Assessing the Impact of a Virtual Lab in an Allied Health Program

by

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Abstract

Demonstrating laboratory skills and competency in a hands-on laboratory requires effective pre-laboratory preparation, knowledge, and experience, all of which can be difficult to achieve using traditional teaching methods. The virtual lab is intended to facilitate effective preparation and to aid in the acquisition of skills in the microbiology laboratory. The purpose of this study was to investigate the effectiveness of an online virtual lab as a learning tool in an allied health program. Both qualitative and quantitative data were collected and analyzed to assess student attitudes towards the virtual lab. A convergent parallel mixed method design was chosen to compare the data from a Likert survey, open-ended questions, and a think-aloud protocol. The data converged to support the assertion that students had a positive attitude towards using the virtual lab. The virtual lab made skill acquisition easier and faster, helped them prepare for hands-on laboratory sessions, and was a tool they would use again without the need of extrinsic motivational factors. The key benefit of the virtual lab was that it enabled students to visualize procedures and reactions outside of the traditional laboratory setting. The study supports the conclusion that prior student visualization of procedures and reactions enhanced preparedness and performance in the laboratory environment.

Keywords: virtual lab, pre-laboratory preparation, skill acquisition

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1 Introduction

1.1 Overview

The use of instructional technology in health care education is a growing expectation of today's students (Brandt, Quake-Rapp, Shanedling, Spannaus-Martin, & Martin, 2010). This expectation is being driven by the increasing demands of improving health care delivery, changes in teaching and learning, and requirements of demonstrated skills in competency-based programs (Scalese, Obeso, & Issenberg, 2007). Achieving competency requires knowledge and experience, which may be difficult to gain within a traditional hands-on laboratory (Arneson, 2010; Baker & Verran, 2004; Sancho et al., 2006). This study aims at examining the attitudes of medical laboratory science students towards using a virtual learning environment (hereafter referred to as a virtual lab) to prepare students for hands-on laboratory sessions. Traditional and practical laboratory sessions are defined as providing students with hands-on experience and hereafter referred to as a hands-on laboratory. To clearly understand the role of the virtual lab and the subsequent study of its effectiveness, the challenges of competency-based education, effective student preparation and skill acquisition will be reviewed.

1.1.1 The Challenges of Competency-Based Education

Ongoing advancements in patient care prompts continual changes in the delivery of health care education (Ruiz, Mintzer, & Leipzig, 2006; Scalese et al., 2007). There has been a recent worldwide paradigm shift to competency-based education in health care, primarily to set benchmarks for quality and to assure professional proficiencies (Ruiz et al., 2006; Scalese et al., 2007). Competency-based educational programs develop pedagogical objectives based on the profession's requirements for entry to practice (Canadian Medical Association, 2014).

Competency-based education can meet the requirements for entrance into the medical laboratory science workforce and produce graduates who are able to acquire, interpret, and apply core scientific knowledge (Arneson, 2010). Competency-based education however, poses numerous challenges for both educators and students (Scalese et al., 2007). One such challenge is mandated learning objectives which guide curriculum content, assessments, and skills acquisition (Canadian Medical Association, 2014). Rigid curriculums may cause educators to focus on the learning outcome over the learning process (Ruiz et al., 2006), therefore, courses can be plagued by content overload (Lewis, 2014). It may be difficult for students to meet all the learning objectives of outcome-based education within the constraints of traditional teaching (Arneson, 2010). For competency-based education to be successful, health care educators may need to alter the way they teach (Ruiz et al., 2006).

There has been a recent push for competency-based education to promote learner-centred curricula (Frank et al., 2010) that is accessible and financially sustainable (Brandt et al., 2010). Competency-based education is shifting from structured time-based learning to a more opportunistic time-flexible model (Frank et al., 2010). Simulations and virtual learning environments could facilitate learning in health care education and competency assessment (Arneson, 2010; Butina, Brooks, Dominguez, & Mahon, 2013; Scalese et al., 2007).

Medical laboratory professionals are central to the delivery of patient care and make up one of the largest health care groups in Canada (Canadian Society of Medical Laboratory

Science, 2015). This regulated health care group routinely performs tasks that require critical decision-making and ethical practices (Arneson, 2010). The majority of a patient's chart (80%) is comprised of results generated by medical laboratory professionals (Canadian Medical Association, 2014). Medical laboratory professionals must master specific skills and knowledge to achieve competence (Arneson, 2010).

While virtual learning environments have been adopted for health care education in medicine, dentistry, and nursing, there is minimal literature regarding its use in allied health education (Butina et al., 2013). Butina et al. (2013) reported that 84.6% of allied health programs that do not currently use virtual learning environments would be interested in doing so. Baker and Verran (2004) noted the importance of allied health students being exposed to as many different scenarios as possible in order to become more efficient in clinical diagnostics, and virtual laboratories may allow for this exposure.

1.1.2 The Challenges of Effective Pre-Laboratory Preparation

Students need to be prepared for the hands-on laboratory in order to engage in meaningful learning (Jones & Edward, 2010). Gregory and Di Trapani (2012) have reported that well-prepared students are more likely to succeed in acquiring laboratory skills. If any long term benefits are to be obtained from hands-on laboratory work, students must be theoretically and procedurally prepared (Gregory & Di Trapani, 2012). Trying to ensure that students prepare prior to laboratory sessions is an age-old problem for educators, as experience has shown that many students do not do so (Ealy & Pickering, 1992; Jones & Edwards, 2010; Pogacnik & Cigic, 2006; Whittle & Bickerdike, 2015). Jones and Edwards (2010) reported that only 15% of their undergraduate biology students (n=128) did substantial preparation, while 85% did some or no preparation. Pogacnik and

Cigic (2006) found 20% of their undergraduate chemistry students (n=223) did no preparation at all.

Poorly prepared students may experience cognitive overload as they attempt simultaneously to learn novel hands-on skills as well as new theoretical concepts (Gregory & Di Trapani, 2012; Jones & Edwards, 2010). If the students' focus is primarily on the immediate skill at hand, they may fail to make the correct observations and, therefore, be unable to make connections between the laboratory experience and theory (Johnstone & Al-Shuaili, 2001; Jones & Edwards, 2010). Cognitive training in the form of pre-laboratory exercises may enable students to observe and record data accurately, which will improve their laboratory learning experience.

1.1.3 The Challenges of Skill Acquisition

With the increasing complexity of health care disciplines, the pedagogical focus has shifted to demonstrated skills and competency, which can be gained only through both theoretical knowledge and practical skill acquisition (Sancho et al., 2006). These may be difficult to attain in a traditional experimental laboratory setting (Baker & Verran, 2004; Sancho et al., 2006), where large amounts of information are received in short periods of time (Pogacnik & Cigic, 2006). Students also may lack the necessary theoretical background for the skills they are required to perform (Limniou & Whitehead, 2010). It is difficult for students to receive the level of personal instruction required for learning techniques, procedures, and problem solving from traditional laboratory sessions (Isom & Rowsey, 1986). The instructor-student ratio in a traditional laboratory results in limited immediate feedback and reinforcement, thereby impeding student learning (Sancho et al., 2006).

