difficult than other topics in biology?" to determine if the type of activity influenced attitude and achievement. Indeed, 58% of the control group reported that molecular genetics was very difficult, indicating a negative attitude, compared with 24–38% of the experimental group. Also, the experimental group showed greater knowledge in this topic than the control group, although interview responses revealed that the animation activity was significantly more effective than the illustration activity (Marbach-Ad, Rotbain, & Stavy, 2008).

Overall, innovations that alter the dynamic of the traditional classroom, from collaborative teaching to the incorporation of technology such as online textbooks and virtual laboratories, to instances of 'learning without walls' such as fully online classes or distance education, initiate a paradigm shift in defining the learning environment. With such innovations, the teacher's role as director diminishes and a new model of teacher as facilitator emerges that allows for more student-focused learning; the focus is on 'learning' and not necessarily on 'teaching' (Chang & Fisher, 2003; Rogers, 2000). Another byproduct of such innovations, especially concerning online and distance education, is the globalization of communication within education, which allows trans-cultural exchange (van de Bunt-Kokhuis, 2001).

Zandvliet and Fraser (2004) note a number of challenges that prevent the successful integration of technology into classrooms. They point out that the use of ICT in schools is partially attributable to technological, commercial and societal pressures but that, once a school invests in ICT, there is little support to make it educationally beneficial. To do so, schools need to better integrate ICT with their curriculum and instruction, which might be augmented by the physical learning environment. The authors discuss the need for a healthy balance of all spheres of influence: the *ecosphere* (eg. equipment, network), the *sociosphere* (interactions with other people, perceptions, outcomes, learning, attitude), and the *technosphere* (i.e. technical factors impact instruction such as the goals of teachers) (Zandvliet & Fraser, 2005).

Another significant factor that affects the usefulness of ICT is the technological experience of the teacher. The National Center for Educational Statistics (Smerdon, Cronen, Lanahan et al., 2000) revealed that 99% of teachers in public schools in US had access to computers or the Internet, and that 84% had at least one computer in classroom, but only 20% felt well-prepared to integrate technology into teaching. Similarly, another study showed that the primary use of ICT for teachers was for email to communicate with homes and for students use was Word processing and Internet research. Therefore, neither users were engaging in the full range of tasks and advantages that ICT offers (The California Educator, 2003). A Common frustration for teachers using ICT is the amount of time spent on technical issues rather than instructional ones (i.e. the technosphere is too large) (Zandvliet & Fraser, 2004).

Perhaps, owing to some of these challenges, Jones (2012) argues that the impact of technology on the teaching and learning of science "has probably not reached the potential we thought we thought it might when we began exploring its introduction 25 years ago" (p. 820). Either studies are simply not producing evidence that technology integration is beneficial (see Section 2.5.3), or the process of integrating technology into classrooms must be refined by incorporating a broader spectrum of technological programs, training teachers in their use, providing better spaces in which to use technology, and designing more accurate studies to evaluate their effectiveness. My study represents one such attempt to add to the body of research on the effectiveness of integrating technology in science classes.

2.5.2 Virtual Laboratories

The National Science Foundation's (NSF) Task Force on Cyberlearning proposes upgrading the state of Science, Technology, Engineering, and Mathematics (STEM) education by incorporating interactive technology (Borgman et al., 2008). It points to a changing society and how education must also "respond dynamically to prepare our population for the complex, evolving, global challenges of the 21st century" (p. 5). More specifically, the NSF promotes the growth of a cyberlearning infrastructure that is networked, customizable, and computationally rich, with one example being virtual laboratories.

This section examines the literature that specifically addresses aspects of virtual laboratories such as its definition (Section 2.5.2.1), history (Section 2.5.2.2), and benefits (Section 2.5.2.3).

2.5.2.1 Definition

The specific attempt to integrate technology into science classrooms that was assessed in this study concerns virtual laboratories, which are interactive environments for conducting simulated experiments. In more general terms, a virtual laboratory is defined as "an electronic workspace for distance collaboration and experimentation in research or other creative activity, to generate and deliver results using distributed information and communication technologies", according to the International Institute of Theoretics and Applied Physics at the Expert Meeting on Virtual Laboratories in Iowa, USA in 1999 (Rauwerda, Roos, Hertzberger et al., 2006, p. 230). Essentially, such modalities make use of networked content to provide a rich immersive learning environment using visualizations, graphics, and interactive applications.

The term 'virtual laboratories' is often used loosely amongst software developers who wish to entice educators into their usage. Indeed, the concept encompasses five different categories, according to Harms (2000), only three of which are currently relevant to this study (Borgman et al., 2008; Nedic, Machotka, & Nafalski, 2003) and whose boundaries also become somewhat blurred (Ma & Nickerson, 2006):

- Simulations that contain certain elements of laboratory experiments, but they are mainly used for visualizations and they are available online. These are referred to as classical simulations and 'CyberLabs' and are further discussed in Section 2.5.3.1.

- Simulations that attempt to represent laboratory experiments as closely as possible by engaging in inquiry skills, called Virtual Labs, the subject of this section.

- Real experiments that are controlled via a network, the settings and output of which are accessible through the Internet. These are known as Remote Labs.

The benefits of Remote Labs are discussed by Alhalabi (1998). Remote Labs first were most commonly used for robotics and then expanded to other areas of engineering. Examples include University of South Australia's NetLab (Nedic, Machotka, & Nafalski, 2003), MIT's iLabs project that offer microelectronics test equipment and the like (http://icampus.mit.edu/ilabs/), Second Best to Being There (SBBT) from Oregon State University that provides remote students with complete access to a control engineering laboratory (Bohus, Aktan, Crowl et al., 1996), and the Virtual Lab at Carnegie Mellon University (http://users.ece.cmu.edu/~stancil/virtual-lab/concept.html). For example, the iLabs inverted pendulum experiment at the University of Queensland permitted users to access the experiment beyond laboratory hours and led to an increased success rate for students to balance the pendulum from 5% to 69.5% (Borgman et al., 2008). Another category delineated by the NSF Task Force on Cyberlearning is a mixed-reality environment that combines digital content and real-world spaces that allows users to see the machinery involved but interpret output electronically (Borgman et al., 2008). However, further discussion about these types of remote virtual laboratories is beyond the scope of this review and better explored under an Information and Communications Technology (ICT) framework. The remainder of this section explores the second category of virtual laboratories (i.e. simulations that closely represent laboratory experiments).

2.5.2.2 History

Virtual laboratories have been developed by educational companies and institutions of higher learning through software or websites over the past four decades. They are utilized at every level of education from primary school through secondary school, at institutions of higher education, and for job training in medicine, security, and the military (Felder & Silverman, 1988; Gallagher, Ritter, Champion et al., 2005; Marchevsky, Relan, & Baillie, 2003; Nedic, Machotka, & Nafalski, 2003; Psotka, 1995; Rogers, 2000; Yasar & Landau, 2003). Recently, virtual laboratories have even emerged in the scientific workplace as extensions of common meeting places, fostering collaboration around certain topics of research (Rauwerda et al., 2006).

While the concept of virtual laboratories (as encompassing remote laboratories and simulations) dates back to the 1970s, the development of true virtual laboratories specifically related to the life sciences are of greater relevance to the current study. One of the first such initiatives in the 1980s was the Genetics Construction Kit (GCK) that illustrates classical Mendelian genetics by simulating fruit fly variations. Similarly, simulations of genetic transmission of traits in cats, called CATLAB (http://www.emescience.com/sci-genetics-catlab.html), in fruit flies, called the Virtual FlyLab (http://biologylab.awlonline.com/), and in pea plants and dragons, called Biologica (http://biologica.concord.org/), were developed in the 1990s and were widely used in science classrooms. Later, ViBE: Virtual Biology Experiments (http://www.ece.rutgers.edu/~marsic/books/SE/projects/ViBE/) was created in 2001 to allow students to discover biological processes and practice laboratory skills. All of these programs served as the inspiration for the Virtual Genetics Lab, developed in 2007, to test predictions of genetic crosses for various traits in a hypothetical insect (http://vgl.umb.edu/). It enabled students to "practice the logic of genetic analysis without the distractions of wet labs" but were not intended to "replace a wet lab" (White, Bolker, Koolar et al., 2007, p. 30).

A myriad of such software emerged in the 21st century for medical students and university and high school students in the sciences (Yu, Brown, & Billet, 2005), but the ones most commonly used in the current study include: the Howard Hughes Medical Institute virtual laboratories (http://www.hhmi.org/biointeractive/vlabs/) for exploring topics in molecular genetics, cardiology, neurophysiology and the immune system (HHMI, 2003), and the University of Utah's virtual laboratories (http://learn.genetics.utah.edu/) that prepare students with basic skills in molecular genetics experiments and involve investigation of the molecular basis of cancer (University of Utah, 2004). A full list of the virtual laboratories used in this investigation are provided in Appendix D, and a description of their implementation is included in Chapter 3.

2.5.2.3 Benefits

Because of the recent rise in the biotechnology industry, and the job opportunities thus afforded, innovations in teaching biotechnology and molecular biology concepts have become vital (Toth, Morrow, & Ludvico, 2009). In this manner, virtual experiments enable users to focus on conceptual explanations because the virtual program can keep track of details in data to allow users to focus on the 'big picture'. Moreover, state education standards are becoming increasingly demanding, as noted in Section 2.2.2, particularly regarding the molecular focus of biology with which students often have difficulty. To address this concern, the use of virtual laboratories in the classroom can help to make these molecular concepts more concrete for students without requiring complex and costly equipment (Marbach-Ad, Rotbain, & Stavy, 2008; Raineri, 2001), and thus assist in narrowing the gap between lagging levels of student achievement and the proposed higher standards to which students are held accountable. Therefore, the use of virtual laboratories can aid in both the conceptualization and constructivist realm, allowing students to learn by doing and become more engaged in their studies (Clancy, Titterton, Ryan et al., 2003; Felder & Silverman, 1988; Gallagher et al., 2005; Marchevsky, Relan, & Baillie, 2003; Yu, Brown, & Billet, 2005).

As well, traditional laboratories face a number of logistical challenges in that they are expensive to maintain and thus scarce, require low student-faculty ratios, entail long durations of time (a resource that is tightly rationed), depend on well-designed activity sequences, and raise safety and ethical issues when handling toxic substances or biological specimen. On the other hand, for virtual laboratories, issues such as time, geographical distance, safety, and expenses are largely irrelevant (Borgman et al., 2008).

Similarly, Toth et al. (2009) describe their efforts to develop a tool that preserves the beneficial aspects of hands-on laboratory work while deepening the quality of inquiry learning in a complex, error-prone environment; according to them, virtual laboratories "allow the user to conduct the same scientific inquiry afforded by hands-on investigation but at a reduced expense, with increased safety, and within the time constraints of a…classroom" (p. 334). They also describe the benefits of virtual laboratory equipment that automates routine tasks, such as mixing solutions and forming agarose gels, and allows students to focus on the inquiry aspects of an experiment rather than the technical tasks. Additionally, many virtual laboratories contain visual representations or animations that explain the mechanism of the virtual equipment, an interactive feature unavailable in hands-on laboratories where only the end state of a reaction occurring inside complex machinery is revealed to students (Toth, Morrow, & Ludvico, 2009).

Regarding safety, simulations of crises such as pandemics or results of natural disasters can be replicated and studied in a non-dangerous manner. Virtual experiments also provide opportunities for physically-disabled students to perform experiments in a risk-free environment by avoiding complex equipment and materials that pose safety hazards (Cobb, Heaney, Corcoran et al., 2009). Such virtual simulations might also benefit potential workers in need of training (Muirhead, 2003).

Other practical advantages of incorporating virtual laboratories into science curricula include reduced teacher preparation and cleanup time, the lack of complex and costly equipment, materials, and physical laboratory space, and allowing experiences not otherwise possible in many high school classroom settings (Yu, Brown, & Billet, 2005). A virtual environment for experimentation also enables better multi-tasking. A number of experiments or equipment can be run at once and, by its nature, the Internet allows a synthesis of different resources for learning rather than the single, 'authoritative' voice of the textbook or instructor (Annetta, Klesath, & Meyer, 2009; Dede, 2005).

Furthermore, virtual learning environments offer an emphasis on authentic scientific experiences because students can revise their original predictions for experiments by way of instant feedback from data manipulations, form more accurate mental models of phenomena, and can even use these virtual simulations as practice to prepare them conceptually for complex hands-on experiments (Zacharia, 2007). Yu et al. (2005) constructed a system that draws on the instant feedback feature by providing an intelligent tutoring agent that offers advice for students to correct their mistakes while conducting a virtual experiment. Naturally, virtual experiments are repeatable within and outside of the classroom, a feature that serves to prepare students prior to beginning a hands-on experiment and allows them to review an experiment after it has been conducted (Cobb et al., 2009; Reising, 2010).

While some virtual laboratories are designed to incorporate student collaboration (Cobb et al., 2009), others are focused on training individuals in the skills and concepts of a particular experiment. The types of laboratories intended to enable student collaboration excel in imitating a true scientific experience of not only investigation but also the building of community. Indeed, one of the most important features of web materials necessary to improve learner outcomes is a high degree of interaction, which can be accomplished asynchronously (eg. emails and bulletins) and synchronously (eg. Chat rooms) (Chandra & Fisher, 2009). On the other hand, virtual laboratories that focus on the individual have the advantages of enabling shy students to find more voice (Dede, 1999) and reducing the peer pressure from both fellow students and teachers, thus allowing users to feel more comfortable about making and learning from mistakes (Yu, Brown, & Billet, 2005); these advantages might be applied to online experimentation that includes collaboration, as well, because there is a degree of anonymity.

On the other hand, disadvantages of utilizing virtual laboratories include the use of idealized data, lack of collaboration, and the absence of interaction with real equipment (Hofstein & Lunetta, 2004; Nedic, Machotka, & Nafalski, 2003). Waight and Abd-El-Khalick (2007) add that true inquiry in virtual experiments can also be affected because of the perceived authority of technology. Winn et al. (2006) point out that such technological tools can favor students who have more prior knowledge. Ultimately, many of these disadvantages can be avoided with the application of good design principles for the implementation of virtual laboratories (Annetta, Klesath, & Meyer, 2009; Toth, Morrow, & Ludvico, 2009). To summarize, hands-on laboratory advocates emphasize design skills (Ma & Nickerson, 2006) and the importance of making and learning from errors (Toth, Morrow, & Ludvico, 2009), while virtual and remote laboratory advocates focus on the benefits gained in conceptual understanding (Marbach-Ad, Rotbain, & Stavy, 2008; Marchevsky, Relan, & Baillie, 2003; Raineri, 2001; Toth, Morrow, & Ludvico, 2009).

2.5.3 Virtual Learning Environments

Researchers and policymakers recommend that a modern learning environment should incorporate media and technology, including virtual experiences (Borgman et al., 2008; Saettler, 2004; Tamim et al., 2011). However, this environment must be characterized by understanding the relationship between tasks and resources, integration, establishing and maintaining good study habits, building confidence, including enrichment, annotation, tracking, and feedback (Sirkemaa, 2003). Naturally, these dimensions of a learning environment differ from a traditional one; this is referred to as a Virtual Learning Environment (VLE) (Yu, Brown, & Billet, 2005), or 'v-learning' (Annetta, Klesath, & Meyer, 2009)

A number of chapters in Khine and Fisher's (2003) book about Technology-Rich Learning Environments characterize VLEs and deal with the changing aspects of a learning environment in the virtual world, but the intervention evaluated in this study was not intended to transport students into a separate VLE. Rather the virtual laboratories in the current study were meant to supplement the traditional classroom learning environment, by borrowing elements from a VLE. Such elements include simulations and the nature of online education, both explored in this section.

2.5.3.1 Simulations

Virtual science learning environments rely on the use of interactive simulations of scientific phenomena that are too small, large, slow, fast, simple or complex to explore in a typical classroom. These simulations might stand alone or serve as the media used by various technologies, such as virtual laboratories and Serious Educational Games (SEGs). Both virtual laboratories and SEGs share the same type of interface regarding simulations and interactivity, and might even share the common goal of improving science learning, but the underlying premise is entirely different. The latter seeks to merely increase students' interest and engagement by enriching a science learning experience (Thurmond, Holmesa, Annetta et al., 2011), but a full review of SEGs is beyond the scope of this discussion. The former, the subject of the current study, is meant to either replace or supplement essential experiences that could not otherwise be had in science classrooms. However, to make virtual laboratories attractive, they are often designed similarly to SEGs because "as the Net Generation (currently the leading population playing online games) reaches college age, the adaptation of a three-dimensional, game-like environment into a virtual classroom seems to be the natural evolution in online learning" (Annetta, Klesath, & Meyer, 2009, p. 27).

Such simulations, based on visualizations and animations, have been heralded as being essential to students' conceptual understanding of complex topics, especially those requiring keen mathematical abilities and sustained logic that burden the cognitive load on students and endanger their abilities to master a concept (Marbach-Ad, Rotbain, & Stavy, 2008; Toth, Morrow, & Ludvico, 2009; Tsui & Treagust, 2004; Yasar & Landau, 2003). In fact, the benefits of simulations for conceptual understanding are so pervasive that Van Rooy (2011) claimed its primacy in instruction: "Much of bioscience can now only be effectively taught via digital technology since its representational, symbolic forms are in digital formats" (p. 1). Her study, based on qualitative data using classroom observations and semi-structured interviews with teachers, pointed to the pedagogical benefit of using digital technologies for students' understanding of concepts in molecular genetics.

While a number of studies highlight only their beneficial outcomes, research regarding the effectiveness of simulations for science learning is inconclusive (Sabah, 2011). Based on past research, the NRC's Committee on Science Learning concluded that there is much evidence for the positive impact of simulations on conceptual understanding, some evidence that simulations motivate interest in science, and less evidence about whether they support other science learning goals. They view computer games and simulations as worthy of future investment from entrepreneurs, and investigation by researchers, as a means to improve science learning (National Research Council (NRC), 2011).

The current study only defined simulations as a component of virtual laboratories. Therefore, the review of literature concerning their effectiveness is limited in this chapter but many other studies contain a more in-depth discussion of the benefits of simulations (Bell & Trundle, 2008; Burkholder, Purser, & Cole, 2008; Dori & Barak, 2001; Finkelstein, Adams, Keller et al., 2005; Marbach-Ad, Rotbain, & Stavy, 2008; Winn et al., 2006).

2.5.3.2 Online Education

One of the areas in which virtual laboratories have the potential to be most useful is online education. This also happens to be the fastest growing area in education today. In the US, enrolment in full-time virtual schools has increased 40% in the last three years and, according to the International Association for K–12 online learning, nearly two million students take at least one online class in the US alone (Banchero & Simon, 2011; International Association for K–12 Online Learning (iNACOL), 2012). Well-known American universities (e.g. Harvard University and Stanford University) are beginning to invest in a venture that offers free classes online despite the lack of economic gain (Perez-Pena, 2012). To ensure that their students are well prepared for the world of online education and the future job market, some school districts and states require the successful completion on an online course in order to graduate (Brown, 2012).

Whether to save costs, provide opportunities to regain credit for a previously-failed course, or offer enrichment options, K–12 schools are increasingly adopting online course options. For instance, many schools in Florida, Illinois, and Massachusetts have avoided the issue of class size by establishing ‘virtual classrooms’, essentially large computer laboratories with a facilitator, that can accommodate more students (Banchero & Simon, 2011; Herrera, 2011).

In some cases, schools are entirely online and there are no bricks-and-mortar buildings. However, this is mostly frowned upon and the most beneficial arrangement is a learning model that blends traditional instruction with online activities or vice versa, as one professor of education and editor of *The American Journal of Distance Education* stated: “There is no doubt that blended learning can be as effective and often more effective than a classroom” (Herrera, 2011, Paragraph

20). In order to create a viable and effective arrangement for blended instruction, Herrera describes three requirements: proper design of the virtual course (or aspect thereof), the inclusion of direct teacher instruction within physical classrooms, and an appropriate maturity level among students taking the course.

Naturally, online courses in the experimental sciences, as with distance education, face challenges without a physical laboratory. Some distance education programs have adapted to these challenges by sending videotapes or home kits or arranging hands-on experiences at local laboratories, but none of these options have proven to be too useful or beneficial (Alhalabi et al., 1998). Virtual laboratories provide a solution for such courses by allowing students to learn the practical skills required for inquiry: students can manipulate virtual equipment, gather and analyze data, and even engage in virtual dissections.

The virtual environment in science can be extremely beneficial to students and institutions in developing countries that do not have access to highly complex equipment and costly resources in laboratories. In fact, an initiative in India has been established to enable such students to understand and 'experience' certain experiments within many areas of science at the university level (http://www.vlab.co.in/). Through this resource, users can access both simulation-based and remote-triggered virtual laboratories, comprising over 800 different experiments. The mission is to provide remote access to laboratories in various disciplines of science and engineering to students and researchers:

> Virtual Lab is a complete Learning Management System. All the relevant information including the theory, lab-manual, additional web-resources, video-lectures, animated demonstrations and self-evaluation are available at a common place. Virtual Labs can be used in a complementary fashion to augment the efficacy of theory-based lectures. Small projects can also be carried out using some of the Virtual Labs. Virtual Labs can be effectively used to give lab-demonstrations to large classes. (Vlab, 2012, FAQ Section)

2.5.4 Overview of Studies Employing Virtual Laboratories

Although some projects using virtual laboratories have only recently begun in schools, and started to show positive results, several researchers note the lack of empirical evidence concerning their effectiveness (Harms, 2000; Hofstein & Lunetta, 2004; Javidi, 1999; Javidi & Sheybani, 2006). Ma and Nickerson (2006) acknowledge the necessity to further evaluate, via controlled studies, the educational effectiveness of laboratory simulations developed by software companies. Conversely, Chandra and Fisher (2009) urge teachers, albeit untrained in ICT, to become more proactive in helping to develop educational technology because they possess valuable knowledge and experience for designing and sequencing such activities.

The following is an overview of studies involving an evaluation of the educational benefits of virtual laboratories; however, this discussion is limited to virtual laboratories that:

- seek to imitate a real laboratory experiment using inquiry skills and which involve students observing phenomena, formulating hypotheses, setting up controls, following procedures, testing hypotheses, and analyzing results. (Virtual experiences to clarify a concept through simulation/modeling are not included.)

- explore topics that are too complex to be investigated in real laboratories at the high school or university levels because of various constraints on time, safety, etc.

- are evaluated in an educational context (i.e. under the framework of improving science education) rather than improving a product's design from the perspective of ICT.

- result in positive learning gains; inconclusive or negative results are presented in Section 2.5.5.

While formal evaluative analysis has yet to be completed, anecdotal evidence and preliminary evidence gathered over four semesters for university students involved in integrating virtual laboratories from iLabs into their biology course point to a gradual increase in class performance. More promising was the significant decrease in the number of students failing the course (Raineri, 2001). In a similar study of 39 college students taking an introductory biology course, using a crossover design to compare hands-on and virtual laboratory activities, quantitative data showed no difference in the order of the instructional methods, but revealed the effectiveness of integrating virtual and hands-on laboratories over hands-on laboratories alone. Qualitative data indeed pointed to the efficacy of engaging in virtual laboratories before the hands-on ones (Toth, Morrow, & Ludvico, 2009).

Significant improvement over four years in student participation and satisfaction was also seen amongst medical students experiencing web-based instruction in a pathophysiology course. Attendance at laboratory sessions using virtual software increased to almost 100%, compared to the approximately 30% to 40% attendance in previous years when students had been required to bring their own microscopes to study histological slides at their own pace (Marchevsky, Relan, & Baillie, 2003).

In another study that used ‘presence’ (the ability to perceive virtual representations as real people or objects despite not being able to touch them directly) as a measure of effectiveness, entomology students reported high levels of such ‘presence’ when creating and manipulating a virtual ‘bug farm’ as a supplemental activity in their course. The activity was a multi-user format similar to video games in a three-dimensional environment. In this case, males experienced a greater sense of ‘presence’ than females (Annetta, Klesath, & Meyer, 2009).

Another evaluation of a virtual laboratory involved 184 high school chemistry students in the US in a two-year crossover design with students being exposed to both virtual laboratories and real laboratories about the same topic (stoichiometry). The measures of effectiveness were laboratory performance, including the ability to interpret data and comprehend the concepts learned from the investigation, students’ perceptions of the learning environment, and students’ attitudes towards laboratory investigations and computers. No significant differences emerged in terms of learning gains for the first trial, which illustrates that substituting virtual for physical experimentation can be equally effective, but some significant learning gains were noted for the second trial; therefore virtual laboratories were shown to be as effective as, if not more effective than, physical laboratories (Pyatt & Sims, 2012).

Furthermore, the authors argued that 'hands-on' is a concept about interaction, interpretation and revelation, more than it is about equipment use. The insight offered by this study shows that opportunities to explore and manipulate experimental variables matter more to students than operating physical equipment (Pyatt & Sims, 2012). Similarly, studies involving using manipulatives for teaching heat and temperature (Zacharia, Olympiou, & Papaevripidou, 2008) and for experimentation in electric circuits (Zacharia, 2007) indicated that the use of virtual equipment, when utilized in conjunction with physical equipment, was superior to the use of physical equipment alone.

In another study, while quantitative results showed no significant differences in learning gains, qualitative results revealed that students performing a virtual laboratory in Second Life (http://secondlife.com/) reported more satisfaction and asked less questions of the staff than when subsequently performing the same laboratory practical in real-life. These results indicate improved understanding amongst students who performed the virtual laboratory compared with students who did not perform the virtual investigation as a prerequisite to the activity. However, the entire implementation of the study took only over three hours, calling into question the validity of results from an activity based on one occasion (Cobb et al., 2009).

Because the topic of dissection in science classes has aroused much controversy (Orlans, 1988), virtual laboratories that involve dissecting 'specimens' online provide a viable alternative to real dissections. Studies of the value of virtual frog dissections compared with traditional dissections using real specimens have revealed mixed results; some suggested that real dissections are more effective (Cross & Cross, 2004), while others suggested the supremacy of simulated dissections for improved achievement (Akpan & Strayer, 2010). It should be noted that all three studies used small sample sizes and contained other methodological limitations.

In reality, science classes should blend real and virtual experiments so that students acquire the skills necessary to perform the required technical tasks; virtual simulations are useful for transferring knowledge and skills from an idealized (virtual) environment into physical reality (Yu, Brown, & Billet, 2005). Indeed, a number of studies suggest the desirability of integrating hands-on laboratories with virtual ones and the effectiveness of engaging in virtual experiences prior to the real, hands-on investigation (Akpan & Strayer, 2010; Cobb et al., 2009; Toth, Morrow, & Ludvico, 2009). As well, Nedic et al. (2003) recommended concentrating on virtual laboratories the first year of a four-year engineering program and then slowly working towards physical laboratories in the remaining years. In general, skill acquisition through virtual environments is expected to be more successful if it is scheduled on an interval basis, including the alternation of physical laboratories and regular lessons, rather than amassed into a short period of intense practice (Gallagher et al., 2005).

While this section examines the merits and demerits of virtual experiments that cannot be conducted in real, physical laboratories, it is important to distinguish between virtual and physical laboratory environments. The laboratory has been a prominent feature of science education since the inception of teaching science systematically in the 19th century. A laboratory refers to "experiences in school settings in which students interact with equipment and materials or secondary sources of data to observe and understand the natural world" (Hofstein & Kind, 2012, p. 190). However, in the early years of science experimentation in schools, laboratories were simply environments in which to practice or confirm information learned from lectures or textbooks. Its evolution into the space in which exploration and inquiry can occur took decades, and is a process that is still ongoing. Ultimately, science learning environments that are rich in practical experiences, as compared to those with few laboratory experiences, have been shown to be beneficial for student attitudes and learning, a benefit that might ultimately contribute to choosing a career in science (Hofstein & Kind, 2012; Hofstein & Lunetta, 2004).

A number of studies have compared the effectiveness of virtual and physical experimentation, as reviewed in a recent paper by de Jong, Linn and Zacharias (2013). They describe a physical laboratory as one that imitates reality. The enthusiasm that results from students practising science in a 'real' laboratory, similar to how 'real scientists' practise, helps in forming positive impressions early on. The hands-on interaction with materials and equipment, and the trouble-shooting involved, expose students to some of the challenges that real scientists encounter. Additionally, the tactile experiences in a physical setting might enhance conceptual development. In comparison, virtual laboratories manipulate reality. As previously mentioned, a virtual environment allows idealized data, as well as unobservable data, and avoids technical problems associated with equipment. Virtual laboratories allow interactions with equipment and materials and so the definition of 'hand-on' takes on a new meaning beyond the tactile realm. In line with the handful of studies described above, the revised thesis also concludes that a blend of physical and virtual environments is the most effective method for allowing both physical interaction and conceptual development in science. In fact, the determining factor in the effectiveness of any method is not the context in which the experience takes place, but the degree to which inquiry is fostered (de Jong, Linn, & Zacharia, 2013).

The term 'inquiry' was originally described by Kempa and Ward (1975) as 1) planning an experiment, 2) carrying out the experiment, 3) observations, and 4) analysis, applications, and explanation of results. More recently, Hofstein and Kind (2012) stress the importance of incorporating metacognition into all activities so that students are engaged in planning how to approach a task, monitoring their comprehension of a task, and evaluating their progress as they execute the task. Four conditions are necessary in order to foster an environment of inquiry where metacognition can occur: time, opportunity, guidance, and support (Baird & White, 1996). Regarding the first condition, time can be afforded by reducing the amount of time spent on tasks that can be handled by technology, as in a virtual experimentation.

There is a plethora of evaluations of virtual innovations from the field of information technology in which the computer basically served as a virtual laboratory that simulates natural phenomena. However, because the purpose of most of those studies was to improve the technology developed in order to expand its usage, and perhaps increase financial gains, evaluation of such products for educational benefits could be superficial. Additionally, as illustrated, many of the studies above evaluating virtual laboratories from an educational standpoint were based on small sample sizes and didn't adhere to strict standards of research. Consequently, there is a dearth of solid evaluative research on virtual laboratories from an educational perspective, and especially within a learning environments framework. Therefore, the aim of my study was to evaluate the effectiveness of virtual laboratories used in educational settings at the high school level, in terms of the learning environment, attitudes, and achievement.

2.5.5 The Critics: The No Significant Difference Phenomenon Regarding Educational Technology

Thomas L. Russell (1999), in his book entitled *The No Significant Difference Phenomenon*, points out an interesting trend regarding educational technology that started in 1928 and continues currently (http://www.nosignificantdifference.org/). In his introduction, Russell reveals that he began with the intention to document a well-known 'fact' that technology improves instruction, but his findings surprised him: only a handful of studies showed any measurable positive effect of technology on education and they were offset by studies indicating a negative impact. Mostly, he concluded, studies of the effectiveness of educational technology resulted in no significant differences. The following is a brief survey of the literature revealing this trend.

Starting with the advent of digital technologies in the early part of the 20th century, overly hopeful inventors envisioned a future without textbooks. In 1913, Thomas Edison stated, "Books will soon be obsolete in the schools.... Our school system will be completely changed in 10 years" (Saettler, 2004, p. 98) referring to the emergence of the motion picture as a new medium for education. Contrary to this claim, textbooks are still currently being used frequently in classrooms.

One of the first academic evaluations the application of technology into the realm of education focused on correspondence education involving the use of media such as loudspeakers (Loder, 1937) and phonographic recordings (Rulon, 1943). The achievement scores of students who were face-to-face with their instructors were compared with scores of students who were not; neither study showed significant differences. Nor were any significant differences found between students learning via instructional radio and students being taught by traditional methods (Woelfel & Tyler, 1945). In 1950, a study with 9th grade biology involved comparing students using three instructional methods: sound films, sound films plus study guides, and a standard lecture demonstration. Again, no significant differences were revealed in achievement scores between the three groups (Van der Meer, 1950).

Early in the 1950s, television promised to be an effective medium of instruction in the classroom, but the data showed otherwise. One of the first such studies indicated that Instructional Television, or ITV, was equally effective as face-to-face instruction (Kanner, 1954). Subsequently, there were many studies of the effectiveness of ITV which showed no significant differences (Thornton & Brown, 1968). Televised instruction was even applied to the acquisition of laboratory skills, but no significant differences were found in students' achievement compared to those in face-to-face laboratories (Seibert & Honig, 1960).

In the 1950s, Purdue University initiated a special laboratory devoted to the acquisition of languages utilizing the most advanced technology available at that time; however, no significant differences were noted in studies that evaluated this method (Fotos, 1955). Similarly, the promise of benefit to students regarding educational media such as the kinescope (Parsons, 1957), telephone (Cutler, McKeachie, & McNeil, 1958), multi-image presentation (Didcoct, 1958), and tape recorder (Popham, 1961) was not fulfilled as evaluative studies produced no significant differences.