Traditional laboratory work is essential to provide hands-on experience (Lewis, 2014; Rollnick, Zwane, Staskun, & Green, 2001). However, inherent constraints on using hands-on laboratories may not allow for an optimal learning experience (Rollnick et al., 2001). Physical laboratories require a great deal of time and materials to operate (Gibbons, Evans, Payne, Shah, & Griffin, 2004) and have rigid teaching schedules (Flint & Stewart, 2010). Laboratory skill training is expensive (Lombardi, 2007; Tuysuz, 2010) and can only accommodate small groups within the constraint of the limited availability of physical laboratories (Lehmann, Bosse, Simon, Nikendei, & Huwendiek, 2013; Tuysuz, 2010). With ever decreasing budgets for traditional educational laboratories, there exists a real need to find less costly alternatives (Baker & Verran, 2004). Gibbons et al. (2004) stated that if the manipulation and interpretation of data are the primary learning outcomes, then virtual laboratories can provide a more economical, easier, and less time-consuming alternative. Virtual laboratories are also regarded as a safer alternative than traditional hands-on laboratory sessions (Baker & Verran, 2004; Lewis, 2014; Scheckler, 2003), as some experiments are too dangerous to perform (Lombardi, 2007).

Virtual environments enhance the learning process by providing a medium to learn by doing, which students prefer (Lombardi, 2007), thus reinforcing Bruner's theory of task performance (Bruner, 1966). The use of virtual laboratories can overcome these limitations through increased accessibility, ease in updating and standardization of content, decreased marking time, and substantially improved economic benefits (Gibbons et al., 2004; Johnson & Gedney, 2001; Ruiz et al., 2006; Tuysuz, 2010).

1.2 Research Goals

This study examined the effectiveness of a virtual lab to prepare students for a hands-on laboratory.

The specific research goals were:

1. To report student attitudes towards the effectiveness of the virtual lab in supporting their pre-laboratory preparation.
2. To evaluate the impact of using the virtual lab as a pre-laboratory preparation resource on student performance in the hands-on laboratory.

The research seeks to provide insight into the value of a virtual lab in a competency-based program and to assist educators in overcoming the unique challenges of laboratory preparedness and skill development.

2 Literature Review

2.1 Overview

Medical knowledge is estimated to double every six to eight years (Mantovani, Castelnuovo, Gaggioli, & Riva, 2003). This expanding knowledge base, the cost of running hands-on laboratory classes, and decreasing budgets are pushing programs to introduce virtual laboratory alternatives (Baker & Verran, 2004). Today's challenge is to provide new, less expensive teaching methods while keeping up with ever increasing medical advances (Baker and Verran, 2004).

This review includes previous research on improving student pre-laboratory preparation and skill acquisition using online exercises, simulations, virtual learning environments, and virtual laboratories. As limited research on virtual laboratories exists (Flowers, 2011) and there is even less in the context of medical laboratory science, the review includes information from biological sciences, chemistry, and health-sciences education.

2.2 Benefits of Virtual Laboratories

Virtual laboratories may offer new solutions to the challenges of competency-based education. Traditional hands-on laboratory education plays an important role in active learning (Maldarelli et al., 2009; Tuysuz, 2010); however, this format requires students to acquire complex competencies involving manual skills and intellectual acumen (Gregory & Di Trapani, 2012; Jones & Edwards, 2010; Sancho et al., 2006). Virtual laboratory environments support learning by increasing student cognitive skills (Johnson & Gedney, 2001), offering visual supports (Gregory & Di Trapani, 2012; Jones & Edwards, 2010), enabling learner control (Gibbons et al., 2004; Gregory & Di Trapani, 2012; Limniou &

Whitehead, 2010; Mantovani et al., 2003), and scaffolding (Gregory & Di Trapani, 2012; O'Brien & Cameron, 2008). Effective virtual laboratory environments should offer a realistic layout (Dalgarno, Bishop, Adlong, & Bedgood, 2009; Flint & Stewart, 2010), be easy to use (Flint & Stewart, 2010; Limniou & Whitehead; 2010), and provide feedback (Chittleborough, Treagust, & Mocerino, 2007; Gregory & Di Trapani, 2012; Limniou & Whitehead, 2010).

2.2.1 Cognitive Skills

Constructivist learning is a widely accepted teaching approach (Tuysuz, 2010), but the advantages of active knowledge construction can be compromised by the cognitive overload of traditional laboratory classes (Lehmann et al., 2013; Limniou & Whitehead, 2010; Sweller, 1994). Students with a limited amount of hands-on laboratory experience (Sancho et al., 2006) may have trouble making the connection between theory and practice (Limniou & Whitehead, 2010). During laboratory training, students may construct erroneous knowledge due to theoretical misconceptions and because their working memory is overloaded (Limniou & Whitehead, 2010; Sweller, 1994). Virtual laboratories may enable students to practice cognitive skills that can be difficult to grasp due to the logistical and mechanical limitations of traditional hands-on teaching laboratories (Johnson & Gedney, 2001). In a study by Limniou and Whitehead (2010), significant differences were found between those who did and did not receive online pre-laboratory preparation. The treatment group had no difficulties with the time limitations of hands-on classes and reported being well-prepared to perform the laboratory activities. The control group (n=100), however, failed to obtain basic laboratory skills. Virtual laboratories can provide students with a setting where they can enhance their cognitive skills, such as those required for bacterial identification (Johnson & Gedney, 2001), in a calm environment (Sancho et al., 2006).

2.2.2 Visual Learning

Traditional passive learning environments, such as providing students with written pre-laboratory procedural manuals, may be insufficient to ensure and motivate student preparedness (Whittle & Bickerdike, 2015). Pre-laboratory exercises need to involve more than just encouraging students to read instructions (Johnstone & Al-Shuaili, 2001; Whittle & Bickerdike, 2015). It can be difficult for students to visualize what they are expected to do in the laboratory (Maldarelli et al., 2009) based solely on written instructions (Jones & Edwards, 2010). Jones and Edwards (2010) reported that 68% of their students were visual learners and that 87% agreed or strongly agreed that visual pre-laboratory exercises were useful in helping them prepare for hands-on classes. Gregory and Di Trapani (2012) received similar feedback from their students who saw the visual aspects of their preparatory resource as being highly helpful. One important benefit noted was that virtual laboratories may allow students to view higher-quality images than what they would be able to produce themselves (Lewis, 2014).

2.2.3 Learner Control

Virtual laboratories offer control over pace (Mantovani et al., 2003), location, and time of learning (Chittleborough et al., 2007; Gibbons et al., 2004). Virtual laboratories enable students to do more experiments in a shorter time than traditional laboratories (Lewis, 2014). Virtual laboratories also support learners because resources may be viewed multiple times and may be paused (Gregory & Di Trapani, 2012). Virtual laboratory tools allow for consistency in the data presented to students, as educators have full control of the environment (Lewis, 2014). They do so by offering self-paced, independent learning (Limniou & Whitehead, 2010), which accommodates diverse learning modalities (Jones & Edwards, 2010). The use of virtual laboratories can overcome teaching limitations through increased accessibility, ease in updating and standardization of content, decreased marking time, and substantially improved economic benefits (Gibbons et al., 2004; Johnson & Gedney, 2001; Ruiz et al., 2006; Tuysuz, 2010).