The 1970s ushered in an era of computer exploration that had instructional relevance. However CAI, or Computer-Assisted Instruction, did not reveal much success in terms of significant differences from traditional methods (Beard, Lorton, Searle et al., 1973; Goldberg, 1997; Judd, Bunderson, & Bessent, 1970; Lee, 1985). Neither did other media, such as movies (Atherton, 1971), time compression of speech (Sticht, 1971), the Spitz Students Response system (Brown, 1972), audio-conferencing (Holdampf, 1983), the electronic blackboard (Partin & Atkins, 1984), video simulations (Atherton & Buriak, 1988; Thomas & Hooper, 1991), and interactive video (Cennamo, 1990), emerge as educationally beneficial. By 1980, Wilkinson (1980) stated: "The results of several decades of research…can be summed up as *no significant difference*" (p. 5). In reviewing educational technology, Thompson, Simonson, and Hargrave (Thompson, Simonson, & Hargrave, 1996)indicated that, for every study showing educational benefits of a medium, there was another that suggests the opposite. Yet again, nearly 20 years ago, Salomon and Perkins (1996, p. 3) observed that "computers, in and of themselves, do very little to aid learning. Their presence in the classroom along with relevant software does not automatically inspire teachers to rethink their teaching or students to adopt new modes of learning".

With the advent of the Internet, the quantitative and qualitative increase of instructional media provided a new focus for educational research. From the integration of online software into classrooms (Goldberg, 1997; Klass & Crothers, 2000) to classes conducted entirely online (Hiltz & Wellman, 1997; Horn, 1994; Johnson, 2002; Martin & Rainey, 1993; Mock, 2000), a new focus for evaluation was borne, but results were generally consistent with the 'no significant difference' trend.

More recently, a myriad of technological innovations have continued to be integrated into classrooms despite the lack of evidence regarding their effectiveness. Currently, progressive schools cannot educate their students without the 'essential' interactive whiteboard, so it seems. Yet, in 2007, a team at the University of London evaluated their Schools Whiteboard Expansion (SWE) project only to discover that using interactive whiteboards did not influence students' educational experiences at all (Moss et al., 2007). The US Department of Education commissioned a study of the effectiveness of reading and mathematics software widely used by primary schools. The conclusion was that there were no statistically significant differences in the test scores of students who used the software and those who did not (Campuzano, 2009). The most recent proposal, while actually mirroring the one envisioned by Thomas Edison 100 years ago, is to abandon physical textbooks in favor of their electronic counterpart; however, a study conducted with university students using digital technologies, such as Amazon Kindle, Sony eReader Touch, Apple iPad, enTourage eDGe, and CourseSmart, showed no significant differences in their learning relative to students using traditional textbooks (Weisberg, 2011). Still, in early 2012, US government officials campaigned for the complete substitution of digital textbooks for hardcover ones within a five-year time span, citing that South Korea has had such an initiative in place for its students by 2013 (Hiltzik, 2012).

While a full review of literature on the effectiveness of educational technology in the last few decades is beyond the scope of this study, the research described above is perhaps a glimpse into the array of literature pointing to the lack of evidence for educational efficacy. More relevant to this review are the studies evaluating the effectiveness of virtual laboratories, however limited in quantity. Some of these studies, which claim educational benefits, are explored in Section 2.5.4. This section is devoted to studies whose results indicate 'no significant differences' or significant differences in favor of traditional methods over virtual ones.

To illustrate, no significant differences were found for an undergraduate oceanography course in which students went on a real field trip to the sea or engaged in a virtual activity that simulated the field trip (Winn et al., 2006). Virtual and real equipment was found to be equally effective for middle school students designing mouse-trap cars in a science class (Klahr, Triona, & Williams, 2007). A comparison of real and virtual frog dissections in an AP biology class showed that students dissecting the organic frogs scored significantly better on a laboratory practical than students using a virtual version (Cross & Cross, 2004). College students taking an online introductory biology course generally perceived face-to-face laboratories to be more effective than the virtual ones, although they did not perceive the virtual laboratories to be ineffective (Stuckey-Mickell & Stuckey-Danner, 2007). Finally, university students in a biotechnology class who performed virtual laboratories through Second Life, a virtual world in which participants create an avatar that interacts with other people and institutions, performed equally successfully as students conducting the same experiment in real life (Cobb et al., 2009). In summary, virtual laboratories, just like any other technological intervention, are generally comparable in effectiveness to traditional methods of learning, even though they are purported by their developers, the media, and even educators as being superior.

Russell, in his original article (1992), questioned why empirical research results for educational technologies are ignored, often to the detriment of the students. Professional educators and, of course, technologists and product developers, adhere to the myth that increased technological interaction, often the more appealing, newsworthy, costly type, improves education. In fact, many new technologies claim to produce statistically significant results. How is that possible?

In his introduction to Russell's book, Richard E. Clark, who left a commercial career in media to pursue a PhD in education, offers the following explanations for the appearance of significant differences. First, many studies involving media are invalidated as a result of inadequate design methods. Second, journal editors are often biased towards reporting positive results, especially for evaluations of educational technology. Naturally, economic interests drive the publication and dissemination of studies showing positive, significant differences (Russell, 1999).

Clark attempts to explain why studies that evaluate technology produce no significant differences. He refers to the 'John Henry Effect', a term first used by Saretsky to memorialize an American steel driver who pushed himself so hard to win against a steam driven chisel; win he did, but he also died as a result (Saretsky, 1972). As applied to educational research on media, this effect describes a situation in which the comparison group works harder to improve teaching and learning in response to the perceived threat of competing with the lure of promised results through sensationalized media. In this way, the experimental and comparison groups both emerge with positive results and no significant differences are uncovered (Russell, 1999).

Another explanation of the 'No Significant Differences' phenomenon is offered by Chris Dede (1999), a professor in Education and Information Technology at George Mason University:

> However, all these studies [evaluating particular educational technologies] are limited in that the average performance of a group is compared for one single mode of delivery versus another. This research does not recognize that, for each medium utilized, some students are empowered, others disenfranchised, and the net impact may average out the differences. (p. 23)

Critics, while admitting some potential effectiveness, also point to other downsides of media: “Well-produced multimedia features can improve students' understanding of difficult or recondite concepts. But there's a fine line between an enhancement and a distraction” (Hiltzik, 2012, para. 21). Also, funds spent on multimedia drain the financial resources available to recruit, hire, and train high-quality teachers, an important determining factor in students’ attitudes and achievement.

Nearly 30 years ago, Clark stated: “The best current evidence is that media are mere vehicles that deliver instruction but do not influence achievement any more than the truck that delivers our groceries causes changes in nutrition...only the content of the vehicle can influence achievement” (Clark, 1983, p. 445). In order to sway public perception, a battle between the message and the media ensues and, usually, the commercialized, sensationalized, and often irrationalized ideas of the media prevail. Clark argues that adequate learning results will be produced regardless of the medium and that we must choose the less expensive media to avoid wasting limited educational resources.

The implications of this field of research do not dictate the abandonment of evaluating educational technology. Rather, they suggest that unbiased empirical research and judicious review of its effectiveness in education are all the more necessary and must parallel the effort invested in the marketing and sensationalizing of such innovations.

In fact, a finding of No Significant Differences is as important a finding as statistical significance. At the very least, such results provide evidence that technology is not detrimental to instruction and that such technologies can be used with confidence when they indeed provide solutions that are cost-effective, efficient, and convenient. For instance, a ‘no significant difference’ result for virtual laboratories is promising for distance education. Furthermore, in trying to adapt content to instructional media, the content and its delivery are actually reviewed, and this process in itself is beneficial to improving instruction (Russell, 1999).

In conclusion, Section 2.5.1–2.5.4 reviewed the benefits heralded by proponents of educational technology, while Section 2.5.5 presented the opponents’ view. With this balance, the reader can better evaluate the evidence presented later in this thesis

(Chapter 4). Ultimately, "Good teaching cannot be replaced by good technology, but the merger of the two holds the promise for truly effective [online] instruction" (Annetta, Klesath, & Meyer, 2009, p. 32).

2.6 Summary

Chapter 2 reviewed literature that provides the context for the current study that sought to evaluate the effectiveness of virtual laboratories in terms of perceptions of the learning environment, attitudes towards science, and achievement.

First, relevant literature that provides the learning environments framework for the current study was reviewed. Included in this section was a review of questionnaires for measuring perceptions of the learning environment from the perspective of the student. This field of research has grown over the last 40 years beginning with Lewin's (1936) and Murray's (1938) monumental ideas of connecting personality and environmental influences to behaviour and accounting for personal needs, environmental presses, and differences perceived by observers and participants. Moos (1974) characterized human interactions into the three dimensions of relationship, personal development, and system maintenance and change, which have served as the basis for various constructs assessed by the burgeoning, valid, and economical learning environment questionnaires. Several of these widely-used questionnaires were selected for this study on the basis of their validity, reliability, and applicability, namely, the Science Laboratory Environment Inventory (SLEI) and the Technology-Rich Outcomes-Focused Learning Environment Inventory (TROFLEI).

Historical developments in this field have led to the establishment of an international journal and book series focusing on learning environments research. Current and past lines of research in learning environments focus on associations between student outcomes and the environment, actual versus preferred environments, cross-national validations, action research, the combination of quantitative and qualitative data, the links between home, the class, and school, as well as others. More recently, a trend to evaluate the effect of innovations in science on the learning environment has emerged, and it is under this sub-genre of learning environments research that the current study falls.

Literature was also reviewed for attitudes towards science, another measure of effectiveness of virtual laboratories in my study. The literature describing the development and application of the Test of Science-Related Attitudes (TOSRA) was explored because scales, specifically Enjoyment of Science Lessons and Attitude to Scientific Inquiry, that were validated in many other studies were adopted from this questionnaire for the assessment instrument in the current study.

Because gender is thought to play a role in the perceptions, attitudes, and achievement of students in science, relevant literature for this factor was reviewed. More specifically, I considered gender differences in these measures of the effectiveness of science education and whether the literature shows that particular interventions either increase or decrease the gender divide.

Next, literature that featured and characterized the intervention in this study was reviewed, including literature concerning the integration of technology into classrooms in general, and the practical benefits of such integration. An example of such educational technology is virtual laboratories, the intervention in my study. The literature describes virtual laboratories as being interactive, concept-friendly, skill building, highly instructive, economical, efficient, safe, and viable alternatives to experiments that would not otherwise be possible in a high-school classroom. Results of various studies that employed virtual laboratories were presented, but their methodological approaches were questioned. The lack of research into the effectiveness of virtual laboratories was noted and therefore used to justify the significance of its evaluation in this study.

The following chapter outlines the methods of the current study and describes the approaches used to answer the research questions concerning the validity of the instrument used, associations between student outcomes and the environment, and the effectiveness of virtual laboratories, as well as its differential effectiveness for males and females, in terms of perceptions of the learning environment, attitudes, and achievement.

Chapter 3

Methodology

"Though this be madness, yet there is method in't." – William Shakespeare

3.1 Introduction

This study investigated the effectiveness of virtual laboratories in terms of students' perceptions of their learning environment, attitudes towards science, and achievement in US high schools. The research design selected for the study was quasi-experimental in that two treatment conditions were established to compare the effectiveness of instruction with and without virtual laboratories. Its principal method of data collection was the use of a new questionnaire containing elements from previously-validated questionnaires to assess perceptions of the learning environment and learner outcomes (i.e. attitudes and achievement). However, qualitative data, through semi-structured interviews, were added to embellish the quantitative results.

This chapter describes and justifies the methodological aspects of this study in terms of the research questions guiding the methods (Section 3.2), the sample selection (Section 3.3), the materials used including assessment instruments and other resources (Section 3.4), the procedures followed (Section 3.5), data collection, entry, and analysis (Section 3.6), and limitations of the study (Section 3.7).

3.2 Research Questions

The aim of the study was four-fold: to validate a new questionnaire, to investigate associations between the learning environment and student outcomes, to determine the effectiveness of virtual laboratories in general, and to examine the differential effectiveness of virtual laboratories for males and females. These research aims are delineated in more detail below; they guided the design, implementation, and data analysis of this study.

1. Are scales from the Test Of Science Related Attitudes (TOSRA), Science Laboratory Environment Inventory (SLEI), and Technology-Rich Outcomes-Focused Learning Environment Inventory (TROFLEI) questionnaires, as

well as achievement items valid and reliable when used with a sample of high school students taking biology in the US?

2. Are there associations between the perceived classroom learning environment and student outcomes of attitudes towards and achievement in science?

3. Is the use of virtual laboratories in high school science classes effective in terms of students':

    a. perceptions of their learning environment,
    b. attitudes towards science, and
    c. academic achievement?

4. Is the use of virtual laboratories differentially effective for males and females in terms of students':

    a. perceptions of their learning environment,
    b. attitudes towards science, and
    c. academic achievement?

3.3 Sample Selection and Characterization

To select participants, an electronic request was sent out over various teacher networks (email lists and listservs from science education organizations). While over 20 teachers initially expressed interest, six teachers followed through on implementation of the treatment procedure with their students. Participating teachers then obtained informed consent from the respective principals at their schools and from students in their classes.

As part of the questionnaire, students answered some personal questions concerning sex, minority status, and others, which informed the characterization of the sample. Thus, participants were biology students in grades 8–10 from six different public schools throughout the following states in the US: Massachusetts (MA), New York (NY), Pennsylvania (PA), and Virginia (VA). The total sample size for the study comprised of 322 students in 21 classes, taught by six teachers. The inclusion of multiple grade levels, as well as different states and different teachers involved, allowed for greater representation of the US population and ultimately led to greater generalizability. The variable of age should not have affected the results in any way because the differences were spread across both groups (students who used virtual laboratories and those who did not). The statistical methods for controlling these variables are described in Section 3.6.3.

As in all quasi-experimental designs (Campbell & Stanley, 1963), the sample was divided amongst two treatment conditions. The two treatment groups were 'naturally occurring' in that they were already organized into classes in their respective schools. Each teacher implemented this study with at least one class that used virtual laboratories and one class that did not, thus maintaining consistent instruction from the same teacher between the experimental and control group, except for the intervention. Therefore, while students were subjected to different treatment groups, other variables, such as the teachers, the physical classrooms, the content delivered, and the level of ability of the students, were controlled for in that they were present in both the experimental and control groups. This was accomplished through stratified random sampling procedures (Gibson & Chase, 2002) in which the variables were equally spread amongst 'strata' or sub-groups. This design allowed for more accurate results because the effects of confounding variables were equally distributed throughout the study's sample.

To address the third research question about the effectiveness of virtual laboratories, students were divided amongst experimental classes that used virtual laboratories and control classes that did not. The experimental group included 169 students and the control group totalled 153 students. Students in VL and non-VL classes were spread fairly equally amongst the teachers as shown in Figure 3.1.

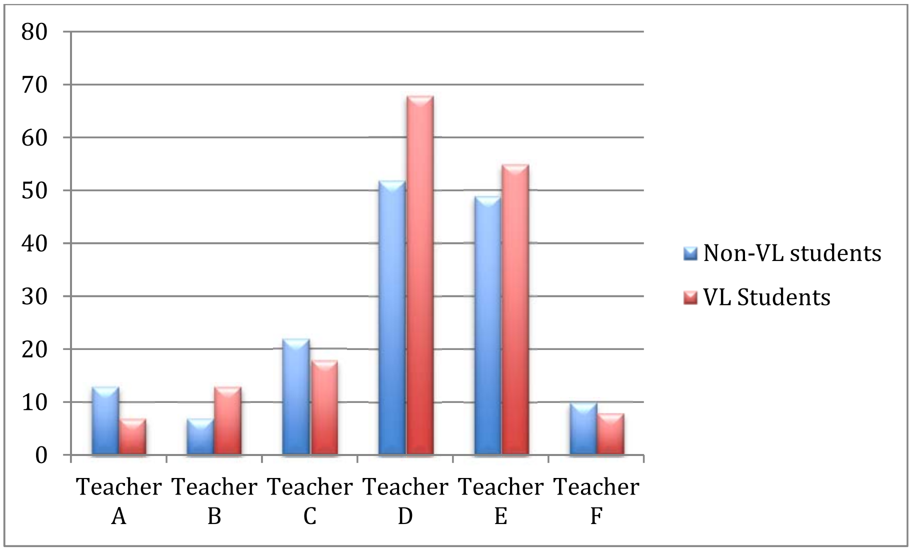

Figure 3.1 Numbers of Students in Experimental and Control Classes for Each Teacher

Out of the 322 students, 171 were females and 151 were males. This delineation is relevant for the fourth research question about the differential effectiveness of virtual laboratories for males and females. The different sexes were distributed equally amongst the participating teachers, as shown in Figure 3.2. As well, males and females were fairly well distributed amongst experimental and control classes. The control group had 79 females and 74 males, while the experimental group had 90 females and 76 males.

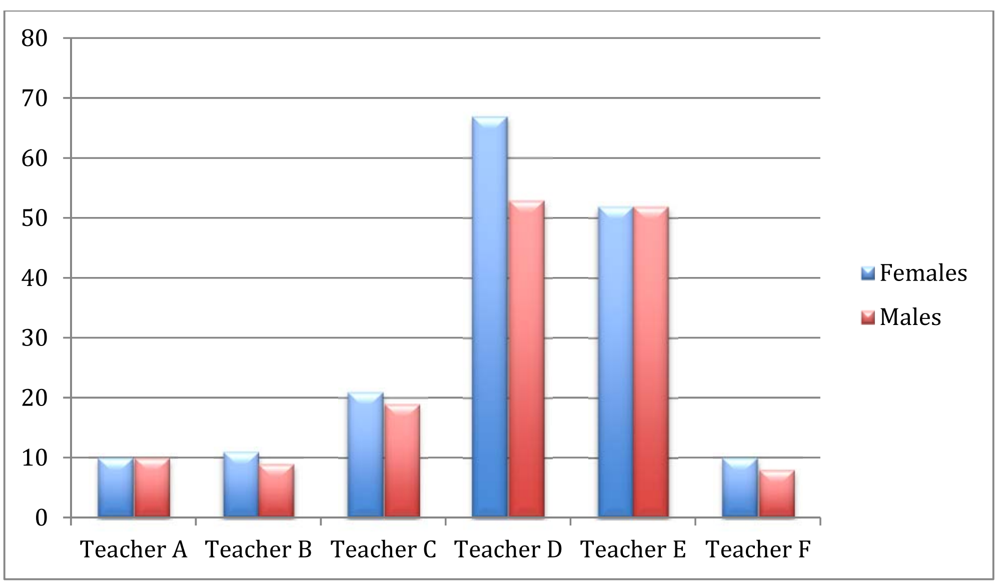

Figure 3.2 Numbers of Female and Male Students for Each Teacher

Other background information supplied by student participants included their age, class type, main language of communication, familiarity with technology, and future career plans. Although the ages of students ranged from 13–18 years, the majority (60%) of students were ages 14–15. Regarding the main language of communication, as 94% of students reported using English, the sample was fairly ‘americanized’. Also, most (81%) students were enrolled in standard level biology classes, while 11% were in honors level biology and 7% were in inclusion classes. Between 94%–98% of students reported having a computer and Internet access at home and around 80% of students reported spending at least two hours a week occupied with such technology; thus, the sample was drawn from a largely digitally-literate population, an important factor for this study that utilized such technology. Nearly all students (92%) expected to enroll in post-secondary institutions. Finally, as another indication of students’ interests in science, 39% responded that they intend to pursue a science or technology-related career, while 54% planned to pursue other careers in the arts and humanities. This background information is relevant because it provides a context for the current study, as well as helping to establish the validity of generalizing the results of this study to other student populations.

3.4 Instrumentation and Resources Used to Implement the Study

The assessment instrument for this study consisted of scales from learning environment questionnaires and from standardized achievement examinations as described in Section 3.4.1. Other resources are noted in Section 3.4.2.

3.4.1 Instrumentation: Development of LAG Questionnaire

A new questionnaire, called the Laboratory Assessment in Genetics (LAG), was developed for the purposes of this study. Most of its scales were adopted from three previously-validated learning environment and attitude questionnaires, as described in the sections that follow. Appendix A contains the full version of this instrument. The LAG consists of items that assess students’ perceptions of the learning environment (Teacher Support, Task Orientation, Investigation, Differentiation, Integration, and Material Environment), students’ attitudes (Attitude to Scientific Inquiry and Enjoyment of Science Lessons), and student achievement. The intended duration for administration of the LAG was 30–45 minutes. The following sections describe the nature of the instruments from which each of the above scales were obtained and how such instruments were developed.

3.4.1.1 Scales to Assess the Learning Environment

Scales to assess the learning environment were obtained from two different instruments: the Science Laboratory Environment Inventory (SLEI) and the Technology-Rich Outcomes-Focused Learning Environment Inventory (TROFLEI), as described below.

The SLEI was developed specifically to assess the unique role of the laboratory in a high school or university science classes. In particular, this instrument was meant to be useful in addressing concerns about the effectiveness of laboratories and whether the associated costs are justified. This goal is particularly significant for the current investigation as virtual laboratories offer a more effective and cost-efficient alternative to traditional laboratories. In developing the SLEI, relevant literature was reviewed to identify dimensions important in the unique environment of a science laboratory class, dimensions in existing instruments were considered, students and teachers were interviewed to guide revisions of the survey during various stages, and the instrument was subjected to item and factor analyses. This resulted in the final version containing 7 items per scale (Student Cohesiveness, Open-Endedness, Integration, Rule Clarity, Material Environment) with a 5-point frequency response scale (Fraser, Giddings, & McRobbie, 1992, 1995).

A sample of over 5,447 students in 269 classes in the USA, Canada, England, Israel, Australia, and Nigeria was used to field test and validate the SLEI. Simultaneous testing revealed consistent scores on internal consistency reliability and discriminant validity when used with 1,594 students in 92 classes (Fraser, Giddings, & McRobbie, 1995), as well as predictive validity when used along with attitude scales to predict the effect on student outcomes (Fraser, Giddings, & McRobbie, 1992). Further validation was accomplished through a study of 489 senior high-school biology students in Australia by Fisher, Henderson and Fraser (1997).

Advantages of this instrument include its economy (its brevity and easy hand-scoring), its cyclic design, and the availability of the personal and class versions and the actual and preferred forms. However, it does contain some reverse-scored items (Fraser et al., 1992); responses are on a 5-point frequency scale. To illustrate its application in the evaluation of educational innovations, the SLEI, or adaptations thereof, have been employed in various studies including the assessment of an innovative science course for prospective elementary teachers (Martin-Dunlop & Fraser, 2007), an inquiry-based, computer-assisted learning class (Maor & Fraser, 1996), and the use of anthropometric activities (Lightburn & Fraser, 2007). More details about the SLEI are described in Section 2.2.2.7.

For the purposes of this study, modified versions of the Integration and Material Environment scales were used, as described below and in Table 3.1. Because Fraser and Tobin (1991) argued that personal forms of scales are likely to be more sensitive in detecting differences between within-class subgroups, the personal form was chosen to examine differences between subgroups, such as males and females. One item, modeled after the original items, was added to each scale to create a uniform version of eight items for each scale on the LAG. To be consistent with responses for scales borrowed from other instruments, response alternatives were also modified to a Likert scale of Strongly Disagree, Disagree, Not Sure, Agree, and Strongly Agree. As well, reverse-scored items were re-worded for clarity and consistency throughout the LAG, as recommended by Barnette (2000). The Integration and Material Environment scales appear as questions 17 through 32 in the LAG (Appendix A).

Integration measures the extent to which the laboratory activities are integrated with non-laboratory and theory classes (see Table 3.1). This was an important aspect in the current study because virtual laboratories are content-based and they can be easily integrated with material learned in class; therefore, it was expected that students would perceive increased integration as a result of using virtual laboratories. The dimension of integration is key to maximizing the retention of knowledge that can be solidified by experience, including experience associated with virtual laboratories. This scale is categorized under Moos' Personal Development Dimension.

Material Environment measures the extent to which laboratory equipment and materials are adequate (see Table 3.1). It is characterized by Moos' System Maintenance and System Change Dimension. Because virtual laboratories use technological materials, it was important to determine whether perceptions of the use of both technological materials and hands-on materials were favorable or not. Therefore, there are two aspects assessed by this scale: 1) the perception of virtual versus real laboratory materials and 2) the inclusion of technological equipment (through which virtual laboratories are accessed) amongst laboratory materials. It was expected that students would have less favorable perceptions of hands-on materials as a result of using virtual laboratories because virtual materials are designed to function perfectly, in order to minimize disruptions to experimentation.

A relatively-new Technology-Rich Outcomes-Focused Learning Environment Inventory (TROFLEI), designed by Aldridge and Fraser (2003) in Australia, draws upon the What Is Happening In this Class? (WIHIC) inventory (Aldridge, Fraser, & Fisher, 2000) by incorporating the WIHIC's scales (Student Cohesiveness, Teacher Support, Involvement, Investigation, Task Orientation, Cooperation, Equity), and adding three additional dimensions (Differentiation, Computer Usage, Young Adult Ethos). In the context of my study, the Student Cohesiveness, Cooperation, Equity, Computer Usage, and Young Adult Ethos scales were omitted because they do not measure aspects of the learning environment that are salient in this study.

The scales adopted for the LAG were originally found to be reliable and valid for assessing students' perceptions of their psychosocial environment when the TROFLEI was administered to 1,035 students in grades 10 and 11 at Sevenoaks Senior College in Western Australia (Aldridge & Fraser, 2003). During the first year of the school's operation, the TROFLEI was designed as part of the formative and summative evaluation of this new school. Strong factorial validity and internal consistency reliability was found for both the actual and preferred forms of the TROFLEI. As well, the actual form of each scale was capable of differentiating between the perceptions of students in different classrooms. Results after four years of the school's operation supported the efficacy of the school's educational programs and revealed differences between the classroom environment perceptions of males and females and between students enrolled in university-entrance examinations and in wholly school-assessed subjects (Aldridge & Fraser, 2008). Since then, the TROFLEI has successfully been modified into two different forms (Aldridge & Fraser, 2008), applied to studies with different methods (Aldridge, Dorman, & Fraser, 2004; Dorman, Aldridge, & Fraser, 2006; Dorman & Fraser, 2009), and adapted for use in other countries (Gupta & Koul, 2007; Koul, Fisher, & Shaw, 2011; Promratrak & Malone, 2006; Welch et al., 2012). More details about the TROFLEI are described in Section 2.2.2.9.

Four scales from the TROFLEI were chosen for incorporation into the LAG because of their relevance in assessing important aspects of a technology-rich learning environment, as described below and in Table 3.1. Each scale contains eight items and responses are recorded using a Likert scale of Strongly Disagree, Disagree, Not Sure, Agree, and Strongly Agree, which are scored 1 to 5, respectively. The wording of some items was modified to fit the conditions of the current study, but the style and content of these modifications were modeled on the original items. Scales adapted from the TROFLEI appear as questions 33 through 64 on the LAG (Appendix A).

Teacher Support is a measure of the extent to which the teacher is helpful to the students and shows interest in them (see Table 3.1). Individual student – teacher interactions are assessed with this scale. The student reports the frequency with which the teacher approaches them or shows interest in their problems. Adopted from the CES and categorized under Moos' Relationship Dimension, Teacher Support is also used in the WIHIC and COLES. This scale was considered appropriate for this study because the use of fairly autonomous virtual laboratories is likely to impact on the frequency with which the teacher approaches the student and the extent to which the teacher is needed to support the student. Therefore, it was anticipated that student perceptions of teacher support would decrease.

Task Orientation is a measure of a student's internal motivation to complete assigned tasks and also to stay 'on task' (see Table 3.1). Classified under Moos' Personal Development Dimension, students respond to items related to the perceived importance of setting goals and seeking to achieve those goals. Students also report on their attention span and focus in the class setting. The Task Orientation scale grew from similar scales in the CES and CUCEI, and it is also featured in the WIHIC and COLES. This scale measures a salient quality of virtual laboratories, namely, the student's self-motivation to complete the laboratory in a virtual setting and remain engaged with the activity despite the lack of 'hands-on' experimentation. Because virtual laboratories are interactive and student-centered, it was anticipated that students' perceived motivation to complete work would increase.

Investigation is the extent to which students engage in problem-solving and use inquiry skills (see Table 3.1). This scale helps to assess the current trend in education to use more inquiry processes, such as laboratory activities, in the classroom. Students report about the frequency with which they seek answers through laboratory work and are asked to report and explain their findings to others. The Investigation scale was adapted from the ICEQ, under Moos' Personal Development Dimension, and is also incorporated into the WIHIC. This degree of experimentation was a significant dimension to assess in the current study because virtual laboratories involve elements of a scientific investigation that are likely to promote increased Investigation.

Table 3.1 Scale Description and Sample Item for each Learning Environment Scale in the LAG

Scale	Scale Description	Sample Item
Integration (SLEI)	Extent to which regular science lessons and laboratory activities are related	My laboratory activities and regular science class work are related.
Material Environment (SLEI)	Efficiency and functionality of laboratory materials	The materials I need for both laboratory activities and technology are in good working order.
Teacher Support (TROFLEI)	Extent to which the teacher helps, befriends, trusts, and shows interest in students	The teacher goes out of his/her way to help me.
Task Orientation (TROFLEI)	Extent to which it is important to complete activities planned and to stay on the subject matter	I do as much as I set out to do regarding the activities in this class.
Investigation (TROFLEI)	Emphasis on the skills and processes of inquiry and their use in problem solving and investigation	I am asked to think about the evidence for statements in this class.
Differentiation (TROFLEI)	Extent to which work assigned is individualized for the pace and level of each student	I work at my own speed regarding the activities I do in this class.

Differentiation, a scale originating from the ICEQ, was included in the TROFLEI to measure the extent to which teachers tailor their instruction and activities for students according to their abilities, rates of learning, and interests (see Table 3.1). It is characterized by Moos under the System Maintenance and Change Dimension. This scale was included in the current study because, as students work independently on virtual laboratories, which are self-paced, it was anticipated that student perceptions of differentiation would improve as a result of using virtual laboratories.

Overall, the TROFLEI was a useful instrument for this study in that it focuses on student outcomes, a feature sought by the implementation of virtual laboratories, and is specific to technologically-integrated environments such as the one in the current study. Most importantly, the validity and reliability of this instrument and its antecedent, the WIHIC, have been established numerous times. Therefore, the TROFLEI provides an economical assessment of key aspects of the classroom learning environment, namely, student interactions with their teacher, the environment, the class, and other students.

3.4.1.2 Scales to Assess Student Attitudes

A widely-used questionnaire for assessing attitudes towards science is the Test of Science-Related Attitudes (TOSRA) (Fraser, 1981). The TOSRA was validated on a total of 1,337 science students, grades 7–10, from 11 schools that varied socioeconomically in Australia, resulting in a final version containing 10 items in each of the seven scales (Social Implications of Science, Normality of Scientists, Attitude to Scientific Inquiry, Adoption of Scientific Attitudes, Enjoyment of Science Lessons, Leisure Interest in Science, and Career Interest in Science).

The TOSRA has been shown to be valid and useful in many studies in different countries (Fraser, Aldridge, & Adolphe, 2010; Welch et al., 2012; Wong & Fraser, 1996), and in the evaluation of educational innovations (Lightburn & Fraser, 2007; Martin-Dunlop & Fraser, 2007; Raaflaub & Fraser, 2002; Wolf & Fraser, 2008; Zandvliet & Fraser, 2005). More details about the TOSRA are described in Section 2.3.2.

Table 3.2 Scale Description, Justification, and Sample Item for each TOSRA Scale used in the LAG

Scale	Scale Description	Justification for this Study	Sample Item
Inquiry	Extent to which science activities are student-centered and curiosity provoking.	Because virtual laboratories are intended to be student-centered and provoke curiosity, attitudes towards scientific inquiry re likely to increase.	I would prefer to find out why something happens by doing an experiment than by being told.
Enjoyment	Extent to which student enjoy science lessons.	Because virtual laboratories are interactive and meant to stimulate students using audio and visual effects, enjoyment are likely to increase.	The technology used in activities makes the science lessons more exciting.

For the purposes of this study, modified versions of the following scales were incorporated into the LAG as shown in Table 3.1: Attitude to Scientific Inquiry (herein abbreviated as Inquiry) and Enjoyment of Science Lessons (herein abbreviated as Enjoyment). Two items were removed from each scale to achieve a consistent length of eight items for each scale of the LAG. The TOSRA's response alternatives were maintained as a five-point Likert scale with response categories ranging from Strongly Disagree to Strongly Agree. As well, reverse-scored items were re-worded for clarity and consistency throughout the LAG (Barnette, 2000), and the wording on some items was adjusted to incorporate technical terminology necessary for classes using virtual laboratories. The Inquiry and Enjoyment scales appear as Questions 1 through 16 in the LAG (Appendix A).