Virtual laboratories also allow for repetitive practice in techniques, as well as data manipulation and interpretation that is difficult to provide in the traditional three-hour laboratory session (Raineri, 2001; Tuysuz, 2010). Johnson and Gedney (2001) found evidence that students' bacterial identification skills improved with successive use of computer simulations. Students were able to practice on a total of 20 bacterial unknowns to determine initial and subsequent testing, interpret results, and exclude taxa (Johnson & Gedney, 2001). For example, students were able to focus on solving bacterial unknowns because they did not need to do the actual testing (Johnson & Gedney, 2001). Raineri (2001) supported the importance of repetitive practice as well as the interpretation of diverse data sets.

2.2.4 Scaffolded Learning

To ensure pre-laboratory preparation, exercises must be designed to include sufficient supports or scaffolding. Kirschner, Sweller, and Clark (2006) found strong evidence that student learning is more effective through guided instructions than through discovery-based learning. Guided instructions in the form of pre-laboratory preparation exercises may facilitate a scaffolded learning experience for skill acquisition (Gregory & Di Trapani, 2012). O'Brien and Cameron (2008) reported the benefits of scaffolded learning when integrating virtual pre-laboratory activities with the laboratory manual. Students were required to complete the online pre-laboratory exercises while using their written laboratory procedure manual, thereby making a direct connection to hands-on laboratory work (O'Brien & Cameron, 2008). Dalgarno et al. (2009) noted that the addition of scaffolded instruction would allow students to become familiar with the requirements and challenges of the hands-on laboratory. Scaffolded learning that includes pre-laboratory checklists, a virtual lab, and traditional laboratory manuals may facilitate a guided learning experience for both pre-laboratory preparation and skill acquisition.

2.2.5 Organizational Design

Virtual laboratory environments must be constructed in a way that encourages, engages, and motivates students (Lewis, 2014) to learn actively and prepare for laboratory sessions (O'Brien & Cameron, 2008). Dalgarno et al. (2009) reported that if the layout of a virtual laboratory mirrors the physical laboratory, students may gain familiarity with the latter. Virtual laboratories may even provide more variables for bacterial identification than in a clinical laboratory (Carnevale, 2003). Flint and Stewart (2010) observed that students liked virtual laboratory exercises with an effective, realistic layout. Online tools, including virtual laboratories, must be user friendly. Limniou and Whitehead (2010) found that students would actively participate in well-constructed online pre-laboratory exercises if information could be accessed quickly and easily. Flint and Stewart (2010) also noted that their students enjoyed using an easy-to-navigate virtual laboratory.

Feedback in virtual environments is vital. Issenberg, McGaghie, Petrusa, Gordon, and Scalese (2005) performed a systematic review of 109 articles examining the use of simulation in health care education. The study found that learner feedback (47%) was the most effective feature of simulation environments (Issenberg et al., 2005). Students also may be more motivated to study when the online tool offers immediate feedback (Limniou & Whitehead, 2010). Correct answers are positively reinforced, which builds student confidence, and incorrect work can be identified and corrected (Chittleborough et al., 2007). Chittleborough et al. (2007) reported that students valued immediate feedback.

2.3 Challenges of Virtual Laboratories

A number of challenges have been reported regarding virtual laboratories, including lack of authenticity (Lewis, 2014; Scheckler, 2003) and motivation (Carnduff & Reid, 2003; Dalgarno et al., 2009; Jones & Edwards, 2010; Konetes, 2010; Meester & Maskill, 1995; Rollnick et al., 2001).

2.3.1 Authenticity

Virtual laboratories lack authenticity because they do not contain the element of uncertainty that exists in hands-on laboratories. (Lewis, 2014; Scheckler, 2003). To be authentic, virtual laboratories also should present learners with incorrect or uncharacteristic experiences (Lewis, 2014). Experiments in real-life laboratories often fail, while experiments in virtual laboratories may be programmed to be consistently successful (Lewis, 2014). So, to be effective, virtual laboratories must compel learners to make connections to real-life experiences (Lombardi, 2007). Authentic learning using a virtual laboratory may be more important than ever given the demands of competency-based education.

2.3.2 Motivation

Virtual laboratories may require well motivated students to participate in active learning (Scheckler, 2003). Students may be resistant to adopting virtual laboratories if they are accustomed to the more passive, time structured, and protocol driven learning climate of traditional laboratories (Lewis, 2014). Online learning environments must be designed with care to motivate students (Masiello, Ramberg, & Lonka, 2005). Conflict exists about how best to motivate students to prepare, with some researchers believing that extrinsic motivation (educator driven) is necessary (Carnduff & Reid, 2003; Dalgarno et al., 2009; Meester & Maskill, 1995; Rollnick et al., 2001), while others argue that intrinsic motivation (student driven) is more effective (Jones & Edwards, 2010; Konetes, 2010).

A number of studies have suggested that the best way to ensure students complete pre-laboratory exercises is by employing extrinsic motivational factors (Carnduff & Reid, 2003; Dalgarno et al., 2009; Meester & Maskill, 1995; Rollnick et al., 2001). Meester and Maskill (1995) reported that students' lack of preparation could only be solved by using extrinsic motivational factors such as making preparation a prerequisite for participating in the laboratory. In a study of two student cohorts (n=33 and n=36), Rollnick et al. (2001) used the same criteria for motivation as did Meester and Maskill (1995). Rollnick et al. (2001) noted, that some students viewed the pre-laboratory exercises merely as obligatory tasks to complete. Dalgarno et al. (2009) also found that less than 50% of their distance education chemistry students chose to use a virtual laboratory as a preparatory resource. They concluded that the lack of associated assessments with the virtual laboratory may have been the cause for the low adoption rate (Dalgarno et al., 2009).

Other researches advocate the use of intrinsic motivation (Jones & Edwards, 2010; Konetes, 2010). Konetes (2010) postulated that the application of extrinsic motivation can decrease a student's internal motivation. An example of students' intrinsic motivation to complete virtual pre-laboratory exercises would be their desire to gain a better understanding of laboratory expectations (Meester & Maskill, 1995) and to improve their confidence. Mantovani et al. (2003) state that virtual reality environments support experiential learning by offering an effective support for skill acquisition, thereby heightening motivation in students.

2.4 The Perceived Impact of Virtual Laboratories

Virtual laboratory exercises may overcome the inherent difficulties of passive learning environments and encourage students to be responsible for their own learning (Brandt et al., 2010). Electronic tools are well accepted among students (Lehmann et al., 2013), and the movement towards the reduction of hands-on laboratories is an opportunity to develop virtual laboratories that can foster laboratory preparation and skill acquisition. Student engagement with virtual laboratories has resulted in a significant increase in student confidence in the hands-on laboratory (Gibbins, Sosabowski, & Cunningham, 2003; Jones & Edwards, 2010; Whittle & Bickerdike, 2015). Students who understand laboratory expectations may experience less anxiety about following and interpreting laboratory manuals (Jones & Edwards, 2010), resulting in improved confidence and skills in the laboratory (Lehmann et al., 2013; Whittle & Bickerdike, 2015).

2.4.1 Student Preparation

Student preparation is important for maximizing the learning benefits of hands-on laboratory classes (Chittleborough et al., 2007; Gregory & Di Trapani, 2012; Jones & Edwards, 2010; O'Brien & Cameron, 2008; Rollnick et al., 2001). After implementing online multimedia pre-laboratory exercises, Jones and Edwards (2010) found a significant shift in how prepared students felt for laboratory sessions. The majority of students rated the usefulness of pre-laboratory exercises highly (Jones & Edwards, 2010). Gregory and

Di Trapani (2012) also found that, after the implementation of online resources, students' perceptions of how prepared they were for the hands-on laboratory increased from 47% to 82% (including Strongly Agree and Agree). Comparison studies showed statistically significant differences between those cohorts of students who did and did not have access to an online laboratory preparation resource (Gregory & Di Trapani, 2012). Lehmann et al. (2013) investigated the perception of both medical students and their tutors concerning the use of virtual patients and a blended learning approach for the preparation of laboratory skills training. Lehmann et al. (2013) noted that with increased student preparation, laboratory time could be used more effectively. This result is particularly noteworthy, as students generally are concerned about using their laboratory time efficiently (Jones & Edwards, 2010). Laboratory classes can be stressful as they require students to combine theoretical and procedural knowledge in a limited time period.

2.4.2 Student Performance

Acquiring laboratory skills requires knowledge and the interpretation and reporting of data. Studies demonstrate that virtual laboratories support problem solving strategies and that participants exhibit improved performance (Gibbons et al., 2004; Johnson & Gedney, 2001). Sancho et al. (2006) reported that 90% of students (n=292) believed learning with a virtual laboratory allowed them to gain both theoretical knowledge and practical expertise they would not have achieved through conventional methods alone. Students demonstrate improved performance in the hands-on laboratory through the prior use of computer simulations, because they are able to gain competence in the identification of bacteria (Sancho et al., 2006). Baker and Verran (2004) reported that students achieved higher scores using a virtual laboratory in combination with traditional methods than they did with traditional methods alone. Virtual laboratories actually improved students' assessment marks by more than 7% in a study of 30 students (Gibbons et al., 2004).

The impact of online resources on student performance was gauged by measuring the acquisition of skills in the hands-on laboratory. In a study by Gregory and Di Trapani (2012), the effect of online resources on measurable skills outcomes was determined by whether students could successfully obtain pure cultures from mixed cultures using bacterial streaking techniques on their first attempt. The comparison study demonstrated a considerable difference between cohorts of students who did and did not have access to the online preparatory resource (Gregory & Di Trapani, 2012). Without the resource, only 54% of students were successful, and after the implementation this number increased to 76%, and the following year to 83% (Gregory & Di Trapani, 2012). Student performance improves when learning activities accommodate their learning preferences (Jones & Edwards, 2010).

The literature supports the impression that students have positive attitudes towards using virtual laboratories for knowledge acquisition (Flint & Stewart, 2010; Jones & Edwards, 2010). Sancho et al. (2006) found that 83% of the students stated that the virtual laboratory was an essential complement to their education. Flint and Stewart (2010) also reported that all 31 students in their study enjoyed the virtual laboratory and believed that it had fulfilled the aims and objectives of the lessons. Virtual laboratories were beneficial regardless of the discipline or format, and in some instances were preferable to traditional ones (Flowers, 2011; Lewis, 2014).

2.5 Conclusion

The literature suggests that there are many benefits to adopting virtual learning environments. A virtual laboratory may help students develop their cognitive skills (Johnson & Gedney, 2001; Limniou & Whitehead, 2010). Students are able to learn visually (Jones & Edwards, 2010) and may be given control over their learning (Gibbons et al., 2004; Mantovani et al., 2003). Virtual laboratories enable a scaffolded learning experience, which allows for students to make a connection between their preparation and laboratory work (O'Brien & Cameron, 2008). In addition, virtual laboratories may lead to an increase in student preparedness (Gregory & Di Trapani, 2012; Jones & Edwards, 2010) and performance (Gibbons et al., 2004; Johnson & Gedney, 2001). In order to reap these benefits, virtual laboratories must be well designed (Dalgarno et al., 2009; Flint & Stewart, 2010; Lewis, 2014), user-friendly (Limniou & Whitehead, 2010), and offer users feedback (Chittleborough et al., 2007; Gregory & Di Trapani, 2012; Issenberg et al., 2005; Limniou & Whitehead, 2010).

Virtual laboratories do not represent a perfect solution however, as they also come with inherent challenges. It may be difficult for virtual laboratories to offer an authentic learning experience (Lewis, 2014; Scheckler, 2003) or a motivating environment (Dalgarno et al., 2009). There also is some debate in the literature whether extrinsic (Carnduff & Reid, 2003; Dalgarno et al., 2009; Meester & Maskill, 1995; Rollnick et al., 2001) or intrinsic motivation is best (Jones & Edwards, 2010; Konetes, 2010).

2.6 Research Gaps

Although previous studies document the benefits of simulations in health care education, outcome-based research varies in rigor and focus (Issenberg et al., 2005).

Minimal literature exists related specifically to the use of virtual learning environments in allied health education (Butina et al., 2013). Existing research literature either does not relate specifically to promoting preparedness for hands-on laboratory and skill acquisition (Butina et al., 2013), or is not within the context of health care education. There is very little formal evidence on the development and implementation of virtual laboratories (Flowers, 2011), particularly in the discipline of clinical microbiology (Baker & Verran, 2004). Additional gaps exist in measurable evidence of skill development in the context of competency-based programs (Ruiz et al., 2006; Scalese et al., 2007). The lack of literature suggests that the benefits of virtual learning tools for hands-on laboratory preparation (Maldarelli et al., 2009) and its impact on cognitive training (Lehmann et al., 2013) have not been fully addressed.

Sancho et al. (2006) stated that the purpose of a virtual lab was not to teach students manual skills, but rather to provide them with essential exposure to non-manual skills such as the interpretation and reporting of data. It has yet to be determined whether the use of virtual laboratory learning tools may aid in the acquisition of hands-on skills and help to fulfill learning outcomes.