3.4.1.3 Scale for Assessing Achievement

The scale for assessing students' achievement in the Genetics portion of their biology classes was composed of items borrowed from various state-level examinations. The researcher selected 10 items from standardized science examinations that have already been validated, administered, and scored. Specific questions were chosen from these examinations to correspond with the content of the virtual laboratories used in this study; this was made possible by the availability of public, searchable, electronic databases containing these validated test-bank items. The standardized examinations from which the achievement items were selected include the New York State Regents Examination for Living Environment courses, the Massachusetts Comprehensive Assessment System (MCAS) for Biology courses, and the Virginia Standards of Learning (SOL) in Biology. The selected items measure the extent to which students understand various concepts in genetics, including Mendelian inheritance, the structure of DNA, mutations, cloning, and genetic engineering.

For ease of administration and scoring, all achievement items utilized a multiple-choice answer format with four possible responses from which to choose. Scoring was based on the number of items correctly answered and ranged from zero (0) for no correct answers to ten (10) for all correct answers. The score was then divided in half for meaningful comparison with scores from other sections of the LAG, which ranged from zero (0) to five (5). The use of a multiple-choice answer format limited the range of responses from students; however, while an open-response format would have reduced this limitation, it might also have led to inconsistency and bias in scoring and/or it could have discouraged students from responding. Achievement questions appear as items 65 to 74 in the LAG (Appendix A).

3.4.1.4 Pilot Study

To ensure that students aged 13–18 years could easily read and comprehend each item on the LAG instrument used in this study, a pilot study was conducted. An earlier form of the LAG was administered to 96 students taking biology in grade nine (ages ranged from 13–15 years) during the year prior to the implementation of this study. This sample was from one school in the state of Massachusetts but its population was quite diverse and representative of the larger sample used for the current study.

Students were instructed to highlight words and questions that they did not understand and comment on the clarity of items. Some students thought that the original instrument was too lengthy and some did not understand certain terms as they were intended by the researcher. Based on students’ comments and patterns in item responses, the researcher modified some of the wording, eliminated the use of reverse items, and narrowed down the scales to the current eight scales used for the LAG.

3.4.2 Other Resources

Other resources necessary to conduct my study into the effectiveness of virtual laboratories included technology. More specifically, every class involved in the study was required to have access to computers with Internet access. All of the virtual laboratories were internet-based, mostly with free access. There were a few sites that required a sign-in feature because access to these laboratories was donated by the company that created them, and the researcher provided the teachers with this access code. Particulars about the selected virtual laboratories are described further in Section 3.5, and the list of virtual laboratories is presented in Appendix D.

Additionally, the researcher provided worksheets, styled after traditional 'lab reports', for each virtual laboratory to ensure completion of the activity and to ensure student accountability so that teachers could have a concrete assignment and score to incorporate into students' academic profiles. In this manner, students involved in this study were not diverted from 'time on task' dictated by state requirements of learning. These worksheets are explained in further detail in Section 3.5, and they appear in Appendix F.

The LAG instrument to assess the effectiveness of virtual laboratories was available in both soft and hard copies. The soft version was administered via a Google Document Survey Form and the link was provided to participating teachers with a teacher-specific code. Responses from the electronic questionnaire were automatically entered into a Microsoft Excel file, available to the researcher immediately upon submission. The paper version was printed, copied, and mailed to the participating teachers who returned the questionnaires via mail at the end of the semester. Responses from the paper version of the questionnaire were entered by hand into the same Microsoft Excel file created by the electronic version, and the hard copies were then stored at the Science and Mathematics Education Centre facilities on the Curtin University campus in Perth, Western Australia. Data files were encoded and only accessible through the use of a password by authorized users. Raw qualitative data, such as recordings and transcripts of interviews, were also stored securely by the researcher in electronic files locked with a password and in hard copies locked in a cabinet.

3.5 Procedures

This section describes how the effectiveness of virtual laboratories was evaluated by explicating the treatment conditions (Section 3.5.1), and the implementation of the educational intervention, including design and delivery of virtual laboratories (Section 3.5.2), the timetable for the execution of the study (Section 3.5.3), administration of the questionnaire (Section 3.5.4), and some ethical issues (Section 3.5.5). The high school science classes involved in this study were divided into two treatment groups: one group engaged in virtual laboratories; and the other group continued to learn in the way in which students had been learning all along. However, both groups covered the same content. At the end of the semester, all the classes were given the LAG questionnaire to assess students' perceptions of their learning environment, their attitudes towards science, and their understanding of the science content. Results for the two groups were compared for significant differences. Further details about the procedure and implementation of my study are embellished below.

3.5.1 Treatment Conditions

Because of the quasi-experimental design of the study, the 322 student participants in 21 different classes studying genetics were divided amongst 10 experimental and nine control classes. Efforts were made to ensure that the two groups were comparable overall with respect to the range of academic capabilities, socio-economic status, gender (Section 3.3) and the physical classroom environment, such as features of the room and the time of day at which students were taught. This was accomplished through stratified random sampling procedures (Gibson & Chase, 2002) in which the variables were equally spread amongst 'strata' or sub-groups. Thus, the two treatment groups were 'naturally occurring' in that they were already organized into classes in their respective schools. Each of the six teachers who volunteered for the implementation of the study taught at least one class with the intervention and one class without the intervention, thus maintaining consistent instruction from the same teacher between the experimental and control group, except for the intervention.

The experimental group learned the topic of genetics supplemented with virtual laboratories. A virtual laboratory is broadly defined as "an electronic workspace for distance collaboration and experimentation in research or other creative activity, to generate and deliver results using distributed information and communication technologies", according to the International Institute of Theoretics and Applied Physics at the Expert Meeting on Virtual Laboratories in Iowa, USA in 1999 (Rauwerda et al., 2006, p. 230).

As applied to the educational setting in this study, students in the experimental group used computers connected to the Internet to complete virtual experiments that employed 'point-and-click' techniques for manipulating various laboratory materials (see Figure 3.3). Each of these virtual experiments simulated a real, hands-on experiment and followed a typical experimental format in which students observe phenomena, formulate hypotheses, set up controls, follow procedures, test hypotheses, and analyze results.

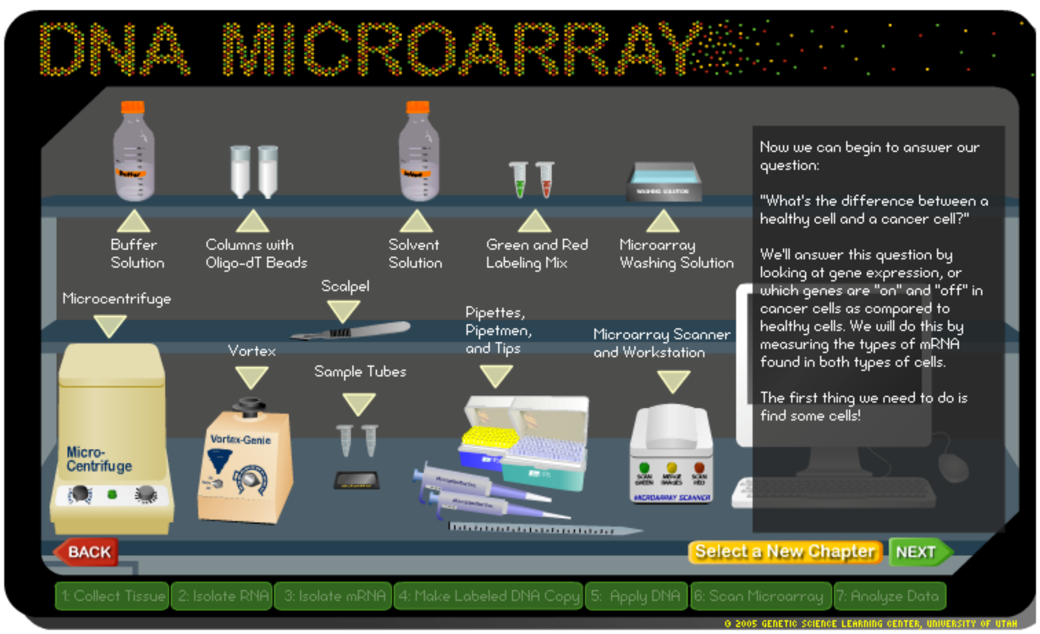

Figure 3.3 Screenshot from a Sample Virtual Laboratory (Perpich, 2012)

The instructions provided to teachers are included in Appendix E. A virtual sharing space (Dropbox) was set up for teachers to access the materials for each virtual laboratory, such as the information about the virtual laboratory and an associated worksheet to assess students' understanding. These materials are also included in

Appendices D and F. As well, I created a blog for the participating teachers to share experiences and a forum through which to ask questions. However, most teachers did not utilize the blog and, instead, preferred to correspond via email.

In order to respect the individuality of teachers in meeting the learning requirements and schedules set by their particular state, district, school, department, and classroom, the researcher provided a 'bank' of at least 10 different virtual laboratories for use in this study (see Section 3.5.2). Teachers were given the freedom to choose the type and number of virtual laboratories that they wished to employ with the experimental classes. On average, teachers administered five, full-period virtual laboratories over eight weeks. Table 3.4 delineates the type and frequency of delivery of virtual laboratories, as well as the interval between administration.

Students in the control group continued learning and experimenting in their normal fashion, without the use of virtual experiments. Instructional methods for these classes included lectures, textbook readings, hands-on experiments, projects, and/or other activities normally employed in a science classroom. While teachers were not provided with specific instructions for teaching students in the control condition, they were directed to ensure that the same content (i.e. genetics) was taught as in the experimental classes.

While a more effective and pure experimental design would have involved comparing an experimental group using virtual laboratories with a control group conducting parallel hands-on experiments for the very same investigation, such a setup was neither possible nor ideal for this study for a number of reasons. First, much of the equipment necessary for complicated experiments in molecular genetics is not available in high school laboratories because of cost and safety issues. As well, many of these experiments require lengths of time not provided in a typical biology class, which usually meets for only 4–5 hours weekly. Secondly, the rationale for evaluating the effectiveness of virtual laboratories is that such an innovation provides an opportunity for students to learn about skills, procedures, and an environment to which they would not otherwise normally be exposed. Virtual laboratories were suggested for use in situations in which such parallel hands-on experiments cannot be conducted. Therefore, the intention of my study was to evaluate the effectiveness of using virtual laboratories as a supplemental method, rather than as a method of substituting virtual laboratories for traditional ones.

Unfortunately, because of the design and respect for teacher individuality, differences existed both within and between experimental and control groups in matters other than the use of virtual laboratories. Administration of the virtual laboratories within the experimental group varied with respect to frequency, to the precise format and content within genetics, and to its blend with other traditional classroom activities such as hands-on laboratories. Naturally, the control classes also lacked uniformity regarding method of instruction. While most of the differences between groups, regarding teachers, students, and classroom environments, were controlled by the design of the study to be equally distributed amongst both groups (See Section 3.6.3), differences within groups were more difficult to control and could have affected results, as described in Section 3.7 on limitations of this study.

3.5.2 Design and Delivery of Virtual Laboratories

This section explains how the researcher selected the virtual laboratories for use in this study and instructed teachers regarding their delivery. More than 20 different virtual laboratories, related to the topic of genetics, were chosen by the researcher for their design and use of inquiry. Table 3.3 shows the title, type, description, and source for eight of the most commonly used virtual laboratories; the respective sample worksheets are included in Appendix F.

The virtual laboratories were all web-based and accessible via a URL provided to participants. Software companies, as delineated in Table 3.3, designed them but the researcher carefully reviewed and picked appropriate experiments in addition to providing participating teachers with some suggestions regarding their use in the classroom (See Appendix E). More specifically, the researcher selected virtual laboratories featuring equipment and associated skill-acquisition not usually available in a typical high school laboratory. Most laboratories involved testing a hypothesis elicited from the student, including the analysis of evidence and other

Table 3.3 Title, Type, Description and Source for Each Virtual Laboratory

Title	Type	Description	Source
Bacterial Identification	Mostly skill-based but follows an experimental method	The activity guides students through the process of identifying the bacterial sources of an infection based on matching a specific DNA sequence; it includes procedures such as PCR, DNA sequencing, sequence analysis, and entry of DNA sequences into BLAST (Basic Local Alignment Search Tool), which searches the public database of DNA sequences to determine the correct bacterial species from which the DNA sequence originates.	Howard Hughes Medical Institute http://www.hhmi.org/biointeractive/vlabs/
Create a DNA Fingerprint	Mostly experimental but focuses on a specific procedural technique	This activity asks students to hypothesize about the culprit of a crime and then leads them through the process of creating a DNA fingerprint to verify the suspect they chose.	NOVA http://www.pbs.org/wgbh/nova/sheppard/analyze.html
DNA Extraction	Skills-based, in order to learn a technique	In this activity students learn the procedure of extracting DNA from human cheek cells.	University of Utah http://learn.genetics.utah.edu/content/labs/extraction/
PCR or, Polymerase Chain Reaction	Skills-based, in order to learn a technique	Students learn the procedure and concept behind a Polymerase Chain Reaction (PCR). In the real lab world, this procedure is used in almost every process using DNA for research, forensics, etc. so it is the beginning step that is part of a larger procedure.	University of Utah http://learn.genetics.utah.edu/content/labs/pcr/
Gel Electrophoresis	Skills-based, in order to learn a technique	In this activity students learn the procedure of gel electrophoresis to visualize and sort DNA fragments by size. In the real world, this procedure is used to check that the materials that one works with (be it DNA, RNA, proteins) are not lost at key points during a complicated experiment; in forensics, gel electrophoresis would be used to compare DNA samples.	University of Utah http://learn.genetics.utah.edu/content/labs/gel/
DNA Microarray	Experimentally-based, it combines three techniques explored in the activities above	In this activity students learn the procedure and concepts that underlie the use of a DNA Microarray for the field of genomics; it includes an investigative piece and students get to make a real-life application to the differences between healthy cells and cancer cells.	University of Utah http://learn.genetics.utah.edu/content/labs/microarray/
Genetics of Organisms	Experimental	This activity allows students to cross Drosophila to obtain new generations of fruit flies to observe the number of phenotypes and eventually determine the genotypes of the original parental generation. Students then compare their observations against a Punnett square that they construct.	APBioLabs http://www.ucopenaccess.org/courses/APBioLabs/course/index.html
Transgenic Fly Lab	Experimental but also teaches some significant techniques	This laboratory first guides students through the process of constructing transgenic flies that "glow" and then experimenting with those transgenic flies to understand circadian rhythms through patterns of light emissions. A number of experiments investigate how light/dark cycles affect patterns of light emissions (the measure for the presence of a biological clock) and eventually lead to locating the biological clock in the fly.	Howard Hughes Medical Institute http://www.hhmi.org/biointeractive/vlabs/

elements of inquiry as described in Section 2.2.3. However, some virtual laboratories were linked in a series so that the aims of the first few 'laboratories' were to acquire the skills and concepts needed to proceed with a virtual experiment at a later point. The researcher was careful to avoid virtual laboratories that lack elements of a true experiment, such as so-called 'virtual laboratories' that were essentially computer games or a simple list of questions for students to research about a particular topic in science.

In order to share with participating teachers resources such as worksheets, sources, and general instructions for virtual laboratories (See Appendices A–F), an online storage system called Dropbox was used. This system had to be downloaded by each user and it also displayed when each user accessed the documents and/or modified the documents. Teachers were instructed to use, within a three-month period, at least four of the virtual laboratories available in the Dropbox file. How each teacher applied the instructions in implementing the conditions of the study with his or her classes is detailed in Table 3.4.

Worksheets were provided for many of the virtual laboratories to guide students through the activity and to enable them to record data and answer questions related to the experiment (see Appendix F). These worksheets also allowed teachers to hold students accountable for their work because they could be given a score, which could have been incorporated into their semester grade.

3.5.3 Timetable

This section reports the logistical aspects of the application of virtual laboratories, namely, the duration of implementation of the virtual laboratories, the frequency with which virtual laboratories were administered, and the time intervals between each virtual laboratory. The selected virtual laboratories were generally meant to occupy one class period. If teachers suspected that their student would require more time to complete the virtual laboratory, teachers were advised to assign students a pre-laboratory designed by the researcher to prime students' knowledge about the topic before beginning the actual laboratory. Some skill-only virtual laboratories required no more than 20 minutes and could be integrated into another lesson or completed at home.

Virtual laboratories and their associated worksheets were made available in February 2010 and teachers were given until the end of the semester, a duration of four to five months, to integrate them into their classes.

The frequency with which virtual laboratories were utilized, the interval between their use, and the duration of implementation of the entire study by each teacher are detailed in Table 3.4.

Table 3.4 Implementation of Conditions of the Study by Each Teacher including Class Composition, Duration of Study, the Administration of the Virtual Laboratories (VL), and Information about Covariates

Teacher and Class Composition	Dur-ation of Study	Number of/Titles of VLs Completed	Frequency & Intervals of VLs	What Did the Control Group do?	Notes about Covariates (Quotes from Teachers)
Teacher A: Five Classes 127 students Grade 8 Standard Level (Experimental Group = 3 classes; Control Group = 2 classes)	2	4: DNA Extraction PCR Gel Electrophoresis DNA Fingerprinting	Two VLs a week; the first week, they were one day apart and the second, two days apart	"I did a paper lab with one, some other hands-on work with another and lecture for the other two"	"The students were heterogeneous, the same topics were covered, classes were both in the morning and later in the school day…I tried very hard to provide the same material to each group" All students did the hands-on for gel electropheresis.
Teacher M: Two Classes 29 Students Grade 10 Standard Level (Experimental Group = 1 class; Control Group = 1 class)	2	4: DNA Extraction PCR Gel Electrophoresis Transgenic Fly Lab	3 VLs in one week and 1 the following week	"'paper labs', where we simulated some of the steps; hands-on lab for gel electrophoresis ; some other computer activities"	"time of day [for classes] differed," "Of the 2 classes, the class that did the virtual labs had a slightly higher academic ability and fewer students with [special] 'ed' plans (10% vs. 18%)" Did not do any hands-on laboratories with experimental classes.

Teacher G Three Classes 47 Students Grade 9 Honors & Honors Prep 13 Students Grades 10-12 ELL Biology (Experimental Group = 1 class; Control Group = 2 classes)	12	~8–10: Bacterial Identification DNA Extraction PCR Gel Electrophoresis DNA Microarray Peppered Moth Simulation Mitosis & Meiosis Labbench Stem Cells Cloning Transgenic Mice	About once a week	"no hands-on laboratories, A DNA model activity with plastic pieces & a Punnett square activity with 4 different colored beads [for dihybrid crosses]."	Used many VLs as demonstrations in the classroom (not only as individual student investigations). Used some VLs that did not contain investigative experiments but just to teach concepts and skills.
Teacher R Six Classes 129 Students Standard Level (Experimental Group = half of all six classes; Control Group = half of all six classes)	10	5: DNA Extraction PCR Gel Electrophoresis DNA Microarray DNA Fingerprinting	About once a week	"I am having all classes participate. Half of the class will do the lab, while the other half complete an alternative, unrelated assignment."	
Teacher D Three Classes 84 Students Grade 10 Standard Level (Experimental Group = 1 class; Control Group = 2 classes)	10	At least 4 No other information available			
Teacher O Two Classes 20 Students Grade 9 Standard Level (Experimental Group = 1 class; Control Group = 1 class)	6	5: DNA Extraction PCR Gel Electrophoresis DNA Microarray DNA Fingerprinting	About once a week	"Lectures, animations, paper lab.s, 1 hands-on lab."	Lost data for most of experimental class (Number of students reflects loss)

While teachers were allowed a certain degree of freedom regarding which virtual laboratories to implement and the frequency of their implementation, the researcher suggested interspersing their delivery with the teacher's normal methods of instruction throughout the semester. This systematic integration of virtual experimentation with traditional instruction was recommended by Gallagher et al. (2005) because it "is more likely to be successful if the training schedule takes place on an interval basis rather than massed into a short period of extensive practice" (p. 364). After completion of at least four virtual laboratories, or whenever their use was no longer applicable, teachers were instructed to inform the researcher, at which point access to the questionnaire was granted, as described in Section 3.5.4.

3.5.4 Administration of LAG Questionnaire

The method of administration of the LAG questionnaire to assess the effectiveness of virtual laboratories is detailed in this section. While only students in classes belonging to the experimental group were exposed to virtual laboratories, students in classes belonging to both the experimental and control groups were given the LAG questionnaire (See Section 3.4.1). Therefore, at the end of the treatment period, all 322 students completed the questionnaire addressing perceptions of their learning environment, their attitudes towards science, and their understanding of the science content. The questionnaire took about 30 minutes to complete. Also, language was purposely generalized so that the word 'laboratory' could include virtual and non-virtual experiences. The instructions to students in the introduction to the questionnaire read "Please note: The word 'laboratory' in this survey refers to any experiment you have done in your science class, whether it was 'hands-on' or virtual."

According to the preferences of participating teachers, the researcher provided both electronic and paper versions of the questionnaire, which were identical in content. Electronic access was granted through a link to the Google Document Form used to create the survey. Students were instructed to click on the responses that applied to them and, upon completion, to click on the 'submit' button to enter their responses automatically into an electronic database. Paper versions were mailed to teachers who returned them via mail upon completion.

The last item on the questionnaire asked students to record their email addresses to enter into a raffle. Email addresses were compiled into the electronic database and a random number generator was used to select the winner of the raffle prize. More useful to this study, the researcher used these email addresses to send out a request asking students to participate in interviews via telephone or Skype because school was no longer in session. Further elaboration of selection and collection of qualitative data sources are described in Section 3.6.1.

3.5.5 Ethical Issues

To ensure fairness of exposure to an innovation that is potentially beneficial, the treatment conditions were reversed after the data-collection stage so that students in the comparison group also had the opportunity to use virtual laboratories. However, no data were collected during this period as it was only meant to guarantee equity of students' learning experiences.

All participants and their parents, in addition to those in the school, such as teachers and principals, were fully informed of the purposes of this study, including the potential risks and benefits, before collecting data from any students. Each student received an information sheet describing the study in plain English and was also told verbally, via a YouTube broadcast. Opportunities for any questions and concerns were given to students to reassure them that they may withdraw from the study at any time without prejudice or other negative consequences, such as affecting students' school grades. Finally, informed consent was obtained for each class and school involved in the study.

Another ethical issue concerns confidentiality and protection of participants' privacy. For this study, all efforts were made to keep the names of the schools, teachers, and students confidential. Upon collection, data were encoded for the analysis stage to protect students' privacy. No names were reported and names of interviewees were changed. The acknowledgement found in the front matter of this thesis is devoid of names of participants, for the very same reason of protecting anonymity.

3.6 Data Collection, Entry, and Analysis

This section explores the various aspects of obtaining and understanding quantitative and qualitative data. In general, multiple methodological approaches allow a more holistic assessment of the effects of an intervention. Additional approaches can further explain idiosyncrasies in quantitative data and assess the uniqueness of each classroom environment established by the teacher. Therefore, to embellish the quantitative data, qualitative methods of data collection were employed in this study, as recommended by a number of researchers in the field of learning environments who extol the merits of triangulation (Fraser & Tobin, 1991; Tobin & Fraser, 1998). A study of technology-based materials by Russek and Weinberg (1993) revealed that more insight was gained from a mixed-method approach, than could be obtained from either type of analysis alone. Moreover, Duit and Confrey (1996) proposed that interviews allow contextualization of students' responses and a more complete image of students' ideas.

After the LAG questionnaire had been administered to both the experimental and control group, the responses from these two groups were compared for significant differences. As well, semi-structured interviews were conducted with students who took the LAG and with their teachers. This section deals with the collection (Section 3.6.1), coding and entry (Section 3.6.2), and statistical methods of analysis (Section 3.6.3) of quantitative and qualitative data.

3.6.1 Collection of Data

Quantitative data were collected using scales from the four instruments included in the Laboratory Assessment in Genetics (LAG), namely, the SLEI, TROFLEI, TOSRA, and achievement examinations. The LAG was administered to 322 students in 21 classes in six different US schools in the states of Massachusetts, New York, Pennsylvania, and Virginia.

Questionnaires were either mailed to the teachers requesting paper versions, or provided as an online link to teachers who requested the electronic versions. In both cases, the researcher provided to the teacher for each class specific codes, which identified the teacher and treatment condition (i.e. experimental or control), without revealing the names of the schools, teachers, or students. Teachers were instructed to ensure that students entered these codes onto the front page of the survey.

Regarding the paper version of the questionnaire, teachers administered them personally, packaged them by class, and returned them via mail for data entry by the researcher. Electronic questionnaires were submitted automatically over the Internet as students completed them. All students of the same teacher completed the same version of the questionnaire; in other words, there were no situations in which some students of a particular teacher filled out the paper version and other students of the same teacher filled out the electronic version. The two different versions were only provided for teachers' ease of use, depending on whether the Internet was easily accessible in their particular school. Teachers B, F, and A utilized the electronic versions of the questionnaire, while Teachers C, D, and E used the paper versions.

To ensure consistency in the administration of the questionnaires, teachers were provided with detailed instructions on how to administer the LAG (see sample directions given to teachers in Appendix E. Teachers were asked to be present during administration of both the paper and electronic versions of the surveys so that they could assist students with any questions that they had and to record feedback from students as they completed the surveys. Therefore, all questionnaires were administered during class time and were not taken home.

Students responding to the LAG provided information regarding personal details, including their sex, main language of communication, ethnicity, and age, as well as class details, including grade level, and teacher code, and other practices and preferences, such as computer usage and future plans (See Appendix B for sample questionnaire). The last item on the questionnaire asked students to record their email addresses to enter into a raffle, as an incentive to complete the questionnaire.

The list of email addresses, supplied by students, was stored in the same file as the quantitative data and provided the pool of potential volunteers for gathering qualitative data trough interviews. Therefore, student interviewees were self-selected from the same sample of students who completed the LAG questionnaire. For the purposes of this study, 10 open-ended questions were constructed based on the LAG questionnaire for semi-structured interviews using standard protocols (Anderson & Arsenault, 1998; Cohen, Manion, & Morrison, 2007; Drever, 1995; Erickson, 1998). While the quantitative data were limited to the personal form (i.e. the use of 'I' statements, as described in Section 2.2.2) of the questionnaire, the collection of qualitative data through semi-structured interviews allowed the researcher to expand the perspective of the responders to the whole class. For instance, after the interviewee answered a question about whether the class work was difficult, the researcher was able to further ask whether the whole class perceived the work as being difficult, in addition to the interviewee's personal perspective. This distinction between personal and whole-class perspectives was noted earlier when reviewing the concepts of 'private' beta press and 'consensual' beta press (Section 2.3.1).

Once the researcher had determined that additional insight was needed to explain the quantitative results, the possibility of gathering qualitative data materialized. An email request was sent out to all student email addresses stored in the database asking for volunteers to participate in the interview process. When a total of six students followed through on their initial expression of interest to be interviewed, telephone or Skype appointments were set up for this purpose. Face-to-face interviews were not possible because the interviewer and interviewees were not located in the same geographic area. Informed consent was obtained from students and their parents. Each interview lasted 20–30 minutes and students seemed eager to contribute to a better understanding of the quantitative results of this study. Selected statements from student responses to the interview questions are presented in Chapter 4.

Additionally, participating teachers were also asked for input, via email, using the same open-ended questions that had been presented to student interviewees. First, when teachers filled out a form indicating what actually took place during the implementation of the study, the information contained in Table 3.4 emerged. All teachers provided this information, but not all teachers chose to answer the questions for the semi-structured interviews. Therefore, the comments of the three teachers who contributed to this effort are embedded throughout Chapter 4.

3.6.2 Entry of Data

Data from both the paper and electronic forms of the questionnaire were organized using Microsoft Excel 2007. Responses to the electronic version were entered automatically into an Excel spreadsheet as they became available. Responses to the paper version of the questionnaire were entered into the same Excel spreadsheet by the researcher personally to ensure precision and they were checked for accuracy.

The researcher assigned each paper questionnaire a unique identification code for tracking purposes that aligned with the number of the row in the Excel spreadsheet. Email addresses shared by the students were stored along with their responses, in case I needed to contact students for further clarification. For the purposes of statistical analysis, responses were coded by transforming descriptive data into numerical values. For instance, personal information regarding students' career choices was recorded in the following manner: careers related to the sciences were given the value '1' while non-scientific careers received a value of '2'. The method of coding was stored in a separate document.

Some patterns of responses in questionnaires indicated that the students did not complete them with integrity, such as consistently responding Strongly Disagree responses to every item, or lack of responses to all items other than personal background questions. Such data were discarded and this phenomenon, in addition to absences of many students on the day of administration, account for the lower number of questionnaires than the actual number of students participating in the study, as reported by teachers.

Regarding recording and entry of qualitative data, each student interview was recorded using an internal software system on a Macintosh Notebook Computer, called Garage Band. Auditory clarity was enhanced because telephone and Skype calls to interviewees were conducted from the same computer. Teacher responses from interviews were written via email, as they preferred.

Recordings of student interviews were transcribed by the researcher and were reviewed multiple times to ensure accuracy. Each transcription of an interview was saved as a separate document and stored in a file accessible only to the researcher. Upon the completion of both student and teacher interviews, names were also encoded to preserve anonymity. Gender identification amongst students was maintained by replacing interviewees' names with fictional names of the same gender.

3.6.3 Statistical Methods for Analysis of Data

Responses to the LAG, taken by 322 students in 21 US science classes, constituted the quantitative data for this study. After numerical transformation, quantitative data were analyzed to address the four research questions using SPSS 17.0 Statistical Package. Sections 3.6.3.1–3.6.3.3 explicate the statistical methods of analysis for each research question in this study. The method of analysis for qualitative data is described in Section 3.6.3.4.

3.6.3.1 Research Question 1: Are scales from the Test Of Science Related Attitudes (TOSRA), Science Laboratory Environment Inventory (SLEI), and Technology-Rich Outcomes-Focused Learning Environment Inventory (TROFLEI), as well as achievement items valid and reliable when used with a sample of high school students taking biology in the US?

Regarding the first research question, the questionnaire administered to a sample of American biology students had to be checked to ensure that it would be a valid and reliable instrument with which to gather data for this population. To accomplish this, the scales from the SLEI, TROFLEI, and TOSRA were subjected to factor analysis to check the questionnaire's structure. Principal axis factoring with varimax rotation (using Kaiser normalization) was employed because of its ability to organize components of the questionnaire by common dimensions. Correlation coefficients, or factor loadings, between items from the SLEI, TROFLEI, TOSRA, and scale total scores were inspected. The criteria for retention of any item were that its factor loadings must be greater than 0.40 on its own scale and less than 0.40 on all other scales. The application of these criteria led to the removal of some items prior to subjecting the refined scales to further validation and reliability analyses.

Next, the revised scales of the LAG measuring perceptions of the learning environment (SLEI, TROFLEI), attitudes (TOSRA), and achievement were checked for internal consistency reliability to determine the extent to which items in the same scale measured a common dimension. To accomplish this, Cronbach alpha coefficients, for two units of analysis (the individual student and the class mean) were calculated. Scales with a Cronbach alpha coefficient greater than 0.60 were considered to have satisfactory internal consistency reliability, as suggested by De Vellis (1991).

To ensure that each scale measured a unique aspect of the learning environment or attitude, an index of discriminant validity (Campbell & Fiske, 1959), namely, the mean correlation of a scale with all other scales, was determined for two units of analysis – the student and the class.

The final method for validating the questionnaire involved confirming the ability of the learning environment scales of the LAG to differentiate between classrooms. The perceptions of students in the same class ought to be relatively similar as compared with the perceptions of students in different classes. An ANOVA, with class membership as the main effect, was used to check differences in the perceptions of the students in different classrooms. Results for this test are reported as an eta^2 value, which represents the proportion of variance in scale scores accounted for by class membership.

Because the researcher selected the achievement items, additional validation of this scale was determined by calculating a frequency distribution of the students' scores on this scale to check for a normal distribution, an indication of its ability to produce the same pattern of scores in a larger population (Herrnstein & Murray, 1996).

3.6.3.2 Research Question 2: Are there associations between the perceived classroom learning environment and student outcomes of attitudes towards and achievement in science?

For the second research aim regarding associations between perceived classroom learning environment and the student outcomes of achievement in and attitudes towards science, simple correlation and multiple regression analyses were used with the individual student as the unit of analysis. Simple correlation (*r*) was used to describe the bivariate relationship between each student outcome (attitude or achievement) with each learning environment scale. Multiple regression analysis was used to investigate the combined influence of the whole set of learning environment scales on each student outcome, with the standardised regression coefficient (β) being used to indicate the contribution of each learning environment scale to the variance in student attitudes or achievement when other learning environment scales were mutually controlled. The multiple correlation (*R*) represented the multivariate association between student attitudes or achievement (the criterion variables) and the set of all learning environment scales (the predictor variables). The strength of associations was measured by the coefficient of multiple determination (R^2).

3.6.3.3 Research Questions 3 and 4: Is the use of virtual laboratories in high school science classes effective in terms of students' perceptions of their learning environment, attitudes towards science, and academic achievement? Is the use of virtual laboratories differentially effective for males and females in terms of students' perceptions of their learning environment, attitudes towards science, and academic achievement?

To analyze data from the third and fourth research aims concerning the effectiveness of using virtual laboratories in terms of academic achievement, attitudes towards science, and perceptions of the learning environment, data were subjected to a two-way multivariate analysis of variance (MANOVA) with the learning environment scales from the SLEI and TROFLEI and student outcomes (attitudes and achievement) as the dependent variables, and with instructional method and sex as the independent variables. Because the multivariate test using Wilks' lambda criterion yielded statistically significant differences for the set of dependent variables, the individual, univariate two-way ANOVA was interpreted separately for each dependent variable (students' perceptions of their learning environment, their attitudes, and achievement), with the student as the unit of analysis. This analysis enabled an exploration of all possible interactions between both independent variables (instructional method and sex) for all three types of dependent variables (students' perceptions of their learning environment, their attitudes, and achievement).

Differences between instructional methods (with and without virtual laboratories) and between different sexes were portrayed by the mean score for each learning environment, attitude, and achievement scale. The mean score of each scale was calculated by dividing the original scale score by the number of items in each scale to allow for meaningful comparison of average scores across scales containing differing number of items. The presence of a significant instruction-by-sex interaction was interpreted to indicate the differential effectiveness for males and females.

Effect sizes were also reported for each comparison to quantify the magnitude of the difference between two groups (i.e. either between instructional methods, or between males and females). According to Vacha-Haase & Thompson (2004), effect sizes indicate a more important aspect of a between-group difference than its statistical significance. Because this difference between means is expressed in standard deviation units, the effect size indicates that the average score in the experimental group is different from the average score in the control group by a certain number of standard deviations. In this study, two different types of effect sizes were utilized: Cohen's *d* and eta-squared (η^2). Cohen's *d* is the difference between two sample means divided by the pooled standard deviations. Eta squared is a measure of the strength of association (or effect size) based on the proportion of variance accounted for by the effect of the independent variable on the dependent variable.

3.6.3.4 Analysis of Qualitative Data

Overall, analyses of data from interviews can complement the results of quantitative analyses and provide a richer understanding by filling in gaps perceived in the questionnaire data. In this study, qualitative data consisted of student and teacher responses to semi-structured interview questions.

Therefore, responses from interviews, that were recorded and fully transcribed as described in Section 3.5.2.2, constituted the raw qualitative data for further analysis. These transcripts were then subjected to content analysis (Neuendorf, 2002) in which content was coded, tallied, ranked, and analyzed for emergent themes. More specifically, raw data were 'chunked' into color-coded categories and reported statistically through well-accepted procedures, such as frequency counts, averages, and percentages for recurring themes (Erickson, 2012; Wolcott, 1994). More specifically, responses to questions from the same scales of the LAG were grouped together; however, the researcher also considered themes that emerged from interviews that were beyond the dimensions measured by LAG scales. Responses from interviews were analyzed as they became available and then re-analyzed as a whole for emerging patterns. Analytic induction (Lindesmith, 1947) was also undertaken in which the qualitative data were viewed and reviewed with various lenses. As a result of analytic induction, the researcher modified some questions during the interview and/or focused on certain questions more than others.

Wolcott (1994) distinguishes between analysis and interpretation, with the former referring to the description of the results of content analysis and the latter referring to "efforts at sense-making, a human activity that includes intuition, past experience, emotion – personal attributes of human researchers that can be argued endlessly but neither proved nor disproved to the satisfaction of all" (2009, p. 30). Thus, the description of content analysis, through statements from interviews that added insight to the results from questionnaires, are embedded throughout the report of the quantitative results in Chapter 4. Additionally, the emergent themes stemming from responses to interview questions, as interpreted by the researcher, are summarized in the discussion included in Chapter 5.

3.7 Limitations

Even when much time and effort are invested in carefully planning and designing a study, methodological errors are unavoidable. This section discusses deviations from the original design and how accommodations were incorporated. Section 3.7.1 describes methodological issues related to loss of sample, while Section 3.7.2 explores ambiguity concerning treatment conditions, Section 3.7.3 notes technical difficulties, and Section 3.7.4 explains issues regarding administration of the LAG questionnaire.

3.7.1 Loss of Sample

In general, a greater sample allows for both the increased detection of statistically significant effects and the generalization of these effects for larger populations. Therefore, if the sample for the current study had been larger, results from quantitative data possibly might have provided more accurate insights into the effectiveness of virtual laboratories.

Originally, the study was designed for a larger sample (~800 students), which was made logistically possible due to placement of the researcher in a large school environment with 21 equally diverse classes all following the same curriculum. However, permission to conduct the study was overturned by the superintendent of the district after implementation had already begun. Therefore, the researcher was transferred to a new school containing 43 students eligible to participate in place of the original 640 eligible, and thus potential, student participants.

Additionally, as described in Section 3.5.4 regarding electronic versions of the questionnaire, the researcher used a form available for free through the Internet to any Google user. While this initially worked well, on the day when many students (at least 100) were to complete the LAG, the link was dysfunctional. Google acknowledged this error and fixed it within two days time, which allowed some students to complete the survey. However, it was too late for most of the students to complete the questionnaire because school was no longer in session and it was difficult to track students down via email. Unfortunately, this error also affected the timetable for collecting qualitative data because the last few days of the semester were spent trying to sort out the technological issue and copying and mailing paper versions of the questionnaire instead of contacting students to interview them.

Nevertheless, the current sample size was large enough to determine validity and reliability of the LAG questionnaire even though a larger sample size could have better informed the quantitative results.

3.7.2 Treatment Conditions

Another issue confounding the results for the effectiveness of virtual laboratories was a certain degree of ambiguity about the nature of the treatment conditions. While the demarcation of teaching methods for the experimental and control groups was clear to the researcher, it was perhaps less clear to the participating teachers. The researcher wished to grant the participating teachers as much freedom and independence as possible in the implementation of the study so as not to interfere with their standards of teaching and preparation of students for end-of-year standardized examinations in biology. However, the lack of uniformity both in how teachers taught classes in the control condition (i.e. without use of virtual laboratories) and in the experimental condition (i.e. use of virtual laboratories) proved to confuse students' perceptions of the definition of a 'virtual laboratory'. For instance, if a teacher also used an educational computer game with students in the experimental group, the students might have thought that such a computer game was also a 'virtual laboratory.'

A number of teachers included other Internet-based activities, such as simulations, games, animations, and Webquests, in their teaching of control classes. In some instances, hands-on laboratories were conducted with students in experimental classes who were only supposed to complete virtual laboratories. Two teachers had their VL classes complete four virtual laboratories within two weeks, which perhaps caused fatigue and boredom in students because they were overexposed to the same medium.

At one point, a participating teacher stated that "perhaps the line between virtual and actual is getting blurry!" This statement indicates the lack of clarity about the definition of a virtual laboratory amongst participants. While not wanting to burden participating teachers with theoretical discussions concerning the definition of a virtual laboratory, perhaps the researcher should have more clearly restricted what sorts of activities should have been employed or avoided in VL classes and non-VL classes. This is further discussed in Chapter 5 as part of suggestions for further research.

Furthermore, while variables such as students' intelligence, age, and socio-economic status were spread relatively similarly amongst the two groups, such differences still could account for some variability in the results. In the future, further statistical analyses could be conducted to investigate the influence of these differences.

3.7.3 Technical Issues

A key factor that might have affected the outcomes of this study was the availability of resources. Participants in the experimental condition required computers in good working order with an uninterrupted Internet connection in order to complete virtual laboratories. Although participating teachers initially indicated that their schools provided these resources, as situations often transpire in large school environments where resources are constrained, access to these materials was not without problems. Some teachers and students reported that a particular computer or Internet link to a virtual laboratory was not in good working order and that each student would have to be paired with another student. In other instances, some students could not complete the virtual laboratory because of a lapse in the Internet connection. Perhaps the experience of completing a virtual laboratory in this manner might have influenced the students' responses to LAG items measuring the learning environment, attitudes towards science, and achievement.

3.7.4 Instrument Administration

Finally, the administration of the questionnaire also presented some methodological issues relevant to this evaluation of the effectiveness of virtual laboratories. Firstly, as noted in Section 3.7.1, the link to the electronic version of the questionnaire was unavailable for a few days at a key time in the implementation of the study. Second, some students did not respond to items consistently or left large sections of the LAG blank, which is predictable amongst students of this age group.

Most detrimental to the administration of the questionnaire was the lack of clarity about the terms used to refer to virtual laboratories in various items. The subject of the questionnaire item was often generalized so that students in both VL and non-VL classes could respond. However, in trying to avoid introducing bias, the researcher overcompensated by generalizing terms (such as 'activity' instead of 'virtual laboratory'), which possibly gave rise to confusion amongst students, whose recorded responses might have differed had a more specific term been used in the item. Therefore, a degree of clarity could have been lost for the sake of integrity. Perhaps a different version of the questionnaire should have been administered to participants in the VL classes and non-VL classes for simplification purposes, as will be suggested in Section 5.4.

3.8 Summary

This chapter explained the methodological details of my evaluation of the effectiveness of virtual laboratories in terms of students' perceptions of their learning environment, attitudes towards science, and achievement in science.

The study used a quasi-experimental design to compare students in 11 classes that engaged in virtual laboratories with students in 10 classes that did not. Eight different virtual laboratories related to the topic of genetics were chosen by the researcher for their design and use of inquiry, and related worksheets were provided. Teachers were instructed to use at least four such virtual activities with the experimental group while students in the control group continued learning and experimenting in their normal fashion. The treatment period lasted from two to 12 weeks.

This study combined quantitative and qualitative methods of data collection. Quantitative methods included the use of a questionnaire called the Laboratory Assessment in Genetics (LAG) administered to all participants at the end of the treatment period. The scales were adopted from previously validated questionnaires that measure students' perceptions of the learning environment, such as the Science Laboratory Environment Inventory (SLEI) and the Technology-Rich Outcomes-Focused Learning Environment Inventory (TROFLEI), in addition to scales measuring students' attitudes towards science from the Test Of Science Related Attitudes (TOSRA) and an achievement scale with items borrowed from standardized biology examinations. For a sample of 322 US biology students, learning environment and attitude scales were tested for validity and reliability, including factor analysis, internal consistency reliability (Cronbach alpha coefficients), discriminant validity (mean correlation with other scales), and the ability of the learning environment scales to differentiate between classrooms (ANOVA).

To investigate associations between perceived classroom learning environment and the student outcomes of achievement in and attitudes towards science, simple correlation and multiple regression analyses were conducted.

Finally, concerning the effectiveness of using virtual laboratories, data from the LAG questionnaire were subjected to a two-way multivariate analysis of variance (MANOVA) with the learning environment scales and student outcomes (attitudes and achievement) as the dependent variables, and with instructional method and sex as the independent variables. Then, when Wilk's lambda criterion revealed statistically significant findings for the set of dependent variables as a whole, the univariate two-way ANOVA was interpreted separately for each dependent variable (students' perceptions of their learning environment, their attitudes, and achievement). To quantify the magnitude of the difference between two groups (i.e. either between instructional methods, or between males and females), effect sizes were also calculated. Analyses explored all possible interactions between the two independent variables (instructional method and sex) for each type of dependent variable (learning environment, attitudes, and achievement).

After quantitative data analysis, qualitative data were collected from six students and three teachers who were interviewed to explore underlying themes that lent further insight into the quantitative data. For the purposes of this study, ten open-ended questions were constructed based on the LAG questionnaire to use in semi-structured interviews. Responses from interviews were recorded, fully transcribed, and subjected to content analysis and analytic induction.

Methodological limitations of this study included sample loss, confusion regarding the treatment conditions, technical issues, and ambiguity of some of the language in the LAG questionnaire.

Chapter 4

Data Analyses and Results

"It is a capital mistake to theorize before one has data. Insensibly one begins to twist facts to suit theories, instead of theories to suit facts." – Arthur Conan Doyle

4.1 Introduction

This chapter reports and interprets the findings of this study. Each of the research questions is addressed by analyzing data and then determining whether the hypothesis for that question is supported.

As described in Chapter 3, the majority of this study was based on quantitative data collected using the Laboratory Assessment in Genetics (LAG). Qualitative data stemming from semi-structured interviews were used in an attempt to fill gaps in the quantitative data, and to provide a more holistic view of the effectiveness of virtual laboratories.

This chapter first presents results for validation of the instrument used to collect quantitative data, the LAG. The LAG contains 74 items in nine scales adapted from several other validated questionnaires: the Science Laboratory Environment Inventory (SLEI), the Technology-Rich Outcomes-Focused Learning Environment Inventory (TROFLEI), the Test of Science-Related Attitudes (TOSRA), and achievement items from state standardized examinations in Biology. More specifically, two scales (Enjoyment and Inquiry) were adapted from the TOSRA (Fraser, 1981) to assess students' attitudes towards science, in general. These scales originally included some negative items but were modified to be positively worded in order to increase the readability and clarity of the LAG for students. Some items were also replaced with new items modeled after the original items contained in the TOSRA and wording was generalized to include all types of activities in science lessons.

In order to measure students' perceptions of their learning environment, two scales (Integration and Material Environment) were modified from the original SLEI (Fraser, Giddings, & McRobbie, 1992) by rewording reverse items and adding a few similarly-worded items to maintain a consistent number of items (eight) per scale.

Items from the Material Environment scale were also reworded to include all possible 'materials' used in science laboratories, namely, computers and internet service that enable normal functioning of virtual laboratories. Similarly, four scales adapted from the TROFLEI, those of Teacher Support, Task Orientation, Investigation, and Differentiation, were also included in the LAG to measure students' perceptions of their learning environment. Wording of the Investigation and Differentiation items was generalized to include hands-on activities as well as computer laboratory activities. Because the scales used on the LAG were modified from their original versions, they required validation as part of this study.

In order to assess readability, the LAG was first given to a pilot sample of students and, based on their comments, the number of items and the item wording were adjusted. In the main study that took place one year later, the LAG was administered to 322 students, aged 13–18 years, in 12 US public school classes from Massachusetts, Pennsylvania, and Virginia.

Qualitative data were obtained from this same sample; students and teachers from these 12 classes were given the opportunity to be interviewed by the researcher and their responses were recorded, transcribed and analyzed. These comments accompany the quantitative data, in an attempt to further explain the results, and they are interspersed throughout Sections 4.4.

Therefore, this chapter reports results for validation of the various parts of the LAG in Section 4.2, for associations between perceptions of the learning environment (SLEI, TROFLEI) and attitudes (TOSRA) and achievement in Section 4.3, and for the effectiveness of virtual laboratories in Section 4.4, including results for the differential effectiveness of virtual laboratories for males and females.

4.2 Validity and Reliability of Learning Environment, Attitude, and Achievement Scales Composing the LAG

In order to address the first research question below, the scales composing the LAG were administered to 322 US students in 12 classes ranging in age from 13–18 years.

Research Question 1: Are scales from the Test Of Science Related Attitudes (TOSRA), Science Laboratory Environment Inventory (SLEI), and Technology-Rich Outcomes-Focused Learning Environment Inventory (TROFLEI) questionnaires valid and reliable when used with a sample of high school students taking biology in the US?

This section reports the factor structure (4.2.1), internal consistency reliability (4.2.2), and discriminant validity (4.2.3) for learning environment scales and attitude scales. Section 4.2.4 focuses on the ability of the learning environment scales to differentiate between classrooms. Validation of the achievement section of the LAG, comprising the last 10 items, is also reported (Section 4.2.5).

4.2.1 Factor Structure of Learning Environment and Attitude Scales

Because items were modified from the original scales from which they were adapted, the internal structure of the various learning environment and attitude scales was examined to ensure validity. Principal axis factoring with varimax rotation (using Kaiser normalization) was employed to inspect the internal structure of the 64-item survey containing learning environment and attitude scales when used with the sample in this study. Principal axis factoring analyses inter-relationships (variability) between all items in the questionnaire and categorizes them by their common underlying dimensions or factors. Each dimension serves as a construct for further analysis in this study. The criteria for retention of any item in its scale were a factor loading greater than 0.40 on its own scale and less than 0.40 on all other scales. Varimax rotation was applied because of its common use in providing a scheme for orthogonal rotation; it minimizes the complexity of the components by making the large loadings larger and the small loading smaller in order to identify each variable with a single factor.

Table 4.1 provides the factor loadings for these eight attitude and learning environment scales. Item numbers shown in the table refer to the question numbers in the questionnaire (Appendix A). Table 4.1 also reports the percentages of variance and eigenvalues for each scale.

Table 4.1 Factor Analysis Results for Attitude and Learning Environment Scales

Item No.	Factor Loadings							
	Inquiry	Enjoyment	Integration	Material Environment	Teacher Support	Task Orientation	Investigation	Different -iation
Q1	.722							
Q3	.413							
Q4	.670							
Q5	.576							
Q6	.658							
Q8	.686							
Q10		.712						
Q11		.685						
Q12		.617						
Q13		.520						
Q14		.547						
Q15		.664						
Q16		.651						
Q18			.560					
Q19			.494					
Q20			.662					
Q22			.672					
Q23			.489					
Q24			.572					
Q25				.589				
Q26				.512				
Q27				.401				
Q28				.613				
Q29				.717				
Q30				.426				
Q31				.452				
Q34					.721			
Q35					.741			
Q36					.735			
Q37					.656			
Q38					.549			
Q39					.724			
Q40					.717			
Q41						.702		
Q42						.695		
Q43						.636		
Q44						.751		
Q45						.670		
Q46						.594		
Q47						.650		
Q48						.721		
Q49							.588	
Q50							.641	
Q51							.719	
Q52							.481	
Q54							.744	
Q55							.646	
Q56							.656	
Q59								.489
Q60								.774
Q61								.436
Q62								.797
Q63								.861
Q64								.783
% Variance	24.75	7.48	5.58	4.47	3.67	3.44	2.88	2.78
Eigenvalue	15.84	4.72	3.57	2.86	2.35	2.20	1.84	1.78

N = 322 students in 12 Classes.
Factor loadings less than 0.40 have been omitted from the table.
Items 2, 7, 9, 17, 21, 32, 33, 53, 57, and 58 were removed from this analysis.

Factor analysis resulted in the retention of the original eight learning environment and attitude scales of the LAG. No more than two items were removed per scale. Therefore, the items retained supported the factorial validity of the scales modified from the TOSRA, SLEI, and TROFLEI when used with the sample of 322 students in this study.

Ten questions were eliminated from the learning environment and attitude scales for further analysis because they had a factor loading lower than 0.40 on their own scale and/or greater than 0.40 on any other scale. The following items were removed in order to improve the internal consistency reliability and factorial validity: Questions 2 and 7 from Inquiry, Question 9 from Enjoyment, Questions 17 and 21 from Integration, Question 32 from Material Environment, Question 33 from Teacher Support, Question 53 from Investigation, and Questions 57 and 58 from Differentiation. For only the scale of Task Orientation, all eight items from the original version were retained.

Table 4.1 indicates that the optimal factor solution occurred for the set of 54 items. The percentage of variance for the different scales ranged from 2.78% for Differentiation to 24.75% for Inquiry, with a total variance of 55.05% for all scales. The eigenvalues ranged from 1.78 to 15.84. Results from the factor analysis strongly supported the factorial validity of the scales from the TOSRA, SLEI, and TROFLEI for this study's sample of 322 students. These findings replicate other validation studies (Aldridge & Fraser, 2003; Fraser, 1981; Fraser, Giddings, & McRobbie, 1992, 1995), as discussed previously in Chapter 2.

4.2.2 Internal Consistency Reliability of Learning Environment and Attitude Scales

Internal consistency reliability is a measure of the extent to which items in the same scale measure a common construct. Cronbach's alpha coefficient was used as the index of internal consistency for this study. After the removal of invalid items from the factor analysis, the alpha coefficient was calculated for the revised 54-item questionnaire measuring learning environment perceptions and attitudes towards science, for two units of analysis (the individual student and the class mean). Scales with a Cronbach alpha coefficient greater than 0.60 were considered to have adequate internal consistency reliability (De Vellis, 1991).

Table 4.2 Scale Mean, Standard Deviation, Internal Consistency (Cronbach Alpha Reliability), Discriminant Validity (Mean Correlation with other Scales), and Ability to Differentiate between Classrooms (ANOVA Results) for Learning Environment and Attitude Scales

Scale	No of Items	Unit of Analysis	Mean	SD	Alpha Reliability	Mean Correlation with other Scales	ANOVA Eta²
Integration	6	Individual	3.76	0.60	0.83	0.40	0.12***
		Class Mean	3.90	0.22	0.96	0.64	
Material	7	Individual	3.76	0.61	0.81	0.36	0.07***
Environment		Class Mean	3.87	0.20	0.85	0.41	
Teacher Support	7	Individual	3.67	0.80	0.91	0.36	0.17***
		Class Mean	3.91	0.35	0.98	0.58	
Task	8	Individual	3.92	0.71	0.91	0.30	0.07***
Orientation		Class Mean	3.99	0.29	0.97	0.25	
Investigation	7	Individual	3.45	0.74	0.90	0.41	0.14***
		Class Mean	3.64	0.30	0.98	0.63	
Differentiation	6	Individual	2.79	0.85	0.86	0.16	0.23***
		Class Mean	2.85	0.36	0.95	0.20	
Inquiry	6	Individual	3.53	0.74	0.81	0.23	
		Class Mean	3.61	0.25	0.93	0.43	
Enjoyment	7	Individual	3.51	0.80	0.90	0.40	
		Class Mean	3.73	0.34	0.96	0.54	
Achievement	10	Individual	2.83	1.38	0.76		
		Class Mean	2.96	0.99	0.96		

***$p<0.001$
N=322 students in 6 classes.

Table 4.2 shows that reliability amongst scales measuring students' perceptions of their learning environment as measured by the Cronbach alpha coefficient ranged from 0.81 to 0.91 with the individual as unit of analysis, and from 0.85 to 0.98 with the class mean as the unit of analysis (Table 4.2). Internal consistency reliability (Cronbach alpha coefficient) for the two scales measuring attitudes adapted from the TOSRA were 0.81 and 0.90 with the individual as the unit of analysis, and were 0.93 and 0.96 with the class as the unit of analysis. These high reliability estimates are in agreement with past studies using scales from the TOSRA (Fraser, 1981; Teh & Fraser, 1994).

These internal consistency reliability results are consistent with other studies using scales from the SLEI (Fraser, 1998a; Fraser, Giddings, & McRobbie, 1995; Lightburn & Fraser, 2007; Maor & Fraser, 1996; Martin-Dunlop & Fraser, 2007), the TROFLEI (Aldridge, Dorman, & Fraser, 2004; 2003; Gupta & Koul, 2007) and the TOSRA (Aldridge & Fraser, 2003; Fraser, 1981; Fraser, Giddings, & McRobbie, 1995; Koul, Fisher, & Shaw, 2011; Wolf & Fraser, 2008).

In general, reliability estimates in Table 4.2 are higher when the class mean was used as the unit of analysis, as evidenced in other studies (Zandvliet & Fraser, 2005). Because all scales had Cronbach alpha coefficients greater than 0.60, they demonstrated satisfactory internal consistency reliability for learning environment and attitude scales.

4.2.3 Discriminant Validity of Learning Environment and Attitude Scales

The purpose of conducting discriminant validity analysis for the learning environment and attitude scales was to check whether each scale measured a unique aspect of the learning environment or attitude towards science. That is, discriminant validity is a measure of whether scales that ought not to be related to one another are indeed not related (Campbell & Fiske, 1959). To calculate an index of discriminant validity, the mean correlation of each scale with all other scales was used. Both the individual and the class were used as units of analysis as reported in Table 4.2.

Discriminant validity results, in Table 4.2, show that most scales were reasonably unique in the dimension that each assessed. For the classroom learning environment scales, the mean correlation of a scale with the other scales varied from 0.16 to 0.41 with the individual as the unit of analysis and from 0.20 to 0.64 with the class mean as the unit of analysis. For scales that measured attitudes towards science, the mean correlations varied from 0.23 to 0.40 with the individual as the unit of analysis and from 0.43 to 0.54 with the class mean as the unit of analysis. These findings suggest that raw scores on these scales measure relatively unique aspects of the learning environment and attitudes, despite some overlap. However, the factor analysis results reported in Section 4.2.1 attest to the independence of factor scores. Discriminant validity results are in agreement with findings from past studies using some of the same scales from the SLEI (Fraser, 1998a; Fraser, Giddings, & McRobbie, 1992, 1995; Lightburn & Fraser, 2007; Maor & Fraser, 1996; Martin-Dunlop & Fraser, 2007), TROFLEI (Aldridge, Dorman, & Fraser, 2004; 2003; Gupta & Koul, 2007), and TOSRA (Fraser, 1981; Teh & Fraser, 1994; Wolf & Fraser, 2008).

4.2.4 Ability of Learning Environment to Differentiate Between Classrooms

An ANOVA, with class membership as the main effect, was used to determine the ability of each learning environment scale to differentiate between the perceptions of the students in different classrooms. Students in the same class should have scores on learning environment scales that are relatively similar to each other, but which are different from the scores of students who are in different classes. Table 4.2 reports the ANOVA results, including eta^2 values to represent the proportion of variance in scale scores amongst individual students accounted for by class membership. Eta^2 scores ranged from 0.07 to 0.23 for scales measuring students' perceptions of the learning environment as measured by the SLEI and TROFLEI.

Overall, the ANOVA analysis revealed statistically significant differences (p<0.001) between student perceptions in different classes for all learning environment scales, indicating the ability of scales from the SLEI and TROFLEI to differentiate between different classrooms. These results are consistent with those from other studies using the same scales from the SLEI (Fraser, 1998a; Fraser, Giddings, & McRobbie, 1992, 1995; Lightburn & Fraser, 2007; Maor & Fraser, 1996; Martin-Dunlop & Fraser, 2007), and TROFLEI (Aldridge, Dorman, & Fraser, 2004; 2003; Gupta & Koul, 2007).

4.2.5 Validation of Achievement Section of the LAG

The scale for achievement was developed by the researcher to assess student overall content knowledge of genetics. The scale included 10 items from valid and reliable standardized examinations in Biology from the following states in which the majority of students sampled in this study attended school: New York, Massachussetts, and Virginia (see Appendix A).

To check the achievement scale for internal consistency reliability, an alpha coefficient was calculated. This analysis resulted in an alpha reliability coefficient of 0.76 with the individual as unit of analysis and of 0.96 with the class mean as unit of analysis, as shown in Table 4.2. These results indicate that the 10-item achievement scale was reliable.

Other methods were also employed to determine the validity of the achievement scale. According to the 'Bell Curve' theory, scores on any measure of achievement result in normal distributions for large populations (Herrnstein & Murray, 1996). Therefore, if valid, this scale should show a relatively normal distribution for the group of students in this study.

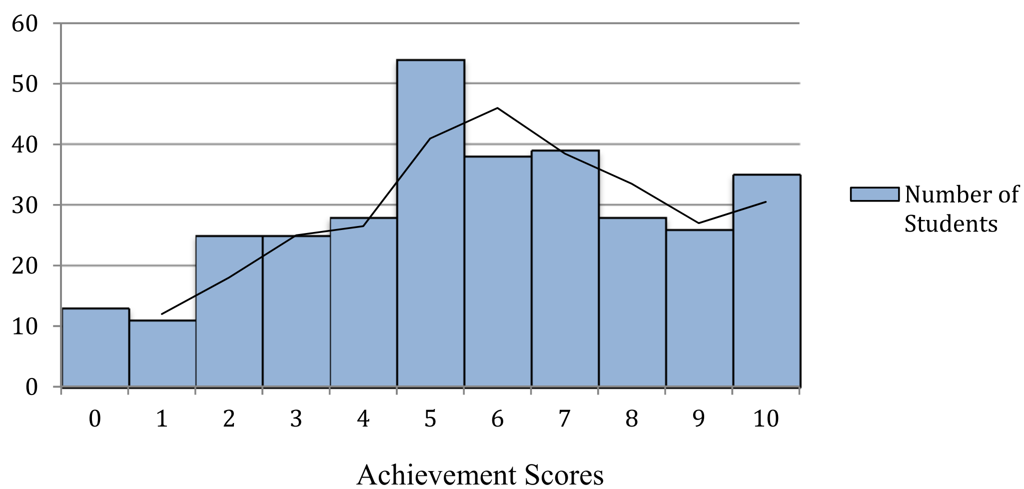

Figure 4.1 Frequency Distribution for Achievement (Mean = 5.67, SD = 2.76, N = 322)

The histogram in Figure 4.1 shows the distribution of achievement scores for all 322 students in this study. The pattern illustrated in the histogram is similar to typical patterns of normal distribution (Herrnstein & Murray, 1996), except that more students than expected received an achievement score of 10. The divergence from a normal distribution might be explained by the relatively small sample size in this study.

As well, statistical data are available online for students who took the biology Massachusetts Comprehensive Assessment System (MCAS) throughout the state of Massachusetts. As two items from the achievement scale were borrowed from this examination, the researcher compared the percentage of students in this study's sample that correctly answered the questions with the percentage of students in Massachusetts that correctly answered these same questions, as another measure of validity. Results indicate that 68% of students (n= 53,296) taking the biology MCAS in 2009 correctly answered a genetics-related item (Massachusetts Comprehensive Assessment System (MCAS), 2009), whereas 70% of participants in any study correctly answered the same item taken from that examination. For another genetics item borrowed from the MCAS, 61% of those taking the examination scored correctly, while 61% in my study did. These results show that student responses in my study were similar to those of a larger population. This finding coupled with the near normal distribution of achievement scores displayed in Figure 4.1 supports the validity of the achievement scale.

4.3 Associations Between Learning Environment, and Attitudes, and Achievement

Research Question 2: Are there associations between the perceived classroom learning environment and student outcomes of attitudes towards and achievement in science?

To answer the second research question, simple correlation and multiple regression analyses, with the individual as the unit of analysis, were used to investigate the relationship between student perceptions of the classroom learning environment and the student outcomes of attitude towards science and achievement in genetics. Simple correlation (r) was used to consider the bivariate relationship between each student outcome (attitude or achievement) with each learning environment scale of the Laboratory Assessment in Genetics (LAG). Multiple regression analysis was applied to investigate the combined influence of the whole set of learning environment scales on each student outcome, with the multiple correlation (R) indicating the multivariate association between an outcome and the set of learning environment scales. The standardized regression coefficient (β) was used to indicate the contribution of each learning environment scale to the variance in student attitude or achievement when other learning environment scales were controlled.

Analysis to uncover associations involved scores from 322 American science students to a refined eight-scale, 54-item version of an attitude and learning environment questionnaire with an additional achievement scale (as described in Section 3.4.1). For these analyses, the scores on the attitude and achievement scales measured the various effects of the learning environment, which served as the independent variables.

This section reports the results for associations between the learning environment and student attitudes (Section 4.3.1) and achievement (Section 4.3.2). Table 4.3 shows simple correlations (r), standardized regression coefficients (β), and multiple correlations (R) — in order to determine the extent of these associations.

Table 4.3 Associations between Learning Environment Questionnaire Scales and Attitudes and Achievement in Terms of Simple Correlations (r), Multiple Correlations (R) and Standardized Regression Coefficients (β)

Learning Environment	Attitude-Environment Associations					
Scale	Inquiry		Enjoyment		Achievement	
	r	β	r	β	r	β
Integration	0.30**	0.10	0.50**	0.11	0.21**	0.18*
Material Environment	0.34**	0.21**	0.54**	0.22**	0.20**	0.14*
Teacher Support	0.51**	0.13*	0.58**	0.29**	0.18**	0.08
Task Orientation	0.25**	0.08	0.48**	0.18**	0.06	0.05
Investigation	0.37**	0.21**	0.51**	0.14*	0.05	0.02
Differentiation	0.22**	0.10	0.17**	0.00	-0.16**	0.21**
Multiple Correlation (R)		0.45***		0.70***		0.34***
R^2		0.20		0.49		0.12

*p<0.05, **p<0.01, ***p<0.001

N = 322 students in 12 classes

4.3.1 Associations Between Learning Environment and Attitudes

Table 4.3 shows that each learning environment scale correlated significantly (p<0.01) and positively with each of the student attitudes (Inquiry and Enjoyment), indicating that positive perceptions of the learning environment are aligned with improved students' attitudes towards science. The learning environment scale of Teacher Support showed the highest correlation with both attitude scales of Inquiry (0.51) and Enjoyment (0.58) and the scale of Differentiation showed the lowest correlation with both attitude scales of Inquiry (0.22) and Enjoyment (0.17).

As shown in Table 4.3, the multiple correlation coefficient (*R*) between the six learning environment scales and attitude was 0.45 for the Inquiry scale and 0.70 for the Enjoyment scale. These values were statistically significant ($p<0.001$), suggesting that student attitudes toward science were related to student perceptions of their learning environment. The coefficient of determination (R^2), which is a measure of the proportion of variance in attitudes explained by learning environment scales, was 0.20 for Enjoyment and 0.49 for Inquiry scales. This means that learning environment scales were stronger predictors of Enjoyment than of Inquiry.