In order to meet the needs of today's students, allied health educators need to assess the potential benefits and challenges of using virtual learning tools (Butina et al., 2013). In a survey of 44 allied health educators, Butina et al. (2013) found that 75% of the 16 respondents who reported using virtual learning environments had not examined their educational effectiveness. Of those respondents, only three virtual environments met the researchers' definition of a virtual reality learning environment, that is, "an interactive, self-contained, computer-generated environment mimicking real-life" (Butina et al., 2013,

p. e7). The low adoption rate is surprising because the literature currently indicates that the benefits of online instructional technologies are well accepted by the health care education community (Ruiz et al., 2006). Future research focusing on evaluating the impact of virtual laboratories on pre-laboratory preparation and skills development in a competency-based program would be an important contribution to the field of allied health education. While student learning is the goal of any educational context, there exists a pressing need to provide evidence of the quality of the educational resources being provided.

2.7 Research Questions

The following three key research questions were used to examine students' attitudes towards the impact of the virtual lab on their preparedness for practical, hands-on laboratory sessions and skills acquisition.

1. What are the perceived benefits of using the virtual lab to prepare students for hands-on laboratory sessions?
2. What are the perceived challenges of using the virtual lab to prepare students for hands-on laboratory sessions?
3. What is the perceived impact of the virtual lab on the development of students' practical skills?

3 Method

3.1 Overview

The study was designed to investigate the attitudes that medical laboratory science students have towards the use of the virtual lab to enhance laboratory preparedness and skills development. A convergent parallel mixed method design was chosen to capture a complete picture of the research problem using both quantitative and qualitative research instruments (Creswell, 2014). This approach presented a grounded reality in assessing the impact of a virtual lab by offering a more flexible and reflective guide to the research design and findings (Fraenkel, Wallen, & Hyun, 2012). The decision to use a convergent parallel mixed method was grounded in the study's research questions and purpose, and involved merging both quantitative and qualitative data to triangulate the overall results. The triangulation of the findings would allow for constant comparative analysis of the data (Creswell, 2014)

The study included a Likert survey with open-ended questions. By using quantitative data collection via the Likert scale survey, the study generated an overview of the research problem and provided a statistical comparison of the results (McMillan & Schumacher, 2010). By using qualitative data collection via open-ended questions, the study generated detailed data that added depth, clarity, and/or a greater understanding of the research problem. Johnson and Onwuegbuzie (2004) stated that open-ended survey questions provide an understanding of the meaning of the research problem from the students' perspective as it is understood by them. The open-ended questions were used to identify the important variables influencing student understanding.

The study also included a think-aloud protocol that provided data concerning the students' thought processes while using the virtual lab. Students were asked to think aloud while using the virtual lab. Charters (2003) found that the words participants utter during think-aloud studies are fragmentary and closely resemble "inner-speech." Inner-speech was described as being difficult to capture by Vygotsky, Hanfmann, and Vaker (1962). The think-aloud method is touted as being one of the most reliable ways to capture higher-level thinking processes that involve working memory (Charters, 2003).

3.2 The Virtual Lab

The virtual lab was used as a supplementary pedagogical tool in clinical microbiology courses with both theoretical and hands-on laboratory components. The virtual lab was available via the Internet to all students enrolled in the courses and was designed to promote the mastery of a broad array of procedures and bacterial nomenclature. The virtual lab, which mimicked algorithmic bacterial identification procedures performed in a clinical microbiology laboratory, included procedural videos and images of expected reactions. It enabled students to view and review expected results prior to the hands-on laboratory sessions. The hope was that procedural mimicking would reduce students' cognitive load during hands-on laboratory sessions, thus resulting in better learning outcomes.

The virtual lab was designed to facilitate authentic learning by allowing students to make mistakes, and learn from those mistakes in a safe environment before undertaking procedures in the hands-on laboratory. Authentic learning immerses students in reality-based complex problems and their solutions (Lombardi, 2007). Repetitive training using the virtual lab may represent an important resource to help students improve their performance in a competency-based program. The underlying motivation for the initial development of the virtual lab was to help students overcome the challenges of content heavy competency-based courses, to aid in student preparedness and skill acquisition. The virtual lab may be viewed at http://virtuallab.apa.uoit.ca/intro.php.

3.3 Participants

The participants consisted of 64 students sampled out of a total population of 97 undergraduate students, for a response rate of 66%. The sample represented student volunteers (55 females, 9 males) enrolled in second (*n*=35), third (*n*=17), and fourth year (*n*=12) of a medical laboratory science program in a Canadian university. The researcher was also the instructor for the second year cohorts. Sixty-seven percent of the students (*n*=42) reported that they were native-English speakers. Thirty-one percent (*n*=23) of the students were between 17-20 years old; 36% (*n*=23) were 21-24 years old; 19% (*n*=22) were 25-29 years old; and 14% (*n*=9) were over 29 years old. Undergraduate students enrolled in the same program were also invited to participate in the think-aloud protocol at a later date. Four percent (*n*=4) of the students (three females and one male) submitted a think-aloud video recording documenting their use of the virtual lab. The sample's demographic characteristics were reflective of the medical laboratory science student population.

3.4 Context

The study was conducted within an undergraduate medical laboratory science program at a suburban Canadian university with an approximate population of 10,000 students. This direct entry program is one of only two medical laboratory science honour degree programs available in Canada. The program, which typically experiences a higher enrollment of female to male ratio, accepts approximately 40 students per year.

3.5 Data Collection Tools

Evaluation of the virtual lab's impact on student attitudes occurred during the winter semester of 2015. The study used an online survey tool consisting of four multiple choice questions, 14 Likert survey items, and six open-ended questions. The think-aloud protocol data was collected during a second phase of the research using an online video and screen-recording tool.

3.5.1 Multiple Choice Questions

The multiple choice questions were used to collect the participants' demographic information, including age, gender, academic year, and whether they were native-English speakers (see Appendix A, Items a to d).

3.5.2 Likert Survey

The online survey contained four multiple choice questions and 14 questions on a 7-point Likert scale ranging from "Strongly Disagree, Disagree, Slightly Disagree, Neutral, Slightly Agree, Agree, to Strongly Agree" (see Appendix A, Items 1 to 14). The Likert survey was used to determine the students' attitudes towards using the virtual lab for laboratory preparedness and the perceived impact on the development of their practical skills. Three items (see Appendix A, Items 1 to 3) related to student learning with the virtual lab. Three items (see Appendix A, Items 4 to 6) referred to the design elements of the virtual lab and eight items (see Appendix A, Items 7 to 14) referred to the perceived impact of the virtual lab.

3.5.3 Open-Ended Questions

The online survey contained six open-ended questions (see Appendix B, Items 1 to 6). The open-ended survey was used to determine the students' attitudes towards using the virtual lab to prepare for the actual laboratory and the perceived impact on the development of their practical skills. Students were asked to comment on the benefits and challenges of using the virtual lab (see Appendix B, Items 1 and 2), on the most beneficial key characteristics of the virtual lab (see Appendix B, Items 3), and on the changes that should be made to the virtual lab (see Appendix B, Item 4). Concerning skill acquisition, students were asked to comment on the most and least beneficial characteristic of the virtual lab (see Appendix B, Items 5 and 6).