In order to further identify which of the six learning environment scales accounted for variance in student attitudes, when the other five scales were controlled, the standardized regression coefficients (β), shown in Table 4.3, were examined. Three learning environment scales (Material Environment, Teacher Support, and Investigation) were statistically significant ($p<0.05$), positive, independent predictors of both attitude scales, whereas two scales (Integration and Task Orientation) were statistically significant, positive, independent predictors of only the Enjoyment attitude scale. The learning environment scale of Differentiation was a statistically significant independent predictor of neither attitude scale.

Generally, these analyses reveal that student perceptions of their learning environment were positively related to student attitudes, therefore suggesting that improving conditions of the classroom learning environment might enhance students' attitudes towards science. These associations replicate the results of past studies (Fraser, 2012; Lightburn & Fraser, 2007; Martin-Dunlop & Fraser, 2007).

4.3.2 Associations Between Learning Environment and Achievement

The simple correlation analysis reported in Table 4.3 reveals statistically significant ($p<0.01$) and positive associations between three learning environment scales (Integration, Material Environment, and Teacher Support) and achievement, while the scale of Differentiation had a statistically significant ($p<0.01$) and negative correlation with achievement. The learning environment scales of Task Orientation and Investigation showed no statistically significant correlation with achievement.

As shown in Table 4.3, the multiple correlation between the six learning environment scales and achievement was 0.34. This value was statistically significant ($p<0.001$), suggesting that there is a multivariate relationship between achievement and student perceptions of their learning environment.

In order to identify which of the six learning environment scales accounted for the variance in student achievement, when the other five scales were controlled, regression coefficients were inspected. Standardized regression coefficients (β) indicated that the learning environment scales of Integration, Material Environment, and Differentiation uniquely accounted for a significant ($p<0.05$) amount of variance in academic achievement. On the other hand, Teacher Support, Task Orientation, and Investigation scales were not statistically significant independent predictors of achievement.

The negative simple correlation between Differentiation and achievement suggests that the more differentiated the classroom environment, the less students achieved. Past studies indicate mixed results; Aldridge et al. (2003, 2008) indicate a positive, non-significant association. Similarly, Gupta and Koul (2007) found a negative association between Differentiation and academic achievement, albeit not statistically significant. Perhaps these students were not familiar with how differentiation was applied to their classroom settings, and they might have feared that differentiated assignments would not result in greater achievement due to a perception that teachers accommodate for the under-achievers.

In another attempt to explain this finding, the six teachers involved in the study were consulted regarding the amount and type of actual differentiation in their classrooms during the implementation of the study. They admitted that not much differentiation was provided. Therefore, perhaps the questionnaire items asking about differentiation confused students, producing the mixed results reported in this section.

However, as noted above, Differentiation did prove to be a statistically significant ($p<0.01$), positive independent predictor of student achievement when there was control for other predictor variables, indicated by its standardized regression coefficient (ß). Thus, the bivariate relationship between differentiation and achievement and the multivariate contribution for differentiation on achievement present conflicting results. This is known as the 'Suppressor Effect', often found with the addition of predictor variables that increase the value of R^2 and lower the error term, resulting in inaccurate statistical significance of a prediction; this effect is characteristic of low sample power (Thompson & Levine, 1997). Therefore, results from this study concerning the relationship between Differentiation and achievement are inconclusive.

Overall, the results of correlation analyses in Table 4.3, show that most learning environment scales were positively correlated with the student outcomes of attitude and achievement, which means that positive perceptions of the learning environment are linked with improved attitudes towards science and better achievement. Such links between the learning environment and students' attitudes and achievement as replicate past studies (Fraser, 2012; Lightburn & Fraser, 2007; Martin-Dunlop & Fraser, 2007).

4.4 Effectiveness of Virtual Laboratories and their Differential Effectiveness for Different Sexes in Terms of Learning Environments, Attitudes, and Achievement

To answer the third and fourth research questions regarding the effectiveness of using virtual laboratories and its differential effectiveness for different sexes, data were gathered from classes that engaged in virtual laboratories (the intervention) and classes that did not.

Research Question 3: Is the use of virtual laboratories in high school science classes effective in terms of students'

a) perceptions of their learning environment

b) attitudes towards science, and

c) academic achievement in genetics?

Research Question 4: Is the use of virtual laboratories differentially effective for males and females in terms of students'

a) perceptions of their learning environment

b) attitudes towards science, and

c) academic achievement in genetics?

Among the six teachers who volunteered for the implementation of this study, each teacher taught at least one class with the intervention and one class without the intervention. The total sample for the study was comprised of 322 American students from Grades 8–10. Over a treatment period of about 2–12 weeks, students in the experimental group completed at least four to eight virtual laboratory experiments in genetics using computers that employed 'point-and-click' techniques for manipulating various laboratory materials. Each of these virtual experiments simulated a real, hands-on experiment and followed a typical experimental format for which students observe phenomena, formulate hypotheses, set up controls, follow procedures, test hypotheses, and analyze results. Students in the control group continued learning and experimenting in their normal fashion, without the use of virtual experiments; instructional methods for these classes included lectures, textbook reading, hands-on experiments, and/or other activities. Further detail regarding the sample, data collection, treatment conditions, and procedures followed to implement this study are described in Sections 3.3 and 3.5.

Upon completion of the treatment period, the Laboratory Assessment in Genetics (LAG), including learning environment, attitude, and achievement scales, was administered to both groups to provide the quantitative data for this study. Qualitative data were also collected from six students and three teachers who were interviewed in order to explore underlying themes that lent further insight to the quantitative data (see Section 3.6 for more detail).

Differences in LAG scale scores between instructional methods and sexes were examined using a two-way multivariate analysis of variance (MANOVA) with the learning environment scales from the SLEI and TROFLEI and student outcomes (attitudes and achievement) as the dependent variables, and with instructional method and sex as the independent variables. Because the multivariate test using Wilks' lambda criterion yielded statistically significant differences for the set of dependent variables, the individual, univariate two-way ANOVA was interpreted separately for each dependent variable (students' perceptions of their learning environment, their attitudes, and achievement), with the student as the unit of analysis. This analysis enabled an exploration of all possible interactions between both independent variables (instructional method and sex) and all three dependent variables (students' perceptions of their learning environment, their attitudes, and achievement).

To quantify the size of instructional differences and sex differences, effect sizes were also calculated to describe the ratio of variance in the dependent variable attributable to the independent variable, while controlling for other independent variables. The size of an effect is particular to the sample with which the test is applied and is purported to be an important aspect of an intervention in addition to statistical significance alone (Vacha-Haase & Thompson, 2004). In this study, two different types of effect sizes were utilized: Cohen's *d* and Eta-squared (η^2). Cohen's *d* is the difference between two sample means divided by the pooled standard deviation. Eta squared (η^2) is a measure of the strength of association (or effect size) based on the proportion of variance accounted for by the effect of the independent variable on the dependent variable. The methods of statistical analysis are also reviewed in Section 3.6.3.

First, a general overview is provided of the results (Section 4.4.1), for the effectiveness of virtual laboratories, as well as for the interactive effect between the two independent variables of instructional method and sex. Then, Sections 4.4.2 and 4.4.3 detail the results for each independent variable (instructional method and sex) separately, while Section 4.4.4 reports the interaction effects that involve the differential effectiveness of virtual laboratories for different sexes.

4.4.1 Overview of Results for Effectiveness for Virtual Laboratories and Differential Effectiveness of Virtual Laboratories for Males and Females

The results of the two-way ANOVAs for instructional method, student sex, and the interaction between independent variables (instructional method and sex) are displayed in Table 4.4 for the six learning environment and three student outcome scales.

Table 4.4 Two-Way Analysis of Variance (ANOVA) for Instructional Method and Sex for each Scale of the LAG

Scale	Instructional Method		Student Sex		Instructional Method/Sex	
	F	Eta^2	F	Eta^2	F	Eta^2
Learning Environment						
Integration	0.85	0.00	3.83*	0.02	1.31	0.01
Material Environment	0.04	0.00	2.38	0.01	5.13*	0.03
Teacher Support	0.15	0.00	0.22	0.00	4.39*	0.02
Task Orientation	0.10	0.00	1.58	0.01	1.52	0.01
Investigation	0.27	0.00	1.91	0.01	0.85	0.00
Differentiation	1.24	0.01	4.46*	0.03	0.00	0.00
Outcomes						
Inquiry (Attitude)	1.09	0.01	3.06	0.02	5.02*	0.03
Enjoyment (Attitude)	0.60	0.00	8.05**	0.04	1.37	0.01
Achievement	0.59	0.00	0.55	0.00	0.04	0.00

Sample Size Instructional Method: Non-VL = 153, VL = 166
Sex: Females = 169 and Males = 150

*p<0.05, **p<0.01

The two-way ANOVAs presented in Table 4.4 yielded a number of statistically significant findings:

- No statistically significant differences existed for instructional method (i.e. between student scores in VL classes versus non-VL classes).
- Regardless of instructional method, statistically significant differences (p<0.05) were found between males and females for the learning environment scales of Integration and Differentiation and for the attitude scale of Enjoyment (p<0.01). The effect sizes for all three of these scales were small.
- A statistically-significant (p<0.05) Instructional Method x Sex interaction emerged for the two learning environment scales of Material Environment

and Teacher Support and for the attitude scale of Inquiry. The effect sizes for all three of these scales were small.

Detailed results for each independent variable (Instructional Method and Sex) are discussed in Sections 4.4.2 and 4.4.3, respectively. As well, a more detailed report of the interactions from the ANOVAs appears in Section 4.4.4.

4.4.2 Effectiveness of Instruction Using Virtual Laboratories in Terms of Learning Environment Perceptions, Attitudes, and Achievement

This section reports in greater detail results for the third research question concerning the effectiveness of virtual laboratories as tested on classes that used these virtual laboratories and classes that did not.

To further clarify the instructional differences presented Table 4.4 above, more details are furnished in Table 4.5, including the mean score, standard deviation, and effect size for the difference in scores between VL and non-VL classes for each learning environment scale and student outcome (attitudes and achievement). The mean was obtained by dividing the original scale mean by the number of items in each scale to allow for meaningful comparison of average scores across scales of varying lengths. *F* values from the ANOVA in the first column in Table 4.4 are repeated in Table 4.5 below. Effect sizes (Cohen's *d* values) displayed in Table 4.5 illustrate the number of standard deviations from the mean for any differences found between classes that had the intervention and classes that did not.

The mean scores represent the average of students' scores on each scale which ranged from 1 (Strongly Disagree) to 5 (Strongly Agree). Because achievement scores were measured from 0 to 10, with each score representing the number of items each student answered correctly out of 10 items, the final score was divided by 2 to allow for consistent and meaningful comparisons of scores between all scales.

Table 4.5 Item Mean, Item Standard Deviation and Difference Between Instructional Methods (ANOVA Results and Effect Size) for each Learning Environment and Student Outcome Measured by the LAG

Scale	Mean		Standard Deviation		Difference	
	Non-VL	VL	Non-VL	VL	*F*	Effect Size
Learning Environment						
Integration	3.80	3.73	0.60	0.60	0.85	-0.12
Material Environment	3.77	3.75	0.59	0.62	0.04	-0.03
Teacher Support	3.66	3.69	0.73	0.85	0.15	0.04
Task Orientation	3.90	3.93	0.69	0.73	0.10	0.04
Investigation	3.43	3.47	0.73	0.75	0.27	0.05
Differentiation	2.73	2.83	0.83	0.87	1.24	0.12
Outcomes						
Inquiry (Attitude)	3.49	3.53	0.74	0.73	1.09	0.05
Enjoyment (Attitude)	3.48	3.53	0.79	0.81	0.60	0.06
Achievement	2.90	2.78	2.80	2.72	0.59	-0.04

Sample Size = 322 (Control Group =153 and Experimental Group =169)

Differences in the means between classes using virtual laboratories and classes that did not use virtual laboratories are illustrated in Figure 4.2. While the mean is reported on a scale from 1 (Strongly Disagree) to 5 (Strongly Agree), the graph only shows the scale of 2 (Disagree) to 4 (Agree) in order to magnify the difference between the means. No mean scores fell below 2 or above 4. The first six scales measure students' perceptions of the learning environment, the next two scales measure students' attitudes, and the last scale measures achievement.

According to the results shown in Table 4.5 and Figure 4.2, students in the experimental group, using virtual laboratories, did not perceive their learning environment too differently from students in the control group who did not engage in virtual laboratories. Statistically significant differences were not found for any of the learning environment, attitude, or achievement scales. Furthermore, effect sizes for using virtual laboratories were small, ranging from 0.03 to 0.12 (all small) standard deviations for the different dependent variables. Although these findings do not support the effectiveness of virtual laboratories, they also provide no evidence that using virtual laboratories negatively impacted on students' perceptions of the learning environment, attitudes, or achievement.

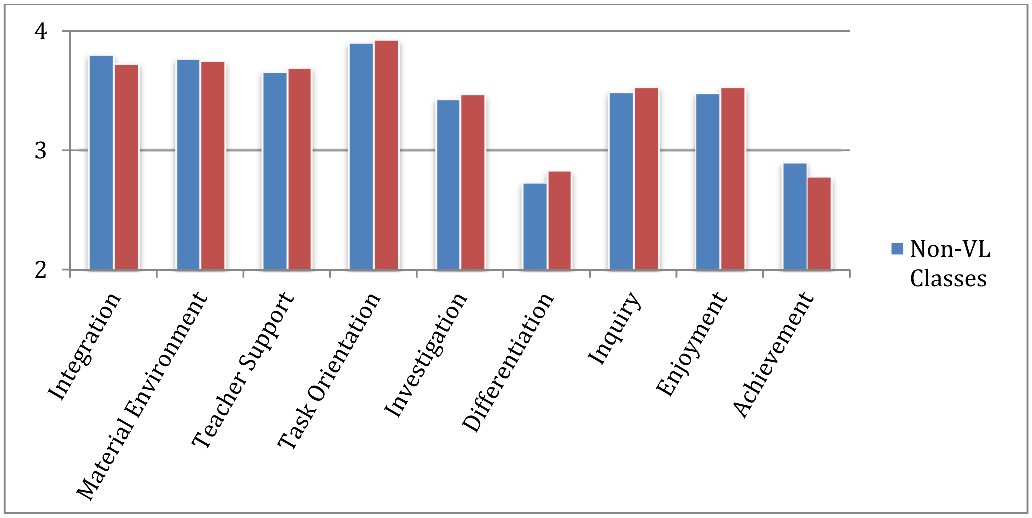

Figure 4.2 Profile of Means for Instructional Groups as Measured by LAG

For most of the learning environment scales in Table 4.5 (namely, Teacher Support, Task Orientation, Investigation, and Differentiation), as well as for the attitude scales of Inquiry and Enjoyment, the mean for the experimental group using virtual laboratories was slightly greater than the mean for the control group for which no virtual laboratories were used. These patterns are also demonstrated in Figure 4.2. Conversely, the means for the VL classes for the dimensions of Integration, Material Environment, and Achievement were slightly lower than the means for the non-VL classes.

My finding of no significant differences between classes that used the intervention (i.e. virtual laboratories) and classes that did not in this study is consistent with a worldwide trend, identified in literature reviewed in Section 2.5.5, in which technological innovations do not always measure up to their intended expectations. More specifically, my findings also replicate those from other studies reporting that virtual laboratories offered neither advantages nor disadvantages over other methods of instruction (Cobb et al., 2009; Cross & Cross, 2004; Javidi & Sheybani, 2006; Russell, 1999; Stuckey-Mickell & Stuckey-Danner, 2007), suggesting that virtual laboratories are useful as a supplementary tool in science classrooms, rather than a substitute for more traditional methods, such as hands-on laboratories (Nedic, Machotka, & Nafalski, 2003; Raineri, 2001; Toth, Morrow, & Ludvico, 2009; Yu, Brown, & Billet, 2005).

Qualitative data were gathered by interviewing participating students and teachers in order to add insight. What follows first is a description of the qualitative data pertaining to the scales for which positive differences (albeit small and non-significant) were noted for the VL classes in comparison to the non-VL classes, which is then followed by qualitative data used to explain negative (albeit small and non-significant) differences.

The quantitative difference between the two comparison groups for Teacher Support was almost negligible. Similarly, replies about Teacher Support during interviews indicated no differences between classes that used virtual laboratories and the classes that did not. Teacher A noted, "Assistance [between the two groups] was about the same. Maybe a little more explanation [was required for VL classes just] to get started." As well, Teacher M agreed but added, "I would say that the non-VL students needed more teacher assistance. The virtual labs that I chose had very clear directions and stepped students through processes at a good pace for them. The main questions from the VL group were more to do with navigation of the site, rather than content." Students tended to agree that teacher assistance was similar for the two treatment groups. In response to being asked whether she needed help with the virtual laboratories, Lara answered "Usually it was just because I put the website in wrong, but it was never just to get things done." Therefore, the *type* of support needed in each treatment condition differed — in the non-VL classes, more instructional assistance was needed and, in the VL classes, more technical assistance was needed — but the *amount* of teacher support was roughly the same.

Additionally, questions about Teacher Support in both the written questionnaire and the semi-structured interview caused mixed understanding among students about whether they referred to the support from the physical teacher or from the virtual program. For instance, Lara stated "I think it's not as easy understanding science when you have one teacher per 20-something students and I think it's easier when you have one computer working with you one-on-one; I think it helps a lot more and you get a lot more out of it." In this instance, virtual laboratories represent the teacher and the personalized feedback is equivalent to the support that a teacher would offer. Perhaps this misunderstanding of the term 'Teacher' (i.e. either the actual teacher or instruction from a computer program) caused the absence of clear quantitative results; in the future, the lack of clarity in the wording of items on the Teacher Support scale ought to be considered when applying the scale when other methods of instruction are used.

The highest score for students' perceptions of their learning environment was for the scale of Task Orientation, even though the difference between the two groups was small and non-significant. Regardless of instructional method, students in these science classes seemed motivated to complete the tasks set. Interest in the aspect of Task Orientation originally motivated the researcher to initiate this study because virtual laboratories contain an extrinsic motivational element that lends itself to task completion, as explained in Section 1.2. However, quantitative and qualitative data showed no differences between students who used virtual laboratories and students who did not in terms of Task Orientation.

Responses from students and teachers during qualitative data collection reflected the high quantitative score for Task orientation amongst both groups. All four students in the experimental group and two students in the control group noted that they were motivated to complete their work. As well, teachers noted that they did not observe any differences between the classes regarding motivation to complete the activities, as indicated by the quantitative data. Thus, it can be inferred that motivation to complete tasks, as measured by Task Orientation, is not an outcome of some extrinsic factor, such as virtual laboratories; rather, it is intrinsic motivation that might be a predictor of the degree of task completion for any activity, whether innovative or traditional. As Teacher M said, "I think that the motivation differs among students, not between the two classes [VL versus non-VL]." As such, perhaps the scale of Task Orientation could be further delineated into extrinsic motivation (the intended measurement in this study) and intrinsic motivation (the measurement perceived by students and teachers in this study) when applied to measuring the effectiveness of an innovative intervention.

Comments from student and teacher interviews also reflected the lack of a significant instructional difference for Investigation. Amongst both treatment groups, students at this maturity level seem to prefer, or have been conditioned to prefer, prescribed instructions and clear guidelines, allowing them to feel more control and preventing them from straying too far from the expected result of the experiment. As Lara in a VL class confided “I’d rather not have to go back and do things a million times because I messed up; I’d rather get it right the first time and learn from it.” Erica in the control group also related: “I prefer the teacher giving us a set of instructions.” These observations suggest that the implementation of innovative interventions that aim to increase students’ sense of Investigation might be more successful with more senior students and/or in non-traditional environments where students are already encouraged to investigate independently.

According to Table 4.5, the difference of 0.12 standard deviations between the means of VL classes and non-VL classes was the greatest for the scale of Differentiation, albeit still not statistically significant. No major differences between the groups were noted during interviews with students and teachers. However, students in the VL classes commented that they were allowed to go on to the next task once they had completed the previous one; this practice is part of the self-paced nature of virtual laboratories. Teacher A observed, “They [virtual laboratories] also allowed the more advanced students to move more quickly through the labs.”

Qualitative data were also obtained for the two attitudes scales, for which means were higher (albeit not significant) for VL classes than non-VL classes. Teachers and students did not observe any differences regarding the level of inquiry between instructional methods. However, the researcher noted a theme that emerged from student interviews based on the Inquiry scale: students preferred hands-on activities and the opportunity to collaborate with other students, both being features present in traditional ‘wet-labs’ and absent from virtual laboratories; these features are both aspects of Inquiry but such inquiry-driven activities might not necessarily have resulted in mastery of concepts or skills. Hayley gave numerous examples of sordid, shock-provoking hands-on activities that piqued her sense of Inquiry, such as “you take the egg and you either put it in vinegar or in syrup…the egg was huge, …it was disgusting!" However, Hayley was unable to explain the concept learned from such activities. Lara's comment also revealed this theme: "…not me [but] a lot of people enjoy doing the [hands-on] labs like mixing the chemicals and dissecting and it wouldn't be as enjoyable for them to just be on the computer clicking on things. But I actually thought it was better because the computer helped [me] to understand things and it would say 'good job, you understand this now' or it would say 'no you didn't do this right, try again'…". Therefore, while higher levels of Inquiry were aligned with hands-on laboratories, according to student interviews, the level of inquiry did not necessarily result in greater learning, which was a separately measured dimension.

Regarding Enjoyment, Table 4.5 shows a mean score of 3.53 for VL classes and 3.48 for non-VL classes (effect size of 0.06). As opposed to traditional 'chalk and talk' instruction, investigative laboratory activities, whether hands-on or virtual, are likely to promote feelings of enjoyment as suggested in Section 2.5, which justifies the tendency of both groups to score closer to the 'agree' side of the scale.

However, upon interviewing students, reports of enjoyment differed slightly between the two instructional groups. Jasper, in a VL class, responded, "most of the [virtual] activities we did were fun" and Hayley also in a VL class said, "I looked forward to that one [biology class] at the end of the day." Lara further clarified, "This year, they were a lot more fun than in the past because we did a lot of online labs."; she also indicated that she enjoyed the "genetics portion of our learning" more than all other topics in biology, and this was the subject of most of the virtual laboratories. Furthermore, when given a choice regarding placement into VL or non-VL classes before beginning the study (which is another measure of Enjoyment of virtual laboratories), most students responded positively for the condition of virtual laboratories and would not have changed this preference even after learning that there were no significant differences between the groups. On the other hand, Ann in the non-VL class, reported that students never went to the computer room for science class and that her science class "wasn't very fun…and some of the labs were unclear, but some of them were fun but most weren't." Erica in the non-VL class also expressed her preference to be in the VL classes, "The virtual seemed kinda cool."

Teachers' assessments of students' enjoyment in using virtual laboratories showed a different perspective, one that did not necessarily offer any advantage for virtual laboratories with regard to Enjoyment. Teacher A related, "I think the students liked the VL classes because they added some variety to the usual classroom environment." Similarly, Teacher M agreed, "In my classroom, I would use virtual labs as another tool in addition to hands-on-labs, class work, and lecture. Virtual labs are great for labs where you might not have the equipment to do the labs, and they are a way to preview/review other work that you have done in class."

Conversely, the means for the VL classes for the learning environment dimensions of Integration and Material Environment were slightly lower than the means for the non-VL classes. The finding concerning Integration (albeit not significant) might suggest that the successful implementation of virtual laboratories depends on how well the particular teacher integrates the intervention with the content of the curriculum, but it might not necessarily indicate anything about the integrative nature of virtual laboratories themselves. That is, students' perceptions for the dimension of Integration might be more affected by differences amongst teachers, than by the instructional method. Comments from student interviews did not differ all that greatly between those who used virtual laboratories and those who did not, thus supporting the quantitative results. As well, all participating teachers claimed that they fully integrated the laboratory activities into the topics explored at the time, irrespective of instructional method.

The difference in the means for Material Environment was slightly negative but nearly negligible. Qualitative data obtained from interviews also supported this finding. Responses from students, regarding the equipment used in science laboratories, were mixed. Students in VL classes reported that computers were "slow" or that the number of available computers was insufficient for the number of students in the class, while Teacher G mentioned, "there were not enough working laptops". Even if there was ample computer access, Teacher M explained that "there were times when the websites that we were trying to access were jammed up, and so they had trouble getting to a lab." The functionality of equipment in non-VL classes was also variable. Lara mentioned that wet-lab equipment was inadequate and that "microscopes definitely were something we had a problem with because…[they] were pretty old…and it took away from our learning time so that was a bit of a pain." Therefore, for schools where the condition of digital equipment far surpasses the condition of traditional laboratory equipment, a phenomenon more common in recent years, the use of virtual laboratories might be beneficial. Teacher M agreed: "The biggest difficulty with hand-on labs in genetics is the expense and technical expertise to use more sophisticated equipment."

Students in the VL classes also scored negligibly lower than students in the non-VL classes in terms of achievement. Therefore, the quantitative data suggest that both instructional methods were equally effective with regard to content retention and understanding. These findings replicate results from the other small number of studies using virtual laboratories (Cobb et al., 2009; Cross & Cross, 2004; Javidi & Sheybani, 2006; Stuckey-Mickell & Stuckey-Danner, 2007).

The results concerning Achievement require further elucidation. In an effort to avoid researcher bias and maintain validity of questionnaire items to measure achievement, the researcher limited herself to choosing items originating from standardized examinations dictated by national learning standards in the US but, in the process, such items could have lost closer relevance to virtual laboratories than if the researcher had created her own questions. Therefore, the achievement items might not have accurately measured understanding of content.

Qualitative data showed that all four students interviewed from VL classes reported that they had a good understanding of genetics (the content for the virtual laboratories), scored highly on their particular class examinations, and were able to explain these concepts to the interviewer orally. Out of the two students in the non-VL classes, one reported that she had a good understanding of genetics and the other did not. Student interview responses from the two groups did not seem to indicate any advantage in using virtual laboratories with regard to achievement. As well, Teacher M noted, "I'm not sure it [VLs] made a difference. The larger factors may be student ability and motivation."

The theme noted in the discussion of the Inquiry scale resurfaced in interview responses concerning achievement: the understanding of content did not correlate with the sense of intrigue from 'hands-on' investigations. For instance, Teacher M observed students "…doing less mental processing of hands-on labs and being more partner-dependent. In the VL [virtual laboratory], they had to do the thinking on their own." In this way, virtual laboratories might have required students to reflect on the content and engage in higher-level inquiry-based skills, as opposed to the more hands-on approach of traditional laboratories that were devoid of such higher-level skills. Virtual laboratories provided an environment free from 'hands-on' distractions. This theme is supported by the literature: simulations and virtual laboratories are likely to increase conceptual understanding (Marbach-Ad, Rotbain, & Stavy, 2008; Raineri, 2001; Toth, Morrow, & Ludvico, 2009; Tsui & Treagust, 2004) and traditional laboratories focus more on design skills and the scientific process (Ma & Nickerson, 2006; Toth, Morrow, & Ludvico, 2009).

Therefore, to conclude the findings obtained from qualitative data, it seems there are two components to laboratories (whether innovative or traditional) that might necessitate separate measurements in future studies: 1) exploration, which includes investigation, use of physical tools and techniques ('hands-on'), and getting dirty, and 2) understanding what the laboratory is investigating and how it relates to the content learned in class.

4.4.3 Sex Differences in Learning Environment Perceptions, Attitudes, and Achievement

Differences between sexes, regardless of instructional method, are reported in this section in detail. The learning environment scales and student outcomes (of attitudes and achievement) served as the dependent variables in exploring sex differences between a group of 171 females and 151 males.

Table 4.6 Item Mean, Item Standard Deviation and Sex Difference (ANOVA Results and Effect Size) for Each Learning Environment Scale and Student Outcome Measured by the LAG

Scale	Mean		Standard Deviation		Difference	
	Female	Male	Female	Male	*F*	Effect Size
Learning Environment						
Integration	3.70	3.83	0.61	0.58	3.83*	0.22
Material Environment	3.70	3.82	0.59	0.62	2.38	0.20
Teacher Support	3.65	3.70	0.81	0.78	0.22	0.06
Task Orientation	3.96	3.86	0.70	0.72	1.58	- 0.14
Investigation	3.39	3.51	0.71	0.76	1.91	0.16
Differentiation	2.69	2.89	0.81	0.89	4.46*	0.24
Outcomes						
Inquiry (Attitude)	3.46	3.60	0.72	0.75	3.06	0.19
Enjoyment (Attitude)	3.38	3.64	0.83	0.75	8.05**	0.33
Achievement	2.78	2.90	2.68	2.85	0.55	0.04

Sample Size = 322(Females =171 and Males =151)
*p <0.05, **p<0.01

To further understand the differences presented in Table 4.4, more details are furnished in Table 4.6, including the mean score, standard deviation, and difference between males and females for each learning environment scale and student outcome (attitudes and achievement). *F* values for sex differences from the ANOVAs in Table 4.4 are repeated in Table 4.6. As for instructional method differences, effect sizes are displayed in Table 4.6 to illustrate the magnitude of differences found between female and male scores expressed in standard deviation units. These mean scores are also displayed graphically in Figure 4.3 to show sex differences in learning environment, attitudes, and achievement scales.

Table 4.6 reveals statistically significant differences (p<0.05) between males and females for the learning environment scales of Integration and Differentiation. Males perceived these aspects of their learning environment to be more positive than females. These differences were associated with small effect sizes (0.22 and 0.24 standard deviations, respectively). A statistically significant difference (p<0.01) also emerged between males and females for the attitude scale of Enjoyment, with males reporting more enjoyment in science than females, and with magnitude that can be considered small to medium (0.33 standard deviations).

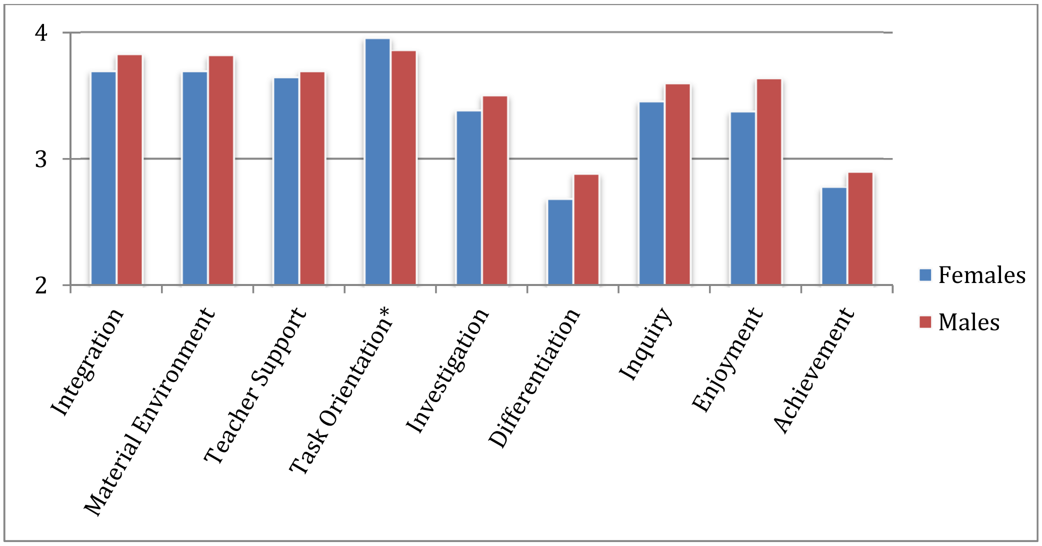

Figure 4.3 Profile of Means for Different Sexes as Measured by LAG

The magnitude of differences for those scales for which sex differences were non-significant ranged from 0.04 to 0.20 standard deviations (all small). Examination of the means in Table 4.6 also clarifies the direction of these differences. Although most differences between the sexes were small and non-significant, a pattern still emerged: males scored higher than females on nearly all scales (i.e. Integration, Material Environment, Teacher Support, Investigation, Differentiation, Inquiry, Enjoyment, and Achievement) except for Task Orientation, for which females scored higher than males.

Integration measures the extent to which regular science classes and laboratories are related. In this case, males perceived the laboratory activities to be more relevant to the content learned in class than did females. If males enjoy the laboratories more, as indicated by the results of this study as well as other studies (see below regarding Enjoyment), then they might perceive a stronger connection between the laboratories and their science classes than do females. However, this finding is inconsistent with other studies of the SLEI, which indicated that females perceived more Integration than males (Fraser, Giddings, & McRobbie, 1995; Kijkosol, 2005).

Differentiation measures the extent to which work assigned is individualized for the pace and level of each student. Males in this sample perceived that they completed tasks at a different pace and level from their female peers, contributing to the significant difference found in this study. Differentiation can be an aspect of the broader phenomenon present in male behavior during laboratory activities, as explained by the qualitative data below and in Section 4.4.4.

The attitude scale of Enjoyment measures the extent to which students enjoy science lessons. According to the results of this study, males enjoyed their science classes significantly more than females. This phenomenon is well documented in the literature (Neathery, 1997; Oakes, 1990; Raaflaub & Fraser, 2002; Wolf & Fraser, 2008), suggesting that males typically derive greater enjoyment from science, and the ensuing laboratory activities, than females.

Qualitative data gathered to support the quantitative results indeed revealed agreement regarding the greater enjoyment that males experienced during science activities. Both male interviewees reported enjoyment in their science classes, although three out of four female interviewees reported likewise. Jasper (male) declared that science “was one of my favorite subjects!”

Nevertheless, many of the non-significant differences between scores of females and males were negligible. Recent research suggests that the gap between the sexes in many aspects of science education, most notably in achievement, has narrowed (Gupta & Koul, 2007; Neathery, 1997; Oakes, 1990; Osborne, Simon, & Collins, 2003). My study, too, showed no differences between males and females regarding achievement.

Upon interviewing, neither students nor teachers mentioned major differences between males and females with regard to achievement. Lara noted that achievement amongst males and females “was about the same” and Erica agreed that the split in achievement levels was “50:50”. Interviewees were in agreement that achievement did not depend on sex but on other factors. Jasper said that “it depends on if you like the subject or not.” Teacher M observed that boys were more motivated to undertake investigative activities and that would affect achievement. Other students mentioned factors, such as distractions. Hayley observed that boys were “just joking around and girls were more quiet” and focused, so girls “got more answers than boys.” She also commented that the boys both create more distractions but can also work better with distractions, whereas the girls “need quiet to concentrate.”

A general theme regarding gender emerged from qualitative data gathered by interviewing students and teachers. Many commented that males prefer to get dirty, handle equipment, make jokes, be noisy, and they don’t focus as much as girls. Ann reported, “I don’t think that the guys normally pay that much attention.” Lara noted such differences too: “I guess with females, they have a little more control…they’d wait patiently…whereas males, they’re a little more hands-on, they’re really excited to get into things and they just can’t wait…We were looking at a rat that was dead and the boys went crazy and wanted to touch it,” while this same rat display seemed to disengage the girls.

Similarly, Teacher M answered, “They seem about equally motivated. In hands-on labs, boys seem to be more motivated to do the activity, but this could be due to the fact that they also are less participatory in the lab write-ups and thought questions about the lab. Girls tend to pick up the slack for the lab analysis, and so they are usually less excited about hands-on labs because they know they will be doing more work.” This comment, which relates to a theme noted in Section 4.4.2, distinguishes between initial interest in laboratory activities and the understanding of content that results from such activities. According to such observations, although males *enjoy* scientific, investigative activities more than females, females might be the ones who are actually motivated to complete the work (as shown by the reverse pattern for Task Orientation). This idea is also explained by Osborne (2003, p. 1072) who notes, “…the general finding that girls are always more motivated to achieve than boys”.

4.4.4 Differential Effectiveness of Virtual Laboratories for Males and Females

Whereas Section 4.4.2 focused on instructional differences separately, and Section 4.4.3 focused on sex differences separately, this section focuses simultaneously on the two independent variables of instructional method and sex. Students’ perceptions of the learning environment, attitudes, and achievement comprised the dependent variables. Table 4.7 repeats the results from the two-way ANOVAs (previously reported in Table 4.4) for the interaction between instructional method and sex. The presence of a statistically significant instruction-by-sex interaction was used to identify the differential effectiveness of virtual laboratories for males and females.

Table 4.7 Differential Effectiveness (Instructional Method x Sex Interaction) of Virtual Laboratories for Males and Females for Each Learning Environment Scale and Student Outcome Measured by the LAG

Scale	Sex	Mean		Standard Deviation		Instructional Method x Sex Interaction	
		Non-VL	VL	Non-VL	VL	*F*	Eta^2
Learning Environment							
Integration	Female	3.77	3.63	0.62	0.60	1.31	0.01
	Male	3.83	3.84	0.57	0.59		
Material Environment	Female	3.80	3.63	0.58	0.60	5.13*	0.03
	Male	3.75	3.89	0.62	0.62		
Teacher Support	Female	3.73	3.58	0.73	0.88	4.40*	0.02
	Male	3.59	3.81	0.73	0.81		
Task Orientation	Female	4.00	3.93	0.71	0.69	1.52	0.01
	Male	3.80	3.92	0.67	0.77		
Investigation	Female	3.41	3.38	0.71	0.72	0.85	0.00
	Male	3.45	3.57	0.75	0.77		
Differentiation	Female	2.63	2.74	0.85	0.77	0.00	0.00
	Male	2.84	2.94	0.80	0.96		
Outcomes							
Inquiry (Attitude)	Female	3.51	3.41	0.68	0.75	5.03*	0.03
	Male	3.47	3.74	0.80	0.68		
Enjoyment (Attitude)	Female	3.40	3.37	0.83	0.83	1.38	0.01
	Male	3.55	3.73	0.74	0.75		
Achievement	Female	2.86	2.71	1.36	1.32	0.04	0.00
	Male	2.95	2.86	1.45	1.41		

*$p<0.05$
N = 79 females in non-VL classes; 74 males in non-VL classes; 92 females in VL classes; 77 males in VL classes

For each scale, Table 4.7 also displays the mean and standard deviation separately for four groups, namely, males in the control group (Non-VL), males in the experimental group (VL), females in the control group (Non-VL), and females in the experimental group (VL).

Although no statistically significant differences were uncovered by the analysis for method of instruction alone (Section 4.4.2), significant ($p<0.05$) interactions between instructional method and sex emerged for three out of the nine dependent variables, namely, Material Environment, Teacher Support, and attitude in terms of Inquiry (see Table 4.7). In other words, virtual laboratories were differentially effective for different sexes in terms of students' attitudes to inquiry and their perceptions of the material environment and how well teachers support them. The amount of variance accounted for by the statistically significant interactions, as represented by the eta^2 statistic, was 0.02 for Teacher Support and 0.03 for Material Environment and Inquiry; each of these interaction effects is small in magnitude.

The average item means reported in Table 4.7 can be used in the interpretation of the statistically significant interactions between method of instruction and sex. Means also have been graphed in Figures 4.4–4.6 for the three significant interactions.

The interpretation of the significant interaction for Material Environment (see Figure 4.4) is that males perceived a more positive Material Environment in VL classes than in non-VL classes. However, females perceived a less positive Material Environment in VL classes than in non-VL classes. Therefore, virtual laboratories were more effective for males than for females for Material Environment, while instruction without the use of virtual laboratories was nearly equally effective for males and females.

Material Environment

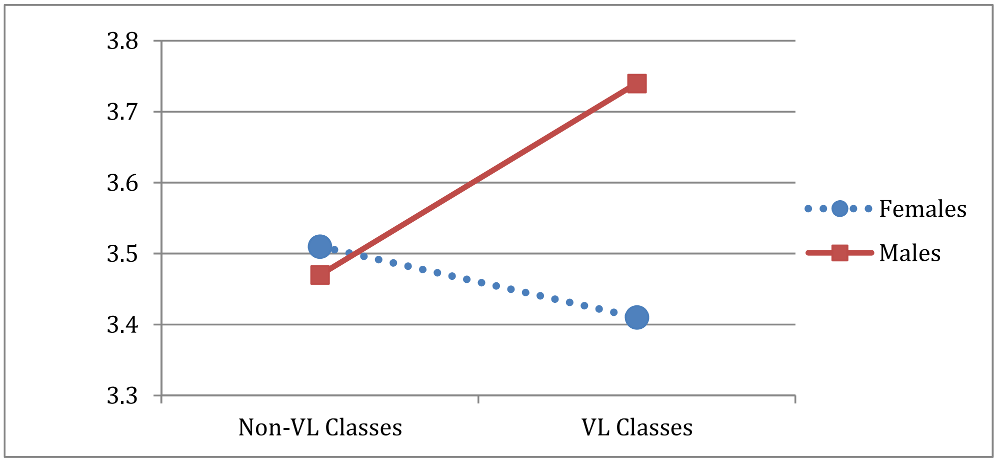

Figure 4.4 Differential Effectiveness of Virtual Laboratories for Females and Males for the Learning Environment Scale of Material Environment

This pattern suggests that males in VL classes might feel that laboratory equipment and materials, such as the technology required for virtual laboratories, were adequate while females perceived this less so. Conversely, males in non-VL classes perceived the functionality of equipment used in traditional laboratories slightly less favorably than females. This finding is supported by results from other studies that show a significant difference between instructional methods for Material Environment (Lightburn & Fraser, 2007; Maor & Fraser, 1996) and by the differential effectiveness reported for an intervention for males and females in terms of Material Environment (Quek, Wong, & Fraser, 2005).

Qualitative data also confirmed the more positive perceptions of learning media (i.e. materials) amongst males in the VL classes compared to females. As teacher A observed, “Perhaps there was a slightly greater interest on the boys part [rather than the girls], simply because some of the [virtual] labs were much like a video game.” Literature suggests that boys are more engaged with interfaces that mimic video games (Brotman & Moore, 2008; Farenga & Joyce, 1997; Hanson, 2009) and, because virtual laboratories share a similar interface, males might be more open to and perceive greater functionality in equipment that engages them. The virtual laboratory interface, as in gaming, gives the user more control over the results and, as Wolf quipped, “males prefer to have a sense of control over the experience and that such control is a motivating factor for them." (2006, p. 118). On the other hand, females did not seem to be as affected by the medium for learning.

Teacher Support

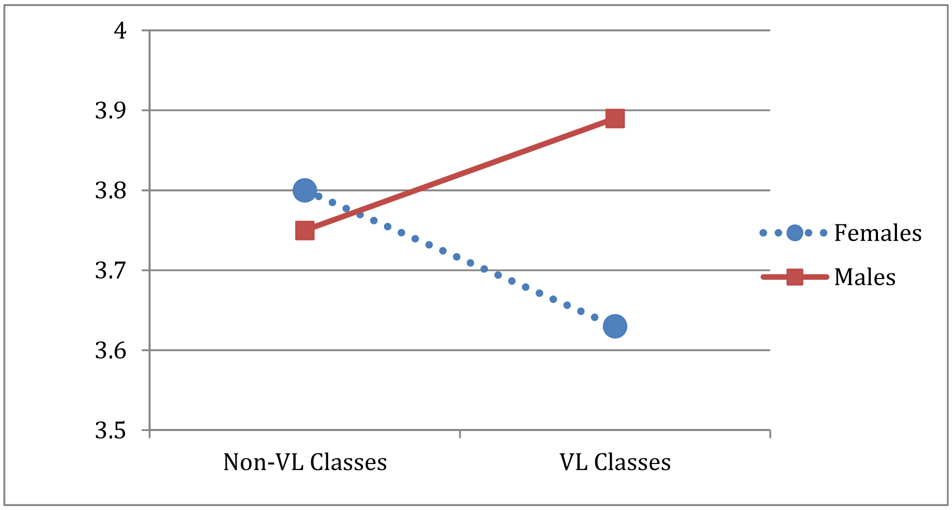

Figure 4.5 Differential Effectiveness of Virtual Laboratories for Females and Males for the Learning Environment Scale of Teacher Support

The statistically significant (p<0.01) interaction between instructional method and sex is shown for Teacher Support in Figure 4.5, which is a graphical representation of the result in Table 4.7. Males perceived greater Teacher Support in VL classes than in non-VL classes. This finding also appears in other studies (Khoo & Fraser, 2008; Raaflaub & Fraser, 2002). The opposite was true for females, who perceived slightly greater Teacher Support in the non-VL classes than in VL classes. Thus, virtual laboratories were more effective for males than females, with regard to Teacher Support, while instruction without the use of virtual laboratories was slightly more effective for females rather than males.

This finding might be a reflection of the fact that males are more willing to explore innovations than females and will ask for, and therefore receive, more assistance from their teachers in so doing. In contrast, females might be more comfortable eliciting and consequently receiving teachers' assistance in the traditional environment to which they are more accustomed. Such a pattern for perceptions of increased Teacher Support by females (in traditional classrooms) replicates past research (Raaflaub & Fraser, 2002; Wong & Fraser, 1996).

Responses from student interviews did not seem to identify any differences between VL and non-VL classes in sex differences for the dimension of Teacher Support. Out of the six students interviewed, three females and two males reported that they felt a high degree of Teacher Support, regardless of instructional method. Only one student in the non-VL class admitted that she felt the teacher was unclear in his instruction. Teachers stated that they did not notice any difference between the different sexes or between the classes (VL versus non-VL).

As noted earlier (Section 4.4.2), perceptions of the definition of Teacher Support might have been blurred because of the particular setting; some students might have considered the instructions from the virtual program to be 'Teacher Support'. Therefore, an accurate assessment of student perceptions for the scale of Teacher Support is inconclusive.

Inquiry

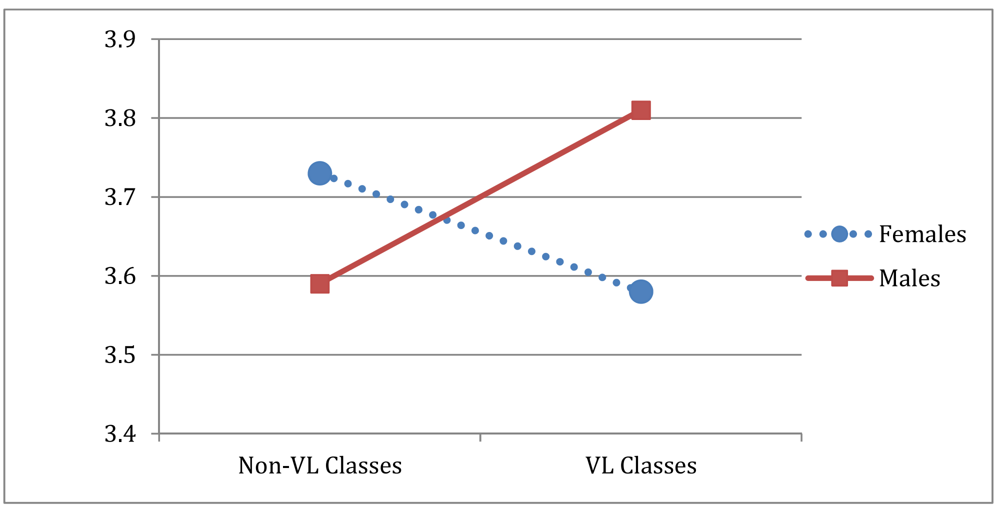

Figure 4.6 Differential Effectiveness of Virtual Laboratories for Females and Males for the Attitude Scale of Inquiry

Figure 4.6 illustrates the interpretation of the interaction between instructional method and sex (see Table 4.7) in terms of Inquiry: virtual laboratories were differentially effective for different sexes, with greater effectiveness for males than for females, while non-VL classes were slightly more effective for females than for males. In other words, males perceived greater Inquiry with virtual laboratories compared with traditional laboratory activities. While females also had positive perceptions for Inquiry, they perceived relatively less Inquiry with virtual laboratories than with traditional methods. Support for this finding is evident from Wolf and Fraser's (2008) study that reported the same pattern of more positive attitudes for males than for females in an inquiry setting, as compared to slightly more positive attitudes for females than for males in a non-inquiry setting.

Qualitative data also supported this finding. Students and teachers alike agreed males seemed to engage in experiential, inquiry-driven activities and therefore perceived more Inquiry, but that females were liable to follow through with the work required and gain more of an understanding from the activities, as demanded by more traditional environments. The delineation between initial interest in an activity and the motivation to understand the content of the activity, as well as follow through with task completion, was a theme previously noted in qualitative data at the conclusion of Sections 4.4.2 and 4.4.3. In this section, the delineation is divided along sex differences. Interviewees observed that males tended to engage because of initial interest of a novel activity (i.e. virtual laboratories), while females were more motivated to understand content and complete tasks, regardless of the activity, and that females might even be intimidated by such novel activities.

By definition, an inquiry-based experience takes place during the initiation of an activity, and therefore it refers to the initial interest that drives students to investigate independently (Edelson, Gordin, & Pea, 1999). Teacher M observed how boys are "…doing less mental processing" compared to girls, but that boys are more aroused by inquiry-based laboratories. In comparing sexes, Lara stated, "…whereas males, they're a little more hands-on, they're really excited to get into things and they just can't wait." Qualitative data indicated that males engaged in such inquiry, which supports the higher Inquiry score for males in Figure 4.6. Females, interviewees noticed, have a "little more control", "were more quiet", and would "wait patiently" to engage in novel activities, such as virtual laboratories, and would be almost apprehensive; this explains the lower Inquiry score (Figure 4.6) for females in the VL-classes. In the non-VL classes, the difference between the sexes was not as apparent, perhaps because of the lack of a novel activity to stimulate Inquiry in males and dampen Inquiry amongst females.

The trend for all three significant interactions is that there were greater differences between males and females in VL classes than in non-VL classes. Males consistently scored higher in the VL classes than did the females, whereas females consistently scored higher in the non-VL classes than did the males. This is a noteworthy pattern in that virtual laboratories seemed to be more beneficial for males than females with regard to perceptions of the learning environment (on two scales, Material Environment and Teacher Support) and attitudes (Inquiry), but females tended to fare better in more traditional learning environments without such technological interventions as indicated by numerous studies (Aldridge & Fraser, 2008; Kijkosol, 2005; Koul, Fisher, & Shaw, 2011; Wolf & Fraser, 2008; Wong & Fraser, 1996).

Furthermore, as displayed in Figures 4.4–4.6, differences between males and females for the scales showing significant interactions (Material Environment, Teacher Support, and Inquiry) were less pronounced in non-VL classes than in VL classes. This makes sense because recent literature (Koul, Fisher, & Shaw, 2011; Scantlebury, 2012; Wolf & Fraser, 2008) negates the idea that males prefer and perform better in science classes; therefore, in the non-VL classes, there is not as much of a difference between the sexes. However, once the environment is changed through technological intervention, males might embrace the stimulus (i.e. virtual laboratories) more than females and thus perceive a more positive learning environment. Teacher A detected this subtlety, "Perhaps there was a slightly greater interest on the boys part, simply because some of the labs were much like a video game [i.e. a technological innovation]."

4.5 Summary

This chapter reported results related to my study's research questions, including validation of the instrument used, associations between the learning environment and student outcomes, the effectiveness of virtual laboratories, and their differential effectiveness for different sexes.

The Laboratory Assessment in Genetics (LAG), the instrument used for this study, contains scales from two learning environment questionnaires (the SLEI and TROFLEI) and an attitude questionnaire (the TOSRA), and some achievement items. Validation of the LAG was based on 322 US students in 12 grade 8–10 classes.

Principal axis factor analysis with varimax rotation and Kaiser normalization led to a reduction in the number of items on the LAG from 64 to 54, which increased the validity and reliability of the six learning environment and two attitude scales. All remaining items had a factor loading of 0.40 or higher on their own scale and lower than 0.40 on any other scale; the total variance was 55.05% for all scales. Use of Cronbach's alpha reliability coefficient confirmed strong reliability for each of the SLEI, TROFLEI, and TOSRA scales, as well as for the achievement items; Cronbach alpha coefficients ranged from 0.76–0.91 with the individual as the unit of analysis and 0.85–0.97 with the class as the unit of analysis. Discriminant validity analysis supported the unique nature of each learning environment and attitude scale. ANOVA results also indicated that all the learning environment scales could differentiate between the perceptions of students in different classrooms. All these results supported the validity and reliability of these scales for use with this sample and add to past research that also validated scales from the SLEI (Fraser, Giddings, & McRobbie, 1995; Lightburn & Fraser, 2007; Martin-Dunlop & Fraser, 2007), the TROFLEI (Aldridge, Dorman, & Fraser, 2004; 2003; Gupta & Koul, 2007) and the TOSRA (Aldridge & Fraser, 2003; Fraser, 1981; Fraser, Giddings, & McRobbie, 1995; Koul, Fisher, & Shaw, 2011; Wolf & Fraser, 2008).

Associations between learning environment and the two student outcomes of attitudes and achievement were also reported using simple and multiple correlation analyses with the individual as the unit of analysis. All six learning environment scales showed positive correlations with the two attitude scales (Inquiry and Enjoyment), whereas multiple regression analysis revealed that Material Environment, Teacher Support, and Investigation were significant independent predictors of Inquiry; all scales except for Differentiation were significant independent predictors of Enjoyment. Integration, Material Environment, and Teacher Support correlated positively with achievement, and Differentiation showed a negative correlation with achievement. Multiple correlation analyses of the SLEI and TROFLEI scales with achievement was statistically significant. Integration, Material Environment, and Differentiation were also positive independent predictors of achievement, even though Differentiation resulted in a significant negative bivariate association with achievement. Overall, these results show strong links between learning environment and attitude scales, and moderate links with achievement; this is supported by past research (Fraser, 2012; Lightburn & Fraser, 2007; Martin-Dunlop & Fraser, 2007).

Finally, the effectiveness of virtual laboratories was investigated for LAG scales. Differences in LAG scale scores between instructional methods and sexes were examined using a two-way multivariate analysis of variance (MANOVA). Because the multivariate test using Wilks' lambda criterion yielded statistically significant differences for the set of dependent variables, the individual, univariate two-way ANOVA was interpreted separately for each dependent variable (students' perceptions of their learning environment, their attitudes, and achievement), with the student as the unit of analysis. Effect sizes were also calculated to quantify the size of instructional differences and sex differences. This analysis revealed no significant differences for instructional method, and moderate significant sex differences, with males reporting more positively for the scales of Integration, Differentiation, and Enjoyment.

Small and statistically significant interactions were found between instructional method and sex for three of the eight scales: Material Environment, Teacher Support, and Inquiry. For each of the three scales showing significant interactions, males consistently scored higher in the VL classes than did the females whereas, in the non-VL classes, males and females consistently scored nearly equally. The more positive classroom perceptions amongst females, as compared to males, that emerged in this study reflect similar results to those reported in past research (Aldridge & Fraser, 2008; Kijkosol, 2005; Koul, Fisher, & Shaw, 2011; Wolf & Fraser, 2008; Wong & Fraser, 1996).

Further interpretation of these results is discussed in the following chapter. The significance of these results, their implications for educational research and the classroom, limitations of this study, and suggestions for future research are all considered in the next chapter as well.

Chapter 5

Discussion

"Intuition becomes increasingly valuable in the new information society precisely because there is so much data." – John Naisbitt

5.1 Introduction

The aim of the current study was to evaluate the effectiveness of virtual laboratories, an educational innovation, in terms of students' perceptions of the learning environment, their attitudes towards science and their achievement in science. The differential effectiveness of such virtual laboratories was also explored for males versus females.

Previous chapters included the rationale for this study in Chapter 1, the literature that provided the context for this study in Chapter 2, the research methods used to implement the study in Chapter 3, and the results for the four research questions that guided this study in Chapter 4.

This chapter will first summarize the earlier chapters regarding research methods and results (Section 5.2), explicate the significance of the results and implications for educational research and practice (Section 5.3), point out the limitations of this study, suggest directions for further research (Section 5.4), and provide a final conclusion for the study (5.5).

5.2 Overview of Thesis

This study was first conceptualized based upon the researcher's anecdotal observation that the interest of students not normally engaged in science classes was piqued by the use of virtual laboratories. Therefore, the researcher set out to test this initial observation methodically to determine if virtual laboratories were indeed effective in increasing students' positive perceptions of the classroom, their attitudes, and levels of achievement. Because this phenomenon seemed to initially manifest especially for males, the researcher also wished to test differential effectiveness of virtual laboratories for male and female students.

The rationale for this study is based on a combination of improved standards in science education, particularly for the topic of genetics, and the lack of improvement in the resources necessary to enable students to attain those higher standards. Virtual laboratories represent a possible method to narrow the gap between lack of resources and higher standards in science education in that they allow students to experience laboratory environments and experiments that would not otherwise be possible in a high school classroom but with which students are required to be familiar.

First, the relevant literature was reviewed concerning learning environments, the framework for this study, and one of the measurements of effectiveness for virtual laboratories. The field of learning environments seeks to understand the effects of the psychosocial aspects of the classroom on learning, from the student's perspective. Over the last 40 years, the field of learning environments has become more important in educational research and, along with its development, numerous important questionnaires have emerged.

Next, the role of students' attitudes towards science was explored by defining the term 'attitude', explaining the assessment of attitudes, and reviewing the effect of various educational interventions on students' attitudes. Attitudes constituted another criterion of effectiveness for virtual laboratories. The issue of student sex in science education was also considered because girls and boys might respond differently to virtual laboratories in terms of their perceptions of and attitudes towards their classes. As well, because research reveals a gender gap in science achievement (Hill, Corbett, & St. Rose, 2010; National Center for Educational Statistics (NCES), 2012a; Scantlebury, 2012), it was deemed appropriate to investigate the differential effectiveness of virtual laboratories for different sexes.

Finally, the topic of virtual laboratories was addressed within the context of educational technology. Virtual laboratories are defined as electronic workspaces that are based on interactive simulations of scientific experiments. Benefits include the increased emphasis on conceptual understanding and reduced reliance on constraints, such as time, safety hazards, geographic distance, and cost. While technological interventions in the classroom are often predicted to be more useful than studies have shown (Russell, 1999), they are not generally detrimental to students' learning and they are therefore considered to be effective alternatives for certain educational experiences.

The remainder of this section reviews the research methods and key findings for each research question (Sections 5.2.1–5.2.4) and also summarizes the qualitative data gathered from students (5.2.5) and from teachers (5.2.6).

5.2.1 Research Question 1

> Research Question 1: *Are scales from the Test Of Science Related Attitudes (TOSRA), Science Laboratory Environment Inventory (SLEI), and Technology-Rich Outcomes-Focused Learning Environment Inventory (TROFLEI) questionnaires valid and reliable when used with a sample of high school students taking biology in the US?*

In order to assess the effect of virtual laboratories on three dependent variables (perceptions of the learning environment, attitudes, and achievement), appropriate instruments were needed to measure each variable. Scales were adopted and adapted from various previously validated questionnaires for inclusion in the Laboratory Assessment in Genetics (LAG), but the LAG's validity and reliability was checked for use with the sample in this study in order to be used as an instrument for this particular instance.

Scales to measure the learning environment were taken from the Science Laboratory Environment Inventory (SLEI) (Fraser, et al., 1992) and the Technology-Rich Outcomes-Focused Learning Environment Inventory (TROFLEI) (Aldridge & Fraser, 2003), both of which have been validated in numerous countries, in different content areas, and with various age levels, as described in Section 2.2.2 (Aldridge & Fraser, 2003; Fraser, 2012; Fraser, Giddings, & McRobbie, 1992). Scales to measure students' attitudes were borrowed from the Test Of Science Related Attitudes (TOSRA), which also has been validated in numerous countries, in different content areas, and with various age levels, as described in Section 2.3.2 (Fraser, 1981; Fraser, Aldridge, & Adolphe, 2010; Ogbuehi & Fraser, 2007; Welch et al., 2012; Wong & Fraser, 1996). Items in each of these scales were modified; for instance, negatively-worded TOSRA items were worded positively, wording in a learning environment scales was generalized to include their application to virtual laboratories, and some items in all scales were removed or added to ensure a consistent number of eight items per scale. Validity and reliability analysis were also necessary to check the validity of these modifications.

To assess the validity and reliability of the scales, the factor structures of the WIHIC and TOSRA items were checked using principal axis factoring with varimax rotation for the sample of 322 students in 12 classes. Next, the internal consistency reliability for each SLEI, TROFLEI, and TOSRA scale was used to measure the extent to which items in a given scale assess the same construct. As well, the mean correlation of a scale with the other learning environment and attitude scales was used an index to assess the uniqueness of each scale and ensure discriminant validity. Furthermore, the ability of each SLEI and TROFLEI scale to distinguish between different classrooms was assessed using an ANOVA.

An achievement scale was constructed by the researcher, consisting of 10 items, each borrowed from previously validated standardized state examinations in biology. The items were all related to the topic of genetics. To assess validity of this scale, achievement scores were plotted in a histogram to assess the overall normality of scores in addition to comparing the means of certain items to the means obtained for much larger populations that answered the same items.

Key findings for the validity and reliability of scales used for the LAG reported in Section 4.2 are summarized below:

- The optimal factor solution occurred for the set of 54 items in 8 scales from the SLEI, TROFLEI, and TOSRA, after the removal of 10 items to increase validity, with a total variance of 55.05% for all scales.
- The 54 remaining items from the SLEI, TROFLEI, and TOSRA showed high reliability and satisfactory discriminant validity for two units of analysis (individual and class mean).
- The learning environment scales (SLEI, TROFLEI) were able to differentiate between the perceptions of students in different classrooms.

- Achievement scores showed a close-to-normal distribution and scores on selected items were similar to scores for a larger population for the same items.

As with past research, modified scales from the SLEI (Fraser, Giddings, & McRobbie, 1992), TROFLEI (Aldridge & Fraser, 2003), and TOSRA (Fraser, 1981) showed strong validity and reliability. The findings suggest that these scales can be effectively utilized to assess student perceptions and attitudes in high school classrooms in the US. The almost normal distribution of achievement scores is in line with patterns of scores from most standardized examinations (Herrnstein & Murray, 1996) and scores on selected items were similar to those of a larger population (Massachusetts Comprehensive Assessment System (MCAS), 2009), therefore suggesting that such items are appropriate measures of achievement in genetics for high school students in the US.

5.2.2 Research Question 2

Research Question 2: *Are there associations between the perceived classroom learning environment and the student outcomes of attitudes towards and achievement in science?*

Associations between the learning environment and student outcomes (attitudes and achievement) were investigated using simple correlation and multiple regression analyses with a sample of 322 students in 12 classes, and using the individual means as the unit of analysis.

Key findings for the associations between the learning environment (as measured by the SLEI and TROFLEI, a total of six scales) and attitudes (as measured by two TOSRA scales) were reported in Section 4.3.1 are summarized below:

- All six learning environment scales correlated significantly and positively with both attitude scales.
- The multiple correlation of the SLEI and TROFLEI scales with attitude scales was statistically significant.
- Material Environment, Teacher Support, and Investigation were positive, independent predictors of the Inquiry attitude scale, and five scales

(Integration, Material Environment, Teacher Support, Task Orientation, Investigation) were positive, independent predictors of the Enjoyment attitude scale.

Key findings for the associations between the learning environment (as measured by six SLEI and TROFLEI scales) and achievement reported in Section 4.3.2 are listed below:

- Integration, Material Environment, and Teacher Support correlated significantly and positively with achievement, while Differentiation correlated significantly and negatively with achievement.
- The multiple correlation of the SLEI and TROFLEI scales with achievement was statistically significant.
- Integration, Material Environment, and Differentiation were positive, independent predictors of achievement.

The overall positive associations between learning environment and student outcomes of attitude and achievement have been replicated many times in past research (Fraser, 2012; Lightburn & Fraser, 2007; Martin-Dunlop & Fraser, 2007). The negative correlation between Differentiation and achievement was surprising and is further discussed in Section 4.3.2; however, this finding warrants further investigation in future research.

5.2.3 Research Questions 3 and 4

Research Question 3: *Is the use of virtual laboratories in high school science classes effective in terms of students'*

d) perceptions of their learning environment

e) attitudes towards science, and

f) academic achievement in genetics?

Research Question 4: *Is the use of virtual laboratories differentially effective for males and females in terms of students'*

d) perceptions of their learning environment *e) attitudes towards science, and*

f) academic achievement in genetics?

The intervention investigated in this study involved six teachers each teaching at least one class that used virtual laboratories and at least one class that did not, over a period of about 2–10 weeks. Altogether, there were 322 students, who were diverse in ability and socio-economic status, in 12 US grade 8–10 classes. The virtual laboratories available for application in the classroom were chosen by the researcher for their emphasis on inquiry skills as well as complex conceptual understanding of techniques not otherwise available in a high school classroom.

To explore the differences between modes of instruction, and also between males and females, as well as to find interactions between instructional method and sex, a two-way MANOVA was used for the set of learning environment, attitude, and achievement scales. The multivariate test using Wilks' lambda criterion yielded significant differences, and so the univariate ANOVA was interpreted for each scale.

Key findings for the differences between the two instructional methods in terms of learning environment and student outcomes from Section 4.4.2 are summarized below:

- No statistically significant differences existed for instructional method (i.e. between student scores in VL classes versus non-VL classes) for any scale.

- For Teacher Support, Task Orientation, Investigation, Differentiation, Inquiry, and Enjoyment scales, scores were slightly higher for VL classes than for non-VL classes, and Integration and Material Environment scores were slightly lower for VL classes than for non-VL classes, but these findings were not statistically significant.