3.5.4 Think-Aloud Protocol

During the same semester, students also were invited to participate in the think-aloud protocol. While using the virtual lab, the participants were asked to think aloud and make a recording using the online screen-recording tool, *Jing*. *Jing* allows users to audiotape and capture the user's screen simultaneously and then share the produced video via a web link. Participants were given a web link to a pre-task orientation video that could be accessed by students at their leisure and in private. The video included a demonstration on how to use the online tool, *Jing.* Once the *Jing* video was completed, a link was produced with no identifiable student information.

Similar to other qualitative research methods, the think-aloud protocol seeks in-depth data from a small sample size (Fonteyn, Kuipers, & Grobe, 1993). Johnson and Gedney (2001) used a small sample size (n=5) in their think-aloud protocol data collection and reported that it was an effective approach for exploring a computer simulation tool related to bacterial identification strategies.

3.6 Procedure

Data was collected over the winter semester in 2015. A convenience sample was selected from three courses in order to include three separate academic cohorts. All medical laboratory science students were given access to the virtual lab as a course resource. All students received training on the virtual lab. Written and audiotape instructions were posted on the virtual lab's opening page (see Appendix C).

The virtual lab supported scaffolded learning through a pre-laboratory checklist explaining the requirements for each hands-on laboratory and directing students to the particular components in the virtual lab (see Appendix D for pre-laboratory checklist). Students were advised that completing the pre-laboratory activities and using the virtual lab was completely voluntary and no extrinsic motivational factors such as assessments or grades would be associated with participation. Students were required to fill out the pre-laboratory checklist but were not penalized or prevented from participating in the hands-on laboratory sessions for indicating that they did not use the virtual lab.

Prior to the administration of the online survey for this study, an email message was sent to students explaining the purpose and the importance of the research in order to motivate them to participate (see Appendix E for the letter of invitation to participate). A subsequent email message was sent containing the letter of consent (see Appendix F). All participants were informed that their responses were confidential and anonymous, that it was their right to answer or decline the questions within their comfort level, and that they could discontinue the survey at any time during the process. Data was not collected until the students clicked on the submit survey icon.

A second letter of invitation was sent to explain the think-aloud protocol (see Appendix G) and was followed by the letter of consent (see Appendix H). Participants were asked to audio record their verbal automatic responses while using the virtual lab for a maximum of five minutes. A summary of the data collection activities is presented in Table 1.

Table 1. Summary of Data Collection Procedures

Schedule - 13 Week Semester	**Description of Activity**
Week #1	Introduction to the use of the virtual lab (see Appendix C) and to the pre-laboratory checklists (see Appendix D) was performed in class during the first week of the semester.
Week #1 to 13	During the semester, the virtual lab was scaffolded into weekly activities that included traditional lectures, pre-laboratory checklists, virtual labs, and hands-on laboratory sessions.
Week #10 to 13	Students were sent an email invitation to participate in the online survey that included multiple choice, Likert survey, and open-ended questions. Data was collected during week 10 to 13 of the semester.
Week #13	Students were sent an email invitation to participate in the think-aloud protocol along with instructions. Think-aloud recordings were submitted within three weeks of the invitation.

3.7 Data Analysis

3.7.1 Overview

Students' attitudes towards using the virtual lab were evaluated using three data collection tools, including Likert scale questions, open-ended questions, and think-aloud protocols. A summary of the research questions and associated data collection tools is presented in Table 2.

Table 2. Summary of Research Questions and Design

Research Question	Data Collection	Data Analysis
1. What are the perceived benefits of using the virtual lab to prepare students for hands-on laboratory sessions?	Six Likert scale items (see Appendix A, Items 1 to 6)	Descriptive statistics: Mean, standard deviation, frequency analysis, and percentage of agree, neutral, and disagree.
	Two open ended questions (see Appendix B, Items 1 and 3)	Thematic analysis. Open coding into themes and categories. Three themes: Learning, Design, and Engagement. Learning Categories: Visual, Authenticity, Learner Control, Remembering, Reflective, Understand, and Content. Design Categories: Graphics, Organization, Interactive, and Ease of Use. Engagement categories: Comparison, Confidence, and General Engagement.
	Think-aloud protocol	Thematic analysis: Open coding into the same themes and categories as above. Mixed method: Convergent validity.

Research Question	Data Collection	Data Analysis
2. What are the perceived challenges of using the virtual lab to prepare students for hands-on laboratory sessions?	2 open ended questions (see Appendix B, Items 2 and 4)	Thematic analysis. Open coding into themes and categories. Three themes: Learning, Design, and Engagement. Learning Categories: Visual, Authenticity, Learner Control, Remembering, Reflective, Understand, and Content. Design Categories: Graphics, Organization, Interactive, and Ease of Use. Engagement Categories: Comparison, Confidence, and General Engagement.
	Think-aloud protocol	Thematic analysis: Open coding into the same themes and categories as above.
		Mixed method: Convergent validity.

Research Question	Data Collection	Data Analysis
3. What is the perceived impact of the virtual lab on the development of students' practical skills?	8 Likert scale items (see Appendix A, Items 7 to 14)	Descriptive statistics: Mean, standard deviation, frequency analysis, and percentage of agree, neutral, and disagree.
	2 open ended questions (see Appendix B, Items 5 and 6)	Thematic analysis. Open coding into themes and categories. Three themes: Learning, Design, and Engagement. Learning Categories: Visual, Authenticity, Learner Control, Remembering, Reflective, Understand, and Content. Design Categories: Graphics, Organization, Interactive, and Ease of Use. Engagement Categories: Comparison, Confidence, and General Engagement.
		Mixed method: Convergent validity.

3.7.2 Multiple Choice and Likert Scale Data

Preliminary analysis included checking the data for outliers or input errors by frequency analysis. Frequency analysis also determined which category and criteria had the most impact and whether the sample represented the actual student population in the program. Descriptive statistics were calculated on the Likert scale data items (see Table 2). In addition, the internal reliability coefficient for each survey scale construct was calculated (see Appendix A for Likert scale questions). The internal reliability estimates for the Likert scale constructs based on Cronbach's α were r=0.67 (learning attitude scale), r=0.69 (design attitude scale), and r=0.88 (perceived impact attitude scale). The internal reliability coefficient for all 14 items was r=0.90 (see Table 3). Values above 0.70 are considered acceptable for measures used in social sciences (Kline, 1999; Nunnally, 1978).