- The largest effect sizes for differences between instructional methods occurred for the scales of Integration (-0.12 standard deviations) and Differentiation (0.12 standard deviations). Other scales had effect sizes of less than 0.10 standard deviations.

These findings replicate those from other studies reporting that virtual laboratories offered neither advantages nor disadvantages over other methods of instruction (Cobb et al., 2009; Cross & Cross, 2004; Javidi & Sheybani, 2006; Russell, 1999; Stuckey-Mickell & Stuckey-Danner, 2007), and suggest that virtual laboratories might be useful as a supplementary tool in science classrooms, rather as a substitute for more traditional methods, such as hands-on laboratories (Nedic, Machotka, & Nafalski, 2003; Raineri, 2001; Toth, Morrow, & Ludvico, 2009; Yu, Brown, & Billet, 2005). Qualitative data were consistent with the quantitative results; a more detailed summary of this can be found in Section 5.2.4. However, a subtle pattern emerged from the qualitative data: higher levels of Inquiry were perceived with hands-on laboratories than with virtual laboratories, but the level of inquiry did not necessarily result in greater understanding while several students who used virtual laboratories did show such understanding.

Key findings for the differences between males and females, regardless of instructional method (see Section 4.43), were:

- Significant but moderate differences were found between males and females for the learning environment scales of Integration (0.22 standard deviations) and Differentiation (0.24 standard deviations) and for the attitude scale of Enjoyment (0.33 standard deviations).
- All significant differences revealed scores that were higher for males than for females.
- For the rest of the scales not showing significant differences, males also scored higher than females, except for the scale of Task Orientation (-0.14 standard deviations).
- Modest effect sizes for other differences between the sexes occurred for the scales of Material Environment (0.20 standard deviations), Investigation (0.16 standard deviations), and Inquiry (0.19 standard deviations). Other scales had effect sizes of less than 0.10 standard deviations.

The finding that males perceived the learning environment more positively than females can be contrasted with past research (Fraser, Giddings, & McRobbie, 1995; Kijkosol, 2005) and requires further investigation. However, past research indicates more positive attitudes for males towards science than for females (Neathery, 1997; Oakes, 1990; Raaflaub & Fraser, 2002; Wolf & Fraser, 2008), and this is consistent with my findings. The finding that no significant differences existed for different sexes regarding achievement is also consistent with recent research suggesting a narrowing of the gender gap in science achievement (Gupta & Koul, 2007; Neathery, 1997; Oakes, 1990; Osborne, Simon, & Collins, 2003). Qualitative data revealed that, although males enjoy scientific, investigative activities more than females, females might be the ones who are more motivated to complete the work (as measured by Task Orientation). More details for qualitative data are summarized in Section 5.2.4.

Key findings for the differential effectiveness of the instructional methods for males and females in terms of learning environment and student outcomes (Section 4.4.4) are summarized below:

- A significant Instructional Method x Sex interaction emerged for the two learning environment scales of Material Environment and Teacher Support and for the attitude scale of Inquiry, all with small effect sizes (the amount of variance accounted for being 0.03, 0.02, and 0.03, respectively).

- Virtual laboratories were more effective for males than for females for Material Environment, Teacher Support, and Inquiry, but instruction without the use of virtual laboratories was nearly equally effective for males and females on all scales.

Similar patterns were described by Wolf and Fraser (2008) in that males perceived a more positive learning environment and attitudes in the class with an inquiry-based intervention than in the class without the intervention, but that generally the opposite was true for females. Other studies also reported differential effectiveness of an intervention for males over females for the dimensions of Material Environment (Quek, Wong, & Fraser, 2005), Teacher Support (Khoo & Fraser, 2008; Raaflaub & Fraser, 2002), and Inquiry (Wolf & Fraser, 2008). In general, more positive perceptions of the learning environment for females in traditional classrooms have been noted (Fraser, Giddings, & McRobbie, 1995; Kijkosol, 2005; Raaflaub & Fraser, 2002; Wong & Fraser, 1996).

Qualitative data indicated that males were keen to plunge into experiments that they perceived to contain high levels of inquiry, whereas females were somewhat apprehensive. Both students and teachers observed that, in general, males are more accepting of, and excited by, interventions, especially technological ones, than are females, which is supported by past research (Brotman & Moore, 2008; Farenga & Joyce, 1997; Hanson, 2009).

As my investigation of the differential effectiveness of virtual laboratories for males and females involved a sample of only 322 students, findings should be considered tentative until they are replicated with larger samples in future research (see Section 5.4).

5.2.4 Summary of Qualitative Data

The method of gathering qualitative data was through semi-structured interviews of students who volunteered to be contacted via email over the summer break. Four students interviewed were from VL classes, consisting of two males and two females, and two students interviewed were from non-VL classes, both of whom were females. All interviewees received parental permission to participate. Interview questions, which were written by the researcher and modeled after the questionnaire items used in this study, were used to explore student perceptions, attitudes, and sense of achievement (see interview questions in Appendices B and C). A summary of the overall responses (Section 4.4) for students who experienced each of the instructional methods (VL and non-VL) is provided in Table 5.1. To be sensitive to students, the researcher refrained from asking questions regarding Differentiation because this scale measures the extent to which class work is personalized for students with different abilities.

Table 5.1 Summary of Student Interview Results for Students Experiencing each Instructional Method for each Learning Environment and Outcome Variable (Based on Section 4.4)

Learning Environment Scale/Outcome	Comments from Students in VL classes	Comments from Students in non-VL classes
Integration	Students cited numerous examples of laboratory activities that connected to concepts recently learned in the classroom or used an introduction to concepts learned subsequently.	Mixed responses revealed that most laboratory activities were related to concepts learned in class, but some were not. Some students were not able to explain how the activity fitted with the topic they learned.
Material Environment	Students cited examples about how some traditional laboratory equipment (microscopes) was old and caused problems, which took away time from learning. Many students also commented on the state of technological equipment (computers, Internet) with mixed responses as to their functionality.	Students reported that equipment was in fine working order, except that sometimes the Internet connection was slow.
Teacher Support	Students recounted that the teacher was always helpful whenever students had questions but that the teacher did not tell them exactly what to do. Examples included evidence of forming personal relationships.	Some reported that the teacher was helpful. Others felt that, while the teacher was knowledgeable, knowledge was not transmitted clearly. They wished for the teacher to provide more instruction.
Task Orientation	Students reported their desires to finish what they started and finish work on time, and described feeling positive as a result.	Students reported their desires to finish what they started and finish work on time, and described feeling positive as a result.
Investigation	Students reported that they were given diagrams and graphs to interpret evidence for investigations, and that they had control over their experiments.	This dimension was not addressed by the interviewees.
Inquiry (Attitude)	Students stated their preferences to experiment themselves rather than be told about a result. However, they preferred to be given a hypothesis to test, rather than construct one on their own.	Students stated their preferences to experiment themselves rather than be told about a result, as well as the opportunity to find solutions together with other students.
Enjoyment (Attitude)	All students described their enjoyment of science classes and looked forward to them. As examples, some cited VLs and others cited hands-on laboratories. All students reported satisfaction about being placed in the VL class. Some students admitted to trying VLs at home.	Students reported that, because the teacher was boring and the laboratory activities were not clear, the class was not much 'fun.' Students stated a preference to be placed in the VL class, even though they enjoyed the 'hands-on' factor of experiments. No students reported trying experiments at home.
Achievement	Students found the content challenging, some admitted needing the teacher's help and not all were able to explain the concepts. Students reported that they generally understood the material in genetics and achieved well in this topic. Some students pointed to VLs in assisting their understanding because of the instant feedback.	Students found the content challenging and had difficulty explaining the concepts. However, they stated that they generally understood the material in genetics and achieved well in this topic.

At the end of each interview, the researcher informed the interviewer that the quantitative data did not show major differences between VL and non-VL classes, and asked the interviewee for his or her thoughts about why no such differences appeared. The following is a summary of the key points that the interviewees mentioned as explanations for the lack of evidence for the effectiveness of virtual laboratories (see Section 4.4.2).

- While the lessons were stimulating, the tests were difficult.
- Instructional effectiveness depends more on the teacher, rather than the method.
- The degree of effectiveness depends on the type of laboratory investigation and whether or not there were differences between the virtual ones and the real ones.
- Virtual laboratories were not conducted often enough.

Students were also asked to comment on differences between males and females that they perceived during laboratory activities (see Section 4.4.3). Additionally, the researcher noted whether statements were made by males or females. These responses were categorized and summarized by the researcher into the dimensions listed in Table 5.2.

Mostly, the qualitative data supported the quantitative results but provided some insight regarding patterns of differences between the sexes, such as the observation that males tended to initiate experiments and relish handling equipment and specimens. In contrast, while initially apprehensive, females would follow-through on the task required and focus on the purpose of the experiment. It follows that technological interventions, such as virtual laboratories, might perhaps serve to distract females from the work that they set out to do, while new media engage males, causing the former to have more positive perceptions in a traditional learning environment and the latter to have more positive perceptions in an altered learning environment. However, there were not enough male interviewees to reach a solid conclusion via the qualitative data and these qualitative results should be verified with a larger sample in a future study.

Table 5.2 Summary of Student Interview Results for Sex Differences for each Learning Environment and Outcome Variable

Learning Environment Scale/ Student Outcomes	Perceived Sex Differences
Integration	No differences between the sexes was noted for this scale.
Material Environment	Males mentioned the audio and visual effects as a positive feature of VLs but no other differences were noted between the sexes regarding the functionality of equipment.
Teacher Support	Females preferred to have the teacher more involved in any activity to better guide them, whereas males tended to go at it alone. Females also described their personal relationship with teachers whereas males simply stated whether or not teachers were helpful. This finding tentatively explains the differences found in the non-VL classes but not in the VL classes.
Task Orientation	Females reported that males would dive right into an activity but often leave unfinished the follow-through work, which the females would complete.
Investigation	No differences between the sexes was noted for this scale.
Inquiry (Attitude)	Males seemed motivated by activities that allowed them to jump in and test things out themselves, whereas females preferred a set of prescribed instructions. This was also noted by female students about their male peers.
Enjoyment (Attitude)	Males were reported as being noisy, which can be interpreted as evidence of their enjoyment of laboratory activities. Otherwise, both sexes seemed to enjoy VLs and non-VLs.
Achievement	Students reported that males and females at achieved at equal levels. Scores posted by the teachers for all to see also revealed this.

5.2.5 Teachers' Perspectives Regarding the Learning Environment and Student Outcomes

While teachers were not identified as the subjects of my study, nor were they included as the unit of analysis, their feedback about the implementation of the study adds valuable insight to the current data. Six teachers, including the researcher, were involved in the evaluation of the effectiveness of virtual laboratories and were asked to comment about the various logistical aspects of this study, as well as note their own observations about students' perceptions of the learning environment, attitudes, and achievement, as well as gender issues. Four of the six teachers responded, excluding the researcher to avoid introducing bias, and their comments were categorized according to the dimensions in Table 5.3.

When teachers were asked why greater differences between the two groups were not apparent in the quantitative data, they responded that confounding variables could include the amount of previous exposure that students have had to other laboratory experiences. Some schools or teachers allow more hands-on investigations whereas other school or teachers lack the resources to be able to do so and might just use texts, lectures or videos instead. As well, some teachers used other computer-based activities while implementing virtual laboratories, which might have confused students when providing their perceptions of virtual laboratories. In conclusion, whether a virtual or hands-on laboratory or a computer-based activity, the boundaries that define each of these activities were somewhat blurred. In future studies, clearer instructions about which activities should or should not be used in providing feedback about each treatment condition might produce different results.

Table 5.3 Summary of Teachers' Observations for each Learning Environment and Outcome Variable, and Gender

Learning Environment Scale/ Student Outcomes	Teachers' Observations
Integration	All teachers mentioned that they tried to align the laboratory activities with the content of what was being learned in class.
Material Environment	Some teachers noted difficulty with accessing the websites for the VLs because of a slow internet connection or because computers were in short supply. One teacher noted mentioned that VLs were advantageous for the topic of genetics because the expense and technical expertise needed to use more sophisticated equipment for hands-on laboratories in genetics are challenging.
Teacher Support	Teachers agreed with the students that assistance for the VL group was mainly about getting started but, otherwise, the VLs were self-guided. Some teachers observed that more help was needed in the non-VL group.
Task Orientation	No differences were observed between the two classes. One teacher commented that the ability to complete a task depends more on the student's motivation and ability than the instructional method. Another teacher mentioned that student motivation was a predictor of the effectiveness of VLs rather than the other way around.
Investigation	No differences between the groups were noted for this scale.
Differentiation	Teachers observed that students in the VL group were able to advance through the activities at their own pace and review parts, as necessary.
Inquiry (Attitude)	One teacher commented that because students could progress at different paces with VLs, the more skilled ones were able to progress further and experience more inquiry. Teachers agreed with students that males tended to take action right away, with VLs and non-VLs, leading to more inquiry.
Enjoyment (Attitude)	All teachers noted that VLs are a valuable *addition* to the regular classroom activities because students seemed to enjoy them, but VLs should not replace other activities. Several teachers perceived the males to be particularly engaged in VLs, more so than the females, which might be because of their familiarity with other virtual environments online and with video games.
Achievement	One teacher reported that her classes, regardless of the instructional method, perceived the genetic achievement items as being too easy. Another teacher observed that males were required to do more mental processing with VLs, as opposed to non-VLs, in that they simply explored and left the mental processing to their female partners.

5.3 Significance and Implications

The National Research Council's Committee on Science Learning: Computer Games, Simulations, and Education calls for partnerships between academic researchers, developers, entrepreneurs from the gaming industry, education practitioners, and policy makers to facilitate "rich intellectual collaboration" (National Research Council (NRC), 2011, p. 3). The results of my study add one more piece to the body of evidence amassed by these professionals about the effectiveness of virtual environments in education. The findings herein pose important implications for both the field of educational research (Section 5.3.1) and for practitioners in education (Section 5.3.2).

5.3.1 Implications for Educational Research

A leading authority in the field of educational research, Fraser (2012) advocates the incorporation of learning environment scales in evaluating the effectiveness of educational innovations because traditional measures of effectiveness (such as achievement) do not provide a complete picture of the educational process. Despite a number of recent studies (see Section 2.3), the amount of research involving assessing the impact of educational innovations on transforming the classroom learning environment is small relative to the speed at which educational innovations are being incorporated into classrooms. Thus, this study was the first of its kind to adopt a learning environment framework in which the classroom environment, in addition to achievement and attitudes, served as a criterion of effectiveness in evaluating educational innovations. Its findings contribute to the growth in research into evaluating educational innovations within the increasingly rich and diverse field of learning environments.

As the roles of and interactions between teachers, students, and instructional materials evolve, the development of robust questionnaires that are economical, valid, and reliable has become necessary for evaluating such changes. This study provided evidence for the validity and reliability of another questionnaire that assesses the impact of technological innovations in science classes on the learning environment and the student outcomes of attitudes towards science and achievement in genetics. The Laboratory Assessment in Genetics (LAG) (Appendix A), which can be administered within one class period and is also available online, is one more instrument that can be used for this purpose. While the validation of an instrument to evaluate the use of simulations or virtual laboratories is an important step in science education research, and while the instrument used in this study is focused on science learning, this research can also be of interest to a broader education community because the use of technology is not limited to science education.

Additionally, the inclusion of qualitative measures in educational research studies has become increasingly important, particularly for innovations that are implemented into classrooms around the world and in various contexts, in order to detect cultural nuances. While this study was conducted in only one country, its design is adaptable to a range of cultural school environments globally because virtual laboratories, and the LAG questionnaire, are available online, and because qualitative evidence was also included. The methodology of this study can be repeated with adjustments, as described in Section 5.4.

The findings of this study also confirmed positive associations between learning environment dimensions and attitudes as reported in previous studies (Aldridge & Fraser, 2003; Fraser, 2012; Lightburn & Fraser, 2007; Wolf & Fraser, 2008). Addressing student attitudes towards science in the early high school years (grades 8–10) is important because studies have pointed to the decline in such attitudes at this time (Oliver & Venville, 2011; Tytler & Osborne, 2012). Based on the results of this study, males who engaged in VLs exhibited more positive attitudes (regarding inquiry) towards the class. Because Material Environment, Teacher Support, and Investigation were positive, independent predictors of the Inquiry attitude scale, these findings further highlight the importance of considering the field of learning environments in future research.

Mainly, this study is important because it evaluated the effectiveness of an educational innovation in terms of students' perceptions of the learning environment and learning outcomes. The results provided quantitative evidence that virtual laboratories are no more effective for students than any other instructional media. On the other hand, virtual laboratories were not shown to be ineffective and, therefore, they offer one efficient, economical, and stimulating approach to experimentation in science classes limited in resources, equipment, and time. Further research on the effectiveness of other technological interventions is needed to ensure that negative impacts on education do not emerge.

Of interest were significant differences between the perceptions and attitudes of males and females in this study. Males perceived greater levels of Integration, Differentiation, and Enjoyment than females. These differences build upon the well-studied topic of gender imbalance in science education (Scantlebury, 2012) and could provide direction for future research in this area, especially with regard to technological innovations in the classrooms.

A degree of effectiveness for virtual laboratories was indeed suggested by the results of this study, but only for a subsample: for males in VL classes versus males in non-VL classes. The positive value of virtual laboratories, however, was not evident for females in VL classes relative to non-VL classes. However, this could be an area of investigation in future research.

Finally, the findings from this study as well as those from similar studies (Raineri, 2001; Toth, Morrow, & Ludvico, 2009) suggest the need for expanded development of virtual laboratories, especially regarding the aspects of inquiry, resources, and teacher support, as well as further evaluative research regarding their effects among students in secondary and post-secondary classrooms.

5.3.2 Implications for Educational Practitioners

The outcomes of this study have the potential to inform policy-makers who call for technological advancements in education and for administrators and teachers who could implement these technological tools in their classrooms.

Innovations that alter the dynamic of the traditional classroom, from collaborative teaching to the incorporation of technology, such as online textbooks and virtual laboratories to instances of 'learning without walls', such as fully online classes or distance education, have been heralded as a solution for increasing student motivation and for initiating a paradigm shift in defining the learning environment. However, the results of this study do not fulfill this promise. The results of this study simply point to the value of virtual laboratories in providing an equally beneficial experience for students in alternative educational environments, such as online or distance education, or for students in schools that lack resources for hands-on laboratories.

Perhaps the most important implication of this study is that it provides a practical model for teachers for integrating virtual laboratories into traditional high school classrooms. The results of this study suggest that virtual laboratories can be incorporated confidently into science curricula without detrimental effects, in contrast to fears that virtual learning is disadvantageous to students. Added benefits include that virtual laboratories are an efficient, safe, and cost-effective alternative to running physical laboratories, that students are able to learn independently and, more importantly, that they are exposed to laboratory equipment, procedures, and skills that they could not otherwise access because of limited funding and maintenance.

Because the use of virtual laboratories is at least as effective as other instructional media, teachers can add this innovation to their repertoire of presentation tools. Although teachers often feel pressure to complete their curricula in the time allotted, and therefore might be hesitant to try new technologies, the justification for attempting to include virtual laboratories as part of their teaching repertoire is that it might ultimately save time, relative to attempting to conduct a physical experiment with equipment that also can intimidate the teacher.

Moreover, the use of virtual environments demonstrates to students that technology, gaming, and virtual activities can be used for learning as well as for pastime activities. This might serve as a valuable reference for the developers of such technology because they can continue to improve and market their products with the knowledge that such interventions are not detrimental or distracting to students' educational experiences. Furthermore, quantitative data and the qualitative data gathered in this study could provide direction for refining virtual laboratories, such as increasing the sense of investigation for all students, building on the personalized feedback that the system affords, and incorporating female-friendly aspects into such an experience.

Based on the findings in this study, males who engaged in virtual laboratories exhibited significantly more positive attitudes (Inquiry) toward the class than males in non-VL classes. Also, because Material Environment, Teacher Support, and Investigation were positive, independent predictors of the Inquiry attitude scale, improving these aspects of the learning environment could result in improved attitudes amongst males in classrooms with such technological interventions, a valuable observation for educational practitioners to note. Furthermore, by redesigning virtual laboratories to incorporate the preferences of females, who appreciate certain aspects of VLs, such as personalized and immediate feedback, it is possible that the attitudes among females could also improve in inquiry classes. To further engage females, perhaps product developers could merge virtual experimentation with the realm of social media to allow for greater collaboration and interpersonal interactions as well as interactions with inanimate objects. In general, improving students' attitudes toward science at this stage might lead to increased overall interest in science that influences the rest of their science courses throughout high school and beyond.

Significant differences also emerged between males and females in this study, regardless of the instructional method. Males perceived greater Integration, Differentiation, and Enjoyment in science classes. Teachers can utilize these findings in their own classrooms to ensure a more gender-fair environment by stressing the integration of laboratory work with class work with females, by providing females with more opportunities for differentiated learning, and by incorporating activities that are of greater interest to females.

With improvement in the perceptions of the learning environment and attitudes for males, and without less positive perceptions of the learning environment, attitudes, and achievement for males or females, it would seem that using virtual laboratories could be an effective method for teaching laboratory-based content by introducing students to specialized techniques not otherwise experienced in a high school classroom setting. This allows teachers to expose students to scientific inquiry in the real world without sacrificing numerous class periods by attempting the techniques on their own (if they are even feasible or affordable at the high school level), and without the safety hazards associated with such activities. Ultimately, while it is possible that this educational innovation can be disregarded as being of limited benefit to students in today's technological society, further research into the development and evaluation of virtual laboratories is necessary.

5.4 Limitations and Suggestions for Further Research

Human error affects all experiments, and my study, which not only involved a human researcher but also human subjects, was no less error-prone. This section revisits and summarizes the limitations of this study that were described in greater detail in Section 3.7. As a result of the quantitative and qualitative data, other limitations also arose, which were not addressed in Section 3.7 but are described in this section. Additionally, this section recommends suggestions for future research on the effectiveness of virtual laboratories based on each limitation noted for this study.

The sample for this study consisted of 322 American high school students. While there was much diversity amongst the students in this sample, the size of the sample was relatively small. An even larger sample would have increased statistical power and could have permitted differences to be identified more confidently. As well, a larger sample would have reduced individual idiosyncrasies that could have existed with this group of students. Similarly, a sample of interviewees greater in number and diversity would have been desirable and likely to increase insight into the quantitative results.

Part of the reason why the sample size was limited was a loss of opportunities that would have allowed more students to respond to the questionnaire. As noted in Section 3.7.1, the link to the online questionnaire was non-operational at the time when two teachers intended to administer it. Because the school year was over, time limitations prevented students from responding to the questionnaire when the link was fixed or when paper versions could have been provided. This error also limited the researcher's ability to recruit interviewees because, during the summer break, students (and teachers) are apt to neither respond to school-related requests nor remember the details of what occurred during the school year. In the future, it would be advisable for the researcher to note the closing date for the school year for each teacher, in order to ensure that the implementation of the study is completed well before that date and to allow extra time to fix any errors. Indeed, at the outset, more time should be allotted to enable increased efforts in finding participants before the implementation of the study. The suggested timetable for implementation of such a study, assuming the experimental design and preparation of materials is complete, is 8–10 months of an academic year.

Regarding the sample, the original research proposal included another group for which to investigate the differential effectiveness of virtual laboratories in addition to different sexes: minorities. However, the data collected and analyzed for this were disregarded because of contradictory results, which would decrease the validity of the conclusions based on this research. Future studies should attempt to investigate the differential effectiveness of virtual laboratories for minorities with a sample with a better representation of minority students in both the experimental and control group.

Controlling the treatment conditions was also a limiting factor in this study (see Section 3.7.2). Ideally, all conditions between the experimental and control groups should have been identical, besides for the use of virtual laboratories. Naturally, such a setup is impossible in a school setting. Nevertheless, certain conditions could have been controlled better, such as uniformity of teaching resources amongst the control group and more consistency regarding the frequency with which VLs were administered.

According to the students' perceptions, some reasons why quantitative differences between instructional methods were not apparent include the difficulty of the topic of genetics, the infrequency with which virtual laboratories were offered, and confounding variables, such as differences between teachers implementing the study and differences between the types of laboratory investigations. While some of these issues cannot be controlled for, and in the current study the researcher wished to provide some instructional freedom to allow teachers to better integrate the study with their own curriculum, future studies could include more detailed instructions regarding the timetable for the implementation of virtual laboratories and the exact types of virtual and non-virtual laboratories to be used to enable a more accurate comparison.

Other aspects of this study also pointed to the importance of the role of the teacher over the instructional method, as noted in Section 4.4 from students' responses to the interview questions. Each teacher taught both VL and non-VL classes, thereby controlling for differences between teachers. However, the precise manner in which the VL activities were integrated into the traditional classes depended on the teacher. Additionally, the degree of enthusiasm and commitment of the teacher to an alternative teaching method could have influenced student perceptions. Similarly, in another study about a web-based learning environment, researchers highlighted the role of the teacher in affecting students' perceptions and, ultimately, in the educational effectiveness of the environment (Chandra & Fisher, 2009; Eklund, Kay, & Lynch, 2003). The inclusion of both pretest and posttest administrations of a questionnaire in future studies that seek to repeat such an evaluation might alleviate some of the issues concerning differences between teachers and differences amongst laboratory activities.

Another issue related to the different treatment groups was the 'John Henry effect' mentioned in Section 2.5.5. According to the quantitative data (see Table 4.2), the mean scores measuring students' perception of the learning environment, attitudes, and achievement ranged from 2.79 to 3.92 with the student as the unit of analysis. These results demonstrate that, overall, regardless of instructional method, students tended to agree with the questionnaire statements, indicating their positive perceptions of the learning environment, positive attitudes, and above-average achievement in their science classes. Therefore, the 'John Henry effect' might explain the lack of significant differences for instructional method; the control group might have worked harder to improve their learning experience because these students (and their teachers) knew that they were competing against the group using virtual laboratories, which was assumed to produce better results.

In fact, while most teachers taught at least one class with the use of virtual laboratories and at least one class without, one teacher divided each of her classes so that half of the students in each class used virtual laboratories and the other half did not. In this instance, the potential for the 'John Henry effect' was stronger because the students in the control group saw what the students in the experimental group were doing, and they might have over-compensated for the expected difference when responding to the questionnaire.

To account for this issue in future studies, a double-blind design might produce more accurate results. Participating teachers should not be informed about the exact purpose of the study, and they should be given more precise instructions for the control group. For example, the researcher could provide alternative activities for the control group so that the comparison of students across different teachers would be uniform. Furthermore, an improved design would involve students in answering the questionnaire before the implementation of the study, in addition to answering the questionnaire upon completing the virtual laboratories or comparison instructional method.

The questionnaire itself might also be improved in a future study to enable the emergence of more accurate results. As reported by participating teachers, a number of their students complained about the length of the questionnaire. Based on the results of this study, the dimension of Differentiation could be removed from the LAG because it did not produce any significant differences for the instructional method or for the instructional method x sex interaction, and because its items were poorly understood by students, as evidenced by the interview process. Also, further clarity regarding terminology in certain items could be enhanced by defining the terms for each scale. For instance, before presenting the items for Teacher Support, instructions could have delineated what is or is not included in the reference to 'teacher'.

The researcher chose to borrow and adapt scales from previously-validated and often-used questionnaires in the field of learning environments but, in retrospect, the novel research presented in this thesis begged for the creation of a new instrument or, at least, some new scales that could more accurately measure the defining features emerging from virtual technology. Also the 10 achievement items could have been better mapped to reflect how simulations affect students' understanding of genetics. Future studies could evaluate the validity of newly-created scales that might be adapted to the implementation of diverse educational technology such as Content and Learning Management Systems, social media, and virtual experimentation.

Finally, to validly assess the effectiveness of virtual laboratories, future studies might aim to compare three groups: classes with no virtual and no physical experiments; classes with only physical experiments; and classes with only virtual experiments. A number of studies have already compared physical and virtual laboratories and many of them conclude that virtual laboratories enhance the effectiveness of physical laboratories, relative to the effectiveness of physical laboratories alone (Akpan & Strayer, 2010; Cobb, Heaney, Corcoran et al., 2009; de Jong, Linn, & Zacharia, 2013; Pyatt & Sims, 2012; Toth, 2009; Yu, Brown, & Billet, 2005; Zacharia, Olympiou, & Papaevripidou, 2008), but most of these studies did not involve lower-secondary classrooms (grades 8–10). Because secondary schools invest in better technological equipment for science experiments, it would be wise to enrich future research with studies involving such a three-way comparison.

5.5 Conclusion

This study provided numerous opportunities to learn about the process of quantitatively and qualitatively comparing students in classes using virtual laboratories with students in classes that did not, especially regarding differences between males and females in these two groups. While significant benefits were not found for students who engaged in virtual laboratories, a number of findings emerged from this study that inform future research and practice in science education.

Learning environment and attitude scales adapted from the Science Laboratory Environment Inventory (SLEI), Technology-Rich Outcomes-Focused Learning Environment Inventory (TROFLEI) questionnaires, and Test Of Science Related Attitudes (TOSRA) were found to be valid and reliable when used with a sample of US high school students taking biology. These scales have been employed in the past and can continue to be adapted to a wide variety of samples and situations.

This study also identified associations between students' perceptions of the learning environment and their attitudes and achievement. All six learning environment scales correlated significantly and positively with both attitude scales, and a number of those scales were positive, independent predictors of the attitude scales, indicating that a more positive learning environment could lead to more positive attitudes. Associations with achievement were significant for three learning environment scales (Integration, Material Environment, and Teacher Support), and two of those scales were positive, independent predictors of achievement, suggesting that greater integration between laboratory work and class lessons and better equipment might lead to improved achievement.

Finally, comparisons revealed no significant differences between students who used virtual laboratories and students who did not. On average, scores were above 3.00, which was between the Agree and Strongly Agree response choices, showing that students on average had positive perceptions of the classroom environment, positive attitudes towards science, and above average achievement, irrespective of the instructional method.

Further analysis revealed that virtual laboratories were somewhat more effective for males than for females, as compared to males and females in the control group. Male who engaged in virtual laboratories, compared to males who did not, perceived better equipment (Material Environment), greater support from teachers (Teacher Support), and experienced more inquiry (Inquiry), while females either perceived negligible differences between the instructional methods for these aspects, or perceived them to be more positive in the traditional environment without virtual laboratories.

These findings suggest that technological interventions, such as virtual laboratories, might not offer any direct educational advantages in traditional school environments, but also that they are not detrimental to students' learning experiences. Because they are comparable to any other instructional method in their effectiveness, virtual laboratories might be particularly useful in alternative school environments (such as online settings or in schools without adequate resources). Further research could be conducted into the effectiveness of virtual laboratories, with improvements to the methodology of this study and with an enhanced product that might be better designed by taking the interest of females into account. On the other hand, educational researchers might also use these findings to conclude that no further research should be conducted regarding this intervention and that resources might be better invested in evaluating other aspects of the learning environment in science classes.

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Appendices

These Appendices contain the questionnaire and semi-structured interview questions used in my study, as well as the teacher instructions for participating in my study, and list of virtual laboratories utilized during the implementation of my study. A sample student worksheet for one virtual laboratory is also presented.

Appendix A: Laboratory Assessment in Genetics (LAG)

Curtin
University of Technology

Study in Science Education by Rachel Oser

Directions:

This survey contains questions about your thoughts on science, your perceptions about science laboratories, and your understanding of the concepts illustrated through laboratory activities. Part I refers to background information about yourself and your class (14 Questions), Part II refers to your attitudes toward science and perception of the laboratory environment (Questions #1-64), and Part III refers to your understanding of the concepts illustrated through the laboratory activities in your class (Questions #65-74).

When you complete this survey, you will be given the opportunity to provide your email address which enters you into a raffle to win a $50 gift certificate, to thank you for your participation.

I. In this part of the questionnaire you will answer simple background questions about yourself and your class.

II. This part of the questionnaire asks questions about student attitudes towards science and student perceptions of the learning environment

This section contains 64 questions in 8 frames. In this part of the questionnaire, there are no *right* or *wrong* answers, only your opinions. Although some statements in this survey may seem similar to other statements, you are asked to indicate your opinion about each statement. For example: Suppose you were given the statement "I like science". You would need to decide whether you Strongly Agree, Agree, Not Sure, Disagree, or Strongly Disagree with this statement and then circle the corresponding number. If you mistakenly circle the wrong number, please place an "X" over that circle and then circle the appropriate response.

PLEASE NOTE: The word "laboratory" in this survey refers to any experiment you have done in your science class whether it was "hands-on" or virtual (on a computer). Thank you.

III. This section contains 10 questions on your understanding of genetics. Example: Suppose you were given a statement "Genetics is the study of_____________". You would need to choose the best answer from the choices given such as "A) the environment, B) heredity, C) evolution, D) plants". For instance, if you selected "B) heredity", then circle the letter "B".