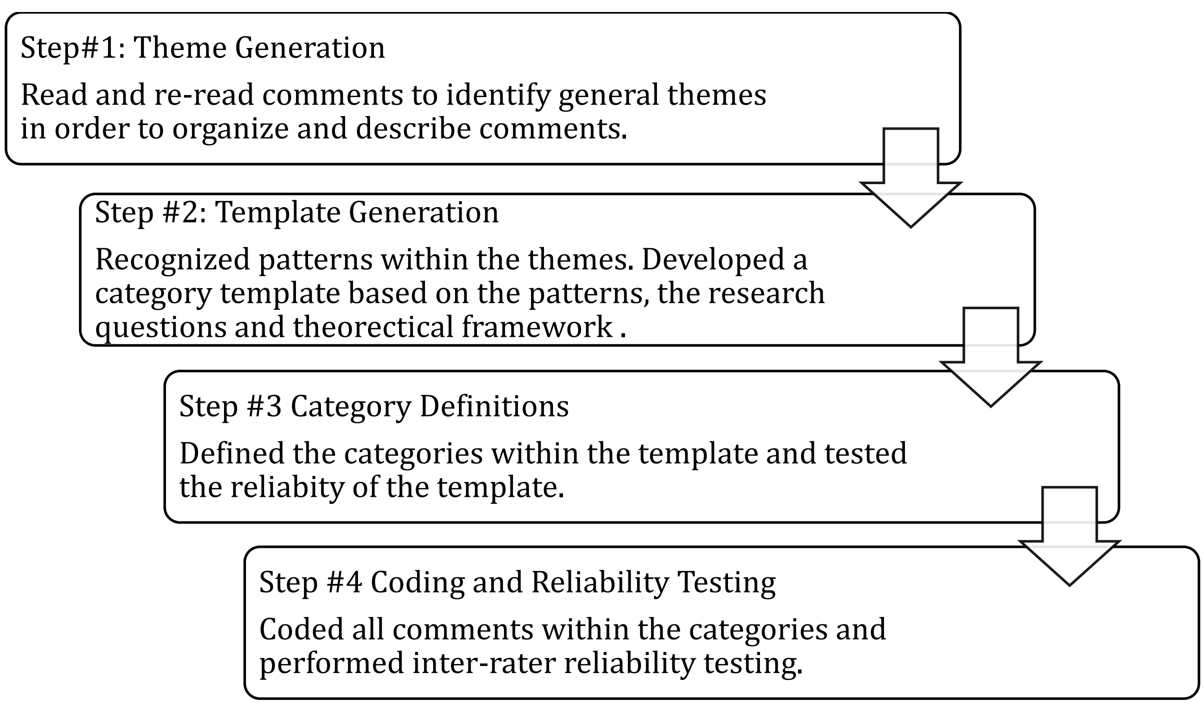
Table 3. Likert Scale Constructs

Scale Construct Measure	No. Items	Range	Type of Question	Internal Reliability
Attitudes				
Learning	3	3-21	7 pt Likert Scale	r =0 .67
Design	3	3-21	7 pt Likert Scale	r = 0.69
Perceived Impact	8	8-56	7 pt Likert Scale	r = 0.88
Total of all Items	14	14-98	7 pt Likert Scale	r = 0.90

3.7.3 Open-Ended Questions

Six open-ended questions were included in the online survey (see Appendix B). The open-ended responses were analyzed thematically by a data-driven organization approach (Boyatzis, 1998), and by the use of a category template based on the research questions and theoretical framework (Crabtree & Miller, 1999). Initially the students' comments were read and re-read in search of overarching themes that would accurately describe the overall meaning of the comments (Boyatzis, 1998). Once themes were generated, a template of categories emerged from pattern recognition (see Figure 1 for a representation of the thematic steps). A list of categories, based on the research questions and theoretical framework, were subsequently defined and used as a template to code all comments (Crabtree & Miller, 1999). This study replicated a similar learning object evaluation scale developed by Kay (2011). See Appendix I for the definition of each theme and category.

Figure 1. Representation of the steps taken in the thematic analysis



Comment categorization was done using spreadsheet software in conjunction with the Statistical Package for the Social Sciences (SPSS). Each comment also was rated on a five-point scale ranging from -2=very negative, -1=negative, 0=neutral, 1=positive, to 2=very positive. The total impact of each category was determined by multiplying the mean of each criterion by the total number of responses for that particular criterion (Kay & Knaack, 2008). This study did not use a process in which participants could validate the researcher's conclusions about their comments because previous research reported that participants were reluctant to take part in such activities (Fereday & Muir-Cochrane, 2006). Instead, a second independent rater assessed the coded comments for inter-rater reliability rates. Thematic analysis of the data from the open-ended questions was completed by one rater, but 23% of all coded responses were checked by a second rater with a 97% reliability. The inter-reliability rate was performed using spreadsheet software by comparing each rater's codes and calculating a percentage of the differences.

3.7.4 Think-Aloud Data

The students were asked to think aloud while using the virtual lab. Recordings of their thoughts ranged from three to five minutes in length. The comments were used as data for analysis to gain insight into their interactions with the virtual lab.

The recordings underwent a coding and analysis process similar to the open-ended responses. They were transcribed, coded, and grouped into three themes: learning, design, and engagement. The same process of thematic analysis used for the open-ended data was used for the think-aloud protocol data. The same 14 categories that emerged from the open-ended questions were used (see Appendix I for the definition of each category).

Thematic analysis of the think-aloud protocol comments was completed by one rater, but 23% of all coded were checked by a second rater with a 91% reliability.

3.7.5 Triangulation of Data

Findings from the opened-ended questions, Likert survey, and think-aloud research methods were integrated to reveal areas of potential convergence. Triangulation of the data was performed to provide greater accuracy and validity (Creswell, 2014; McMillan & Schumacher, 2010). This method may give the findings greater credibility (McMillan & Schumacher, 2010). The degree to which all data collection sources agree is proportional to the validity of the conclusions between the virtual lab, laboratory preparedness, and skill acquisition (McMillan & Schumacher, 2010).

4 Results

4.1 The Benefits of the Virtual Lab

To answer the first research question, ‘‘What are the perceived benefits of using the virtual lab to prepare students for hands-on laboratory sessions?” data was collected from six Likert scale items (see Appendix A, Items 1 to 6), two open ended questions (see Appendix B, Items 1 and 3), and a think-aloud protocol. Data analysis on the Likert scale items included mean, standard deviation, and percentage of agree, neutral, and disagree. Thematic analysis was performed on the open-ended questions and the think-aloud protocol.

4.1.1 Likert Survey Data

The means for each item in the benefits scale construct (see Appendix A, Items 1 to 6) ranged from 5.9 to 6.6 on a 7-point Likert scale. The scores suggested that most students agreed that the virtual lab was easy to use, provided images and videos that helped them learn, presented a useful checklist that helped them prepare for hands-on laboratory sessions, offered a helpful layout for bacterial identification, and provided helpful feedback. The images in the virtual lab received the highest mean, with 97% of students agreeing and strongly agreeing that the images were beneficial. The lowest mean concerned whether the virtual lab provided helpful feedback, with 75% of the students agreeing and strongly agreeing that this feature was a benefit. A summary of the students’ ratings of the virtual lab is presented in Table 4.

Table 4. Student Rating of the Benefit Constructs of the Virtual Lab

Item	M^1	*SD*	**Disagree**[2]	**Agree**[3]
Images help me to learn	6.6	0.6	0%	97%
Videos help me to learn	6.4	0.9	0%	86%
Pre-laboratory checklist exercise helped me to prepare for labs	6.4	0.9	2%	81%
Easy to use	6.2	1.1	3%	86%
Helpful layout for bacterial identification	6.2	0.9	0%	80%
Helpful feedback	5.9	1.1	2%	75%

Note.