Part I. Background Information

Personal Details:

1. Gender:
   - ☐ Female
   - ☐ male
2. Is English the main language you use to communicate?
   - ☐ Yes
   - ☐ No
3. Ethnity:
   - ☐ White
   - ☐ Hispanic
   - ☐ Black (non-Hispanic)
   - ☐ Asian
   - ☐ Other:_________
4. Age:_____

Class Details:

5. Grade:
   - ☐ 8th
   - ☐ 9th
   - ☐ 10th
   - ☐ 11th
   - ☐ 12th
   - ☐ Other:________
6. Type of class:
   - ☐ Standard/College Preparatory
   - ☐ Honors
   - ☐ Inclusion
   - ☐ Advanced Placement
   - ☐ Other:___________
7. Teacher Code:________

Computer Usage:

8. Do you have a computer at home?
   - ☐ Yes
   - ☐ No
9. How many hours a week do you spend on the computer?
   - ☐ 0-2
   - ☐ 2-5
   - ☐ 5-10
   - ☐ 10-15
   - ☐ More than 15
10. Do you have Internet access at home?
    - ☐ Yes
    - ☐ No
11. How many hours a week do you spend on the Internet?
    - ☐ 0-2
    - ☐ 2-5
    - ☐ 5-10
    - ☐ 10-15
    - ☐ More than 15

Future Plans:

12. Do you plan on going to college?
    - ☐ Yes
    - ☐ No
13. Which type of job would you like when you leave school?

☐ Doctor	☐ Psychologist	☐ Chef
☐ Lawyer	☐ Actor	☐ Fashion Designer
☐ Politician	☐ Nurse	☐ Journalist
☐ Scientist	☐ Athlete	☐ Businessman
☐ Accountant	☐ Teacher	☐ Designer
☐ Mechanic	☐ Model	☐ Other:_____
☐ Programmer	☐ Banker	

Please go on to Part II. Thank You!

Part II. Student Attitudes towards Science and Student Perceptions of the Learning Environment

	Strongly Disagree	Disagree	Not Sure	Agree	Strongly Agree
1. I would prefer to find out why something happens by doing an experiment than by being told.	1	2	3	4	5
2. I would prefer to do experiments than to read about them.	1	2	3	4	5
3. It is better to create my own hypothesis than to be given a hypothesis to test out.	1	2	3	4	5
4. I would prefer to do my own experiments than find out information from a teacher.	1	2	3	4	5
5. It is better to try out different ways of setting up an experiment than to be told exactly how to set it up.	1	2	3	4	5
6. It is better to find an answer by doing experiments than to ask the teacher the answer.	1	2	3	4	5
7. I would prefer to guess the results than to be told the expected results before doing an experiment.	1	2	3	4	5
8. It is better to find out scientific facts from experimenting than to be told them.	1	2	3	4	5

	Strongly Disagree	Disagree	Not Sure	Agree	Strongly Agree
9. Science is one of the most interesting school subjects.	1	2	3	4	5
10. The activities we do in science lessons are fun.	1	2	3	4	5
11. I enjoy the audio and visual effects of the activities we do in science lessons.	1	2	3	4	5
12. The technology used in activities makes the science lessons more exciting.	1	2	3	4	5
13. The activities we do in science lessons are useful.	1	2	3	4	5
14. The activities we do in science lessons helped develop my problem-solving skills.	1	2	3	4	5
15. I look forward to the activities we do in science lessons.	1	2	3	4	5
16. I would enjoy school more if there were activities such as the ones we do in science lessons.	1	2	3	4	5

	Strongly Disagree	Disagree	Not Sure	Agree	Strongly Agree
17. The laboratory activities are related to the topics that I am studying in my science class.	1	2	3	4	5
18. My regular science class work is integrated with laboratory activities.	1	2	3	4	5
19. I use the theory from my regular science class sessions during laboratory activities.	1	2	3	4	5
20. The topics covered in regular science class work are quite similar to topics in laboratory activities.	1	2	3	4	5
21. What I do in the laboratory helps me to understand the theory covered in regular science classes.	1	2	3	4	5
22. My laboratory activities and regular science class work are related.	1	2	3	4	5
23. The concepts addressed in the laboratory are those I need to know for my science class.	1	2	3	4	5
24. The skills used in laboratory activities are similar to the skills addressed in my science class.	1	2	3	4	5

	Strongly Disagree	Disagree	Not Sure	Agree	Strongly Agree
25. The materials that I need for laboratory activities and technology are readily available.	1	2	3	4	5
26. The laboratory is an appealing place for me to work in.	1	2	3	4	5
27. I find the audio and visual effects used in the technology in this class to be appealing.	1	2	3	4	5
28. The laboratory and/or technology space has enough room for individual or group work.	1	2	3	4	5
29. The materials that I need for laboratory activities and technology are in good working order.	1	2	3	4	5
30. I find the instructions to use the materials in laboratory activities and technology to be clear and precise.	1	2	3	4	5
31. I do not have to wait to use both laboratory and technology materials.	1	2	3	4	5
32. Help is available for laboratory materials when I need it.	1	2	3	4	5

	Strongly Disagree	Disagree	Not Sure	Agree	Strongly Agree
33. The teacher takes a personal interest in me.	1	2	3	4	5
34. The teacher goes out of his/her way to help me.	1	2	3	4	5
35. The teacher helps me when I have trouble with my work.	1	2	3	4	5
36. The teacher is interested in my problems related to schoolwork.	1	2	3	4	5
37. The teacher moves about the class to talk with me.	1	2	3	4	5
38. The teacher's questions help me to understand the topic.	1	2	3	4	5
39. The teacher guides me through activities when I am stuck.	1	2	3	4	5
40. The teacher helps me with problems related to schoolwork.	1	2	3	4	5

	Strongly Disagree	Disagree	Not Sure	Agree	Strongly Agree
41. Getting a certain amount of work done is important to me.	1	2	3	4	5
42. I do as much as I set out to do regarding the activities in this class.	1	2	3	4	5
43. I know the purpose of completing the activities in this class.	1	2	3	4	5
44. I am ready to start my work in this class on time.	1	2	3	4	5
45. I know what I am trying to achieve in this class.	1	2	3	4	5
46. I pay attention during this class.	1	2	3	4	5
47. I try to understand the work in this class.	1	2	3	4	5
48. I know how much work I have to do in this class.	1	2	3	4	5

	Strongly Disagree	Disagree	Not Sure	Agree	Strongly Agree
49. I carry out investigations to test my ideas in this class.	1	2	3	4	5
50. I am asked to think about the evidence for statements in this class.	1	2	3	4	5
51. I carry out investigations to answer questions during the activities in this class.	1	2	3	4	5
52. I explain the meaning of statements, diagrams, and graphs during activities in this class.	1	2	3	4	5
53. I carry out investigations to answer questions that puzzle me in this class.	1	2	3	4	5
54. I carry out investigations to answer the teacher's questions in this class.	1	2	3	4	5
55. I find out answers to questions by doing investigations in this class.	1	2	3	4	5
56. I solve problems by using information obtained from my own investigations in this class.	1	2	3	4	5

	Strongly Disagree	Disagree	Not Sure	Agree	Strongly Agree
57. I work at my own speed regarding the activities I do in this class.	1	2	3	4	5
58. Students who work faster than me in these activities move onto the next task.	1	2	3	4	5
59. I am given a choice of tasks regarding the activities I do in this class.	1	2	3	4	5
60. I am given tasks that are different from other students' tasks.	1	2	3	4	5
61. I am given work that suits my ability.	1	2	3	4	5
62. I use different materials from those used by other students.	1	2	3	4	5
63. I am assessed in a different manner from other students in this class.	1	2	3	4	5
64. I do work that is different from other students' work in this class.	1	2	3	4	5

Please go on to Part III. Thank you!

Part III. Understanding of Concepts in Genetics

1. Which of the following features of DNA is **most important** in determining the phenotype of an organism?
   A) The direction of the helical twist
   B) The number of deoxyribose sugars
   C) The sequence of nitrogenous bases
   D) The strength of the hydrogen bonds

2. Fireflies produce light inside their bodies. The enzyme luciferase is involved in the reaction that produces the light. Scientists have isolated the luciferase gene.

   A scientist inserts the luciferase gene into the DNA of cells from another organism. If these cells produce light, the scientist knows that which of the following occurred?
   A) The luciferase gene mutated inside the cells.
   B) The luciferase gene was transcribed and translated.
   C) The luciferase gene destroyed the original genes of the cells.
   D) The luciferase gene moved from the nucleus to the endoplasmic reticulum.

3. Steps in a reproductive process used to produce a sheep with certain traits are listed below.

   Step 1 — The nucleus was removed from an unfertilized egg taken from sheep *A*; **Step 2** — The nucleus of a body cell taken from sheep *B* was then inserted into this unfertilized egg from sheep *A*; **Step 3** — The resulting cell was then implanted into the uterus of sheep *C*.; **Step 4** — Sheep *C* gave birth to sheep *D*. Which sheep would be most genetically similar to sheep D?

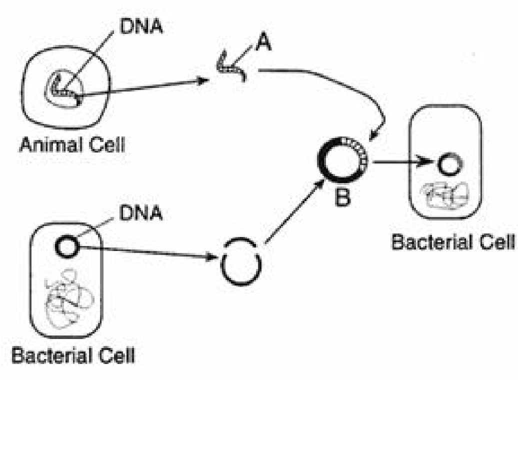
   A) Sheep A, only
   B) Sheep B, only
   C) Both sheep A and B
   D) Both sheep A and C

4. Bacteria in culture *A* produce slime capsules around their cell walls. A biologist removed the DNA from some of the bacteria in culture *A* and injected it into bacteria in culture *B*, which normally do not produce slime capsules. After the injection, bacteria with slime capsules began to appear in culture *B*. What conclusion can best be drawn from this investigation?

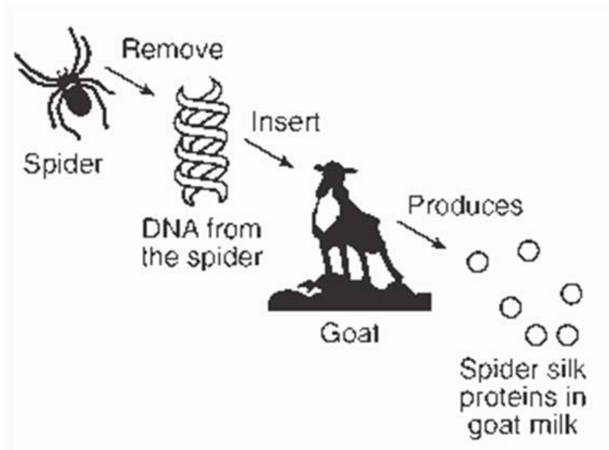
   A) The bacteria in culture *A* are mutations.
   B) Bacteria reproduce faster when they have slime capsules.
   C) The slime capsules of bacteria in culture *B* contain DNA.
   D) DNA is most likely involved in the production of slime capsules.

5. What does structure B represent in the diagram?

   A) a ribosome
   B) transfer RNA
   C) recombinant DNA
   D) a male gamete



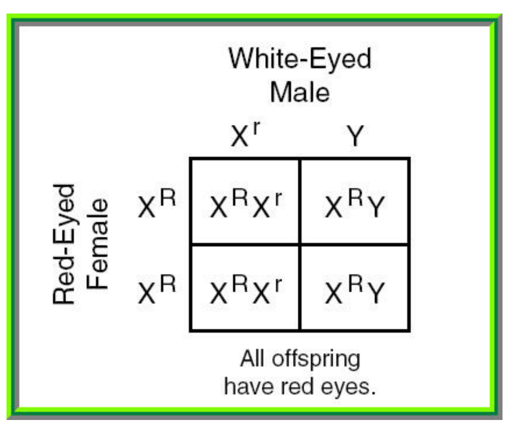
6. Which process is illustrated in the diagram below?
   A) chromatography
   B) direct harvesting
   C) meiosis
   D) genetic engineering



7. After a culture of cells is allowed to multiply and is viewed through a microscope, the cells are x-rayed with high-energy radiation for less than 1/100th of a second. After the radiation, many newly reproduced cells appear different. What has probably occurred?
   A) mutation
   B) speciation
   C) contamination
   D) bacterial infection

8. In 1910, Thomas Morgan discovered traits linked to sex chromosomes in the fruit fly. The Punnett square below shows the cross between red-eyed females and white-eyed males. Fruit flies usually have red eyes. If a female and male offspring from the cross shown above are allowed to mate, what would the offspring probably look like?

   A) 1 red-eyed female and 1 white-eyed female; 2 red males
   B) 2 red-eyed females; 2 white-eyed males
   C) 2 red-eyed females; 1 red-eyed male and 1 white-eyed male
   D) 2 white-eyed females; 1 white-eyed male and 1 red-eyed male

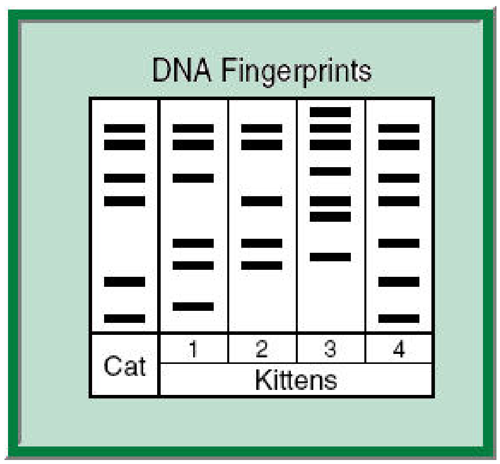


9. The chances of developing cancer, diabetes, or sickle-cell anemia are higher if a family member also has the disorder because they are —

A) Genetically based
B) Passed through blood contact
C) Highly infectious
D) Related to diet

10. The picture below shows a segment of DNA from a cat. Which of these is most likely the kitten of this cat?

A) 1
B) 2
C) 3
D) 4



You have finished the questionnaire. Thank you!

Please write your email address here if you wish to be entered into a raffle to win a $50 gift certificate to be drawn at the end of June:

____

In this Part II of this questionnaire, items 1–16 are based on the Test Of Science Related Attitudes (TOSRA) (Fraser, 1981) as described in Section 2.3.2, items 17 – 32 are based on the Science Laboratory Environment Inventory (SLEI) (Fraser, Giddings, & McRobbie, 1992)described in Section 2.2.2, and items 33–64 are based on the Technology-Rich Outcomes-Focused Learning Environment Inventory (TROFLEI) (Aldridge & Fraser, 2008) described in section 2.2.2. Modification of these items from their original scales is described in Section 3.4.1. The questionnaire items were used in this study and included in this thesis with the authors' permission.

Appendix B: Semi-structured Interview Questions for Students

Introduction to students: Before we get started, do you have your parents consent to participate in this interview and to have this interview recorded? Hi! Thank you for agreeing to participate in this study on science education. The purpose of this research is to help me understand how experiences in the science classroom affect students' attitudes towards science, how students perceive their environments, and how students achieve in science. There are no right or wrong answers; only your opinions count and, what you say will not be reported back to your teacher! The results will inform teachers in general on how to best teach science so that students will be able to learn better. I will start recording now - please say your name when I pause during my introduction. This is an audio recording on [date, time, place] between Rachel Oser and __________. I want to remind you that you may stop this interview at any time. Let's begin.

- [ENJ] Do you find the activities you did in your science classes to be fun?
  - Can you give an example of a memorable activity? Such as games, demonstrations, labs, puzzles, virtual labs, etc.
  - Were there any laboratory activities you liked doing?
  - Was it useful?
  - Did you look forward to such activities?
  - What did that make you think about your science class in general - was it your favorite subject?
  - Would you ever try any activities from class at home?

- [ACH] How well do you understand the topic of genetics?
  a. What contributed to that understanding – what sorts of activities, labs, virtual labs, etc. helped you understand?
  b. Do you feel that you understand this topic more than other topics you learned in your class? Why/why not?

- [MTE] Please tell me about the materials you used for labs and technology.
  - Were they useful, available, in good working order?
  - What about computers?
  - How did you find the audio and visual effects of the activities you did?

- [TSP] How did you find the attitude of your teacher towards helping you?
  - Did s/he help you when you had trouble with your work? How so?
  - Did your teacher guide through activities when you were stuck?
  - In what way do you think the teacher should be involved?
  - In your opinion, what helps you learn more from computer activities – more or less teacher involvement?

- [INQ] Do you prefer to learn scientific facts by experimenting or by listening to the teacher tell you about them? Why?
  - What do you like/not like about experimenting?
  - Do you like to create your own hypothesis (guess the results) or test out a hypothesis given to you by your teacher?
  - What types of experiments did you like doing best? Why?

- [INT] Were the labs that you did related to the topics you studied in your science class?
  - How so? Can you give me an example?
  - Did what you learned in class help your labs or vice versa?

- [TOR] Did you feel that it was important to complete a certain amount of work in class? In general, how motivated are you to get stuff done?
  - Were you aware of the work you needed to complete in science class?
  - Did you know the purpose of doing that work?
  - Did you pay attention in class so that you could complete the work?
  - Tell me about a time that you felt good about completing the work in this class.

[INV] Were you asked to think about evidence for statements in this class?
a. What kind of evidence were you given? Statements, diagrams, graphs?
b. During which sorts of activities were you asked to investigate such evidence?
c. Do you prefer to do such investigations to find answers to questions? Why/why not? Can you give an ex.?
d. How important is it for you to have control over what you are doing during lab activities?

[Gender] Do you think there's a difference between males and females in the class, in terms of how they learn, perceive their environment, their attitudes, or achievement? How so?

[VL] You were involved in a research study where some classes did virtual labs and some did not. Which group do you think you were in?
a. If you had a choice, which group would you prefer to be in? Why?

Follow-up for students in Experimental Group: Lastly, I will tell you what I have found from the data I collected from the surveys. It turns out that there doesn't seem to be a significant difference in perceptions, attitude, or achievement between students who did the virtual labs and students who did not. Perhaps you can help inform me why not, since I was hoping there would be such a difference.

a. Can you tell me what you have observed in your class that could account for this?
b. Please describe the virtual lab arrangement in your class. Around how many were completed? Do you remember which ones (read off list)? Were there any problems with the virtual labs or computer equipment?
c. Knowing these results, would you change your answer to 10. a.?

12. Is there anything else I have not asked about lab activities in your classroom that you think I should know?

Thank you so much for your time. What I have learned from you and this conversation will help me inform teachers about how students learn in science classrooms. I will send you a transcript to review shortly and email you your $10 iTunes certificate. Have a good summer!

Appendix C: Semi-structured Interview Questions for Teachers

<u>Introduction to teachers</u>: The purpose of this research is to help me understand how experiences in the science classroom (namely, virtual laboratories) affect students' attitudes towards science, how students perceive their environments, and how students achieve in science. There are no right or wrong answers; only your opinions count. (VL = Virtual Lab)

Practical Details:

- ☐ How many virtual labs did you do with your VL classes?_____ Which VL's did you choose to do with them (see attached list as a reminder)?
- ☐ Period of time for implementation of this study: (# of days/weeks/months)
- ☐ Please describe how often (or the interval) you did VL's with your VL classes: (did you do them every day for a week straight or once a week, etc…)
- ☐ In contrast, what sort of activities did you do with your non-VL classes? (was it regular lecture, rich discussions, hands-on labs, other computer activities)
- ☐ Please mention any confounding variables between the VL and non-VL classes: (did you teach the same topic, were students at the same level, did the time of day differ for those classes consistently, etc.)

- [ENJ] How do you think your students differed in their opinions of how 'fun' the activities were in your science classes? Did students who did the VL's overall find science classes to be more enjoyable or students who did not do VL's? Do you think that students who did VL's found them to be more useful/would look forward to doing them/would try them at home? If given a choice, would students prefer or not prefer to be in the VL class?

- [ACH] How do you think your students differed in their understanding of genetics? Did the students who did VL's understand the topic better as a result of doing VL's or did it make no difference?

- [MTE] Was the equipment used for VL's in good working order? Ex. Internet speed, enough computers, etc. Please describe any technical difficulties, if any. In contrast, were there any technical problems with other materials you may have used in hands-on labs?

- [TSP] How much did you have to help your students along with the VL's? Did you find that you provided more assistance in VL classes or non-VL classes?

- [INQ] How do you think students differed regarding the level of inquiry? Were students in VL classes more/less/about the same as curious about experimenting using VL's as students in non-VL classes?

- [INT] Were the labs (whether VL's or other activities you did with your non-VL classes) that you did related to the topics you taught in your science class? Was there a difference in the integration of these activities amongst the two classes (VL and non-VL)?

- [TOR] How do you think students differed in their motivation to complete activities/labs between the VL and non-VL classes? Did students in the VL classes complete the VL's more/less/the same than students in non-VL classes or more/less/the same than other activities?

  [Gender] Did you notice any differences in gender regarding the VL's? Did boys or girls seem to be more engaged/motivated to do them? If so, does the same gender difference exist with other activities or in non-VL classes? you think there's a difference between males and females in the class, in terms of how they learn, perceive their environment, their attitudes, or achievement? How so?

  Lastly, I will tell you what I have found from the data I collected from the surveys. It turns out that there doesn't seem to be a significant difference in perceptions, attitude, or achievement between students who did the virtual labs and students who did not. The only quantitative, significant difference was found when comparing VL and non-VL classes against gender so that males showed a significantly higher score on the attribute of 'inquiry' for VL's versus non-VL's. Perhaps you can help inform me why more significant differences were not apparent, since I was hoping there would be such differences. (Although, since there was no negative effect of doing VL's, they are at least as effective as any other educational method and can be implemented in classrooms with confidence.) Can you tell me what you have observed in your class that could account for this?

10. Is there anything else I have not asked about the implementation and results of this study that you think I should know?

Thank you so much for your time.

Appendix D: List of Virtual Laboratories Available for Teachers

List of Virtual Labs (Just the links):

- http://highered.mcgrawhill.com/sites/0073031208/student_view0/virtual_labs.html - On this page, there are 2 labs relevant to this study (Reproduction and Heredity & Molecular Genetics), but they are quite advanced and not too interactive. They do not allow for use of virtual lab materials only for analyzing data from a graph. These are excellent sources for advanced students interested in the particular questions explored in the labs and they include a self-checking feature to determine if the data supports the hypothesis.
- http://www.biologylabsonline.com/ - This site contains many great virtual labs but requires an access code (provided below) and registration. I will be mailing each of you the instructor's packets for these labs. Access code: USCS-BLUFF-TREND-POWAN-FIORI-PRIES (please do not distribute as I have procured this code solely for the purpose of this study which can be accessed up to 1,000 times; otherwise there is usually a fee).
- http://www.hhmi.org/biointeractive/vlabs/index.html - There are 2 labs relevant to this study (Transgenic FlyLab, Bacterial Identification) for which I have created instructor guides and student worksheets (see the dropbox and/or your email accounts – please let me know if you need another copy).
- http://learn.genetics.utah.edu/ - All the labs on this website are relevant to this study for which I have created instructor guides and student worksheets (see the dropbox and/or your email accounts – please let me know if you need another copy).
- http://virtuallaboratory.colorado.edu/Biofundamentals/index.htmlhttp://www.phschool.com/science/biology_place/labbench/ - Some of these are great, interactive and realistic labs that require data collection, but they also require extensive background reading so these are for more advanced students.
- http://www2.edc.org/weblabs/WebLabDirectory1.html - This website contains a list of genetics virtual labs – some are great and really interactive (more animated than realistic) whereas others are more clicking-through types to cover content.
- http://www.jdenuno.com/TechConnect/OnLineLabs.htm - This is a list of many virtual labs, which are worthwhile to peruse as you may choose to do these over the others. Some include virtual labs on Mendelian genetics.
- http://www.ucopenaccess.org/courses/APBioLabs/course/index.html - This is a resource used for online AP biology courses and contains a number of virtual labs about various topics. I will be creating worksheets to go along with the "Genetics of Organisms" (Fruit Flies) lab and the "Molecular Biology" (Bacterial Transformation) lab.
- http://virtuallabs.stanford.edu/ - A general list of virtual labs for your own resources (not too many on genetics).

More to be added as deemed appropriate…… (Open to suggestions!)

Appendix E: Instructions to Teachers for Participating in My Study

General Instructions for Participation in Virtual Lab Study

Thank you for participating in this study to evaluate the effectiveness of virtual laboratories in science classrooms, specifically applied to the topic of genetics. Here are just a couple of quick instructions for you to follow, in order please, so that I can ensure validity and reliability of the resulting data. All forms are available via 'dropbox' or I will send as an email attachment. Please:

1. Read and sign the 'Consent Form for Teachers' – return via email, mail, or fax.
2. Fill out the 'Teacher Information Sheet'- return via email, mail, fax, or Dropbox.
3. Introduce participation of this study to your students via my video (on the blog) or read a transcript of the video aloud to them. DO NOT mention the real goal of this study (so they remain unbiased!) but you can describe it as a 'study on learning methods in science classrooms'.
4. Hand out consent forms for students and their parents (I will provide copies, if you wish) and let them know that they only need to return these forms if they wish NOT to participate in the study. Keep returned forms in a safe place to be returned to me with all other materials at the end of the study.
5. Read the 'Introduction to Virtual Laboratory Activities' document.
6. Browse the suggested virtual laboratories and choose 4-5 that are appropriate for your classes – print student worksheets or let me know which documents you need copied and I'll mail those to you. Re: you will only be doing this with half of your classes.
7. Implement the virtual laboratories any time between Feb.- June 2010; they need not follow in succession nor follow equal intervals of time between their administrations. You will need to ensure Internet access for each student completing the virtual lab activity so be sure to reserve computer labs or laptop carts ahead of time. Re: you will only be doing this with half of your classes.
8. Notify me when you have finished using the virtual laboratories and I will send you the surveys to administer to all of your classes (even the ones who did not use virtual labs as they are the control group) – surveys should be completed during one class period (perhaps you can offer extra credit for compliance!). I may select some students to interview at this time.
9. Notify me when all students have completed the survey and I will send you an envelope in which you will return all forms and surveys to me. You may keep any materials used during this study, but I ask that you do not share them with others until this study is complete (June 25, 2010). Thank you for all your help and your name will be entered into a raffle for $100 of coffee!

My Contact Information:

82 Eighth St., Providence, RI 02906

Cell: 917-640-8355 / Fax: 781-982-4201 (Attention: Rachel Oser)

RachelOser@gmail.com

http://oserscienceedstudy.blogspot.com/ -blog for announcements, FAQs, etc.

www.dropbox.com – Storage and sharing of all documents (I emailed you a link)

Appendix F: Example of a Virtual Laboratory Worksheet

Title of Lab: *DNA Microarray Virtual Lab – University of Utah*

Access: http://learn.genetics.utah.edu/content/labs/microarray/

Brief Description: *In this activity students learn the procedure and concepts that underlie the use of a DNA Microarray for the field of genomics. The purpose of each of the lab materials is explained clearly and the tasks are simple. This lab takes more time, relatively, than the other labs from the same website but it does include an investigative piece and students get to make a real-life application to the differences between healthy and cancer cells.*

Rating: **Advanced → Basic**

Comments: This lab is a little more complicated than the other three labs from the same website but is great for applying all of the techniques to a real-life problem. It is important that students have studied Protein Synthesis and have an introduction to genomics first, but if not, the lab does have a link to educational pages that explain such processes. There are a number of options as to how you can use this lab:

1 – as a stand-alone virtual laboratory

2- in conjunction with the other 3 labs from the same website so that it leads to an investigative piece

Vocabulary:

- Organism
- Genomics
- Genetics
- Genes
- Gene expression
- Gene expression profile
- DNA microarray
- Cancer
- RNA
- Vortex
- Microcentrifuge
- Poly-A tail
- Buffer
- cDNA
- Oligo-dT primers (poly-T tails)
- Reverse transcriptase
- Nucleotides
- Hybridization
- Complementary

Standards:

- *NY: Standard 1, Performance Indicators 1.1, 1.2a, 1.3a, 2.3, 2.4, 3.1, 3. & Standard 4, Performance Indicators 2.1, 2.2*
- *MA: Standards 3.1-3.8*
- *National Standards: THE MOLECULAR BASIS OF HEREDITY [Content Standard B (grades 9-12)]*

  - In all organisms, the instructions for specifying the characteristics of the organism are carried in DNA, a large polymer formed from subunits of four kinds (A, G, C, and T). The chemical and structural properties of DNA explain how the genetic information that underlies heredity is both encoded in genes (as a string of molecular "letters") and replicated (by a templating mechanism). Each DNA molecule in a cell forms a single chromosome.
  - Most of the cells in a human contain two copies of each of 22 different chromosomes. In addition, there is a pair of chromosomes that determines sex: a female contains two X chromosomes and a male contains one X and one Y chromosome. Transmission of genetic information to offspring occurs through egg and sperm cells that contain only one representative from each chromosome pair. An egg and a sperm unite to form a new individual. The fact that the human body is formed from cells that contain two copies of each chromosome—and therefore two copies of each gene—explains many features of human heredity, such as how variations that are hidden in one generation can be expressed in the next.
  - Changes in DNA (mutations) occur spontaneously at low rates. Some of these changes make no difference to the organism, whereas others can change cells and organisms. Only mutations in germ cells can create the variation that changes an organism's offspring.

http://www.nap.edu/openbook.php?record_id=4962&page=185

Student Worksheets: *See attached* – you may decide to give the first page as a pre-lab for HW to save time

Name:______________________ Period:_____ Date:_____________

DNA Microarray Virtual Laboratory (Student Worksheet) – University of Utah

"DNA microarray analysis is one of the fastest-growing new technologies in the field of genetic research. Scientists are using DNA microarrays to investigate everything from cancer to pest control. Now you can do your own DNA microarray experiment! Here you will use a DNA microarray to investigate the differences between a healthy cell and a cancer cell." (Taken from website below)

Background: Read the introduction in chapters 1 and 2 and answer the questions below:
http://learn.genetics.utah.edu/content/labs/microarray/

1. About how many genes do humans have?_____________________________
2. What is genomics?____
3. What does it mean for a gene to be "expressed"? If a gene is expressed, what would be produced?____
4. Briefly explain how many different cell types can form in the body if they all have the same DNA. ____
____
5. What is a gene expression profile and why is it useful?_____________________
6. What's the advantage of using a DNA microarray?_______________________
7. What are some other names for the DNA microarray (see the pull-down "+" sign)?____
8. From where can one get a DNA microarray?____________________________
9. What does each spot on the DNA microarray represent?___________________

Problem: What's the difference between a healthy cell and a cancer cell?

10. Explain the usefulness of looking at cancer cells under the microscope. Will cancer cells appear to be different?_______________________________________
11. In cancer cells, something has gone wrong with the genes that control:_________
12. Why is it important to find out which genes are the culprits each type of cancer?
____

Procedure: Read and follow all the prompts given to you in the lab and answer the questions that follow in order as you perform the specific tasks (read the questions ahead of time!)

1. List the 7 steps in the experiment in which a DNA microarray is used to compare the differences in gene expression levels between cancer cells and healthy cells:

2. List all the materials needed for this experiment:_________________________

3. What substance will you measure from both healthy and cancer cells to determine which genes are turned on/off?_______________________________________

4. From where will you obtain the cancer cells?_____________________________

5. What do the vortex and microcentrifuge do?_____________________________

6. Where is the RNA found at this point?_________________________________

7. How will you retain only the mRNA? Why do you want to retain that particular type of RNA? ____

8. What is the buffer used for?_______________________________________

9. Why do you have to convert mRNA back into DNA (called complementary DNA or, cDNA)? ____

10. Which substance converts the mRNA into cDNA?______________________

11. What is hybridization? ____

12. A single spot on the microarray contains multiple copies of the same/different (circle one) DNA sequences whereas the DNA is the same/different (circle one) from one spot to another.

13. Each spot number on the microarray corresponds to a____________________

Outcomes: You now have a chip to which your sample DNA has been added that represents every known gene in this organism and how the sample and spots on the chip match up will determine the relationship between those matched genes and the particular cancer.

14. What do the darker colored spots on the green (healthy) image represent?_________

15. Interpret the data from the merged image:
    a. What does a yellow spot show?_______________________________
    b. What does a green spot show?________________________________
    c. What does a red spot show?__________________________________

16. As the prompt describes, imagine you are a researcher studying such genes in skin cancer cells, on which color spot would you focus and why?

    ____

17. As the prompt asks, what color are the spots that are turned down by gene 4263? __

18. As the prompt asks, what color is gene 6219 on the microarray? _____________

19. What are some of the advantages of using the DNA microarray technique?_______

    ____

20. What are some limitations of using the DNA microarray technique?

    ____