[1] 7-point Likert Scale (1=Strongly Disagree to 7=Strongly Agree)
[2] Includes both Disagree and Strongly Disagree
[3] Includes both Agree and Strongly Agree

4.1.2 Open-Ended Questions

In the first opened-ended question (see Appendix B, Item 1), students offered 159 comments about the benefits of the virtual lab as a means to prepare for hands-on laboratory sessions. Seventy-five percent (*n*=119) of the comments focused on learning, 18% (*n*=29) referred to the design of the virtual lab, and 7% (*n*=11) targeted engagement.

4.1.2.1 Learning

In the learning theme, students' comments were organized into six categories. The mean rating (ranging from -3 to 3) for each category was calculated and the total impact was determined by multiplying the mean rating by the total number of comments made by the students. The total impact ranged from 2 to 55 for each criterion (see Table 5 for a summary of the students' comments in the learning theme).

Table 5. Summary of Student Comments about Learning Benefits of the Virtual Lab (*n*=119)

Theme: Learning	***n***	**%**	***M***	***SD***	**Total Impact[1]**
Category					
Visual	46	39	1.2	0.4	55
Authenticity	32	27	1.1	0.4	35
Learner control	17	14	1.2	0.4	20
Remembering	11	9	1.5	0.5	17
Understanding	12	10	1.1	0.5	13
Reflective	1	1	2.0	-	2

Note.

[1]Total impact was determined by multiplying the mean rating by the total number of comments made by the students.

Students referred to the visual aspect (39%, *n*=46) as the most frequent beneficial characteristic of the virtual lab in preparing for the hands-on laboratory sessions. Twenty-seven percent (*n*=32) of the comments referred to the virtual lab's ability to offer authentic learning with a genuine interactive experience. Fourteen percent (*n*=17) of the students' comments were about the benefits of learner control, which allowed them to learn at their own pace, no matter where they were, and at their own convenience. The virtual lab's ability to help students remember (*n*=11) and understand (*n*=12) the material and concepts received approximately the same number of comments. Only one comment was made in the reflective category, which referred to the ability of students to learn from their mistakes while using the virtual lab. Samples of students' comments about the benefits of the virtual lab are presented in Table 6.

Table 6. Sample Student Comments about the Learning Benefits of the Virtual Lab

Theme: Learning	**Sample comments**
Category	
Visual	"We can see clearly how the tests is being done and what are the possible results."
	"[I] can see procedures beforehand."
	"Allowed for us to see the positive and negatives for the different reactions."
	"It's fantastic to have a visual way of preparing for the labs."
Authenticity	"It was as if we were at the laboratory bench."
	"It gave you an idea of what to expect in the lab."
	"You had an idea when going into the lab what to look for."
	"It even took students through the steps they needed to do in lab without being in the lab itself."
Learner control	"It's fantastic to be able to sit at home and view these videos."
	"It gave me the opportunity to go back and review what I missed."
	"It's essentially a lab session but you can dictate the speed at which you perform the tests."
Understanding	"We're able to understand the material easily."
	"By watching it before the lab, it helps me to grasp the new concept even better."
Remembering	"I was able to remember the procedure very easily."
	"Able to review tests you forgot."
Reflective	"If the option was incorrect, you have clicked an incorrect option and recommends to return to the previous step."

4.1.2.2 Design

In the design category, students' comments were organized into four categories that included the organization, graphics, ease of use, and interactivity of the virtual lab (see Table 7).

Table 7. Summary of Student Comments about Design Benefits of the Virtual Lab (*n*=29)

Theme: Design	***n***	**%**	***M***	***SD***	**Total Impact[1]**
Category					
Organization	16	55	1.3	0.4	21
Graphics	5	17	1.0	0.0	5
Ease of use	5	17	1.2	0.5	6
Interactivity	3	10	1.7	0.6	5

Note.
[1]Total impact was determined by multiplying the mean rating by the total number of comments made by the students.

Fifty-five percent (*n*=16) of the comments indicated that the organization of the virtual lab was of the greatest benefit in preparing for laboratory sessions. Most comments noted the fact that the virtual lab was organized exactly as bacterial identification is performed in hands-on laboratory sessions in algorithmic flow charts. Seventeen percent of the comments offered were about the quality of the graphics and the ease of use of the virtual lab. The lowest number of comments (10%, *n*=3) offered by students regarded the degree of interactivity of the virtual lab (see sample comments in Table 8).

Table 8. Sample Student Comments about the Design Benefits of the Virtual Lab

Theme: Design	**Sample comments**
Category	
Organization	"I love how it was set up as a flow chart kind of system."
	"It was like a nice flow chart that gave you an idea of how to proceed with different reactions."
Graphics	"Good pictures of tests and media."
	"The length of each video was ideal."
Ease of use	"Easy to understand."
Interactivity	"Each click brought to the next step down the flow chart in organism identification."

4.1.2.3 Engagement

In the engagement theme, students' comments were organized into three categories that included comparison to other learning methods such as reading a procedure or searching on the Internet, students' overall confidence, and general student engagement in the virtual lab (see Table 9 for the summary of comments).

Table 9. Summary of Student Comments on the Engagement of the Virtual Lab (n=11)

Theme: Engagement	***n***	**%**	***M***	***SD***	**Total Impact[1]**
Category					
Comparison	6	55	1.2	0.4	7.2
Confidence	3	27	1.3	0.6	3.9
General engagement	2	18	1.5	0.7	3.0

Note.

[1]Total impact was determined by multiplying the mean rating by the total number of comments made by the students.

The engagement category had the least number of responses 7% (*n*=11) out of the total 159 comments made addressing the benefits of the virtual lab. The majority of comments pertained to the virtual lab being more beneficial than traditional methods of learning such as reading laboratory procedural manuals or hands-on laboratory sessions, and more advantageous than conducting Internet searches. Students also commented (*n*=3) that the virtual lab increased their confidence for hands-on laboratory sessions. A few comments (*n*=2) referred to general engagement (see Table 10 for sample comments).

Table 10. Sample Student Comments Concerning the Engagement of the Virtual Lab

Theme: Engagement	**Sample comments**
Category	
Comparison	"Drastically better than reading the procedures."
	"When a test is done in the [hands-on] lab as a demonstration, it's hard to capture all the information, also it's hard to remember every single detail. The virtual lab gave me the opportunity to go back and review what I missed."
Confidence	"Gave me more confidence for the lab sessions."
General Engagement	"Good learning tool."

Students also were asked which key characteristic of the virtual lab was most beneficial in preparing for the laboratory sessions (see Appendix B, Item 3). The comments (*n*=94) offered closely mirrored the results found regarding the overall benefits of the virtual lab. The visual aspects (48%, *n*=45) and organizational design (29%, *n*=27) emerged as the most significant key characteristics. All other categories ranged between one to five comments.

4.1.3 Think-Aloud Protocol Data

There were a total of 97 recorded comments made by the four participants in the think-aloud recordings made while using the virtual lab. The majority of the comments related to learning (70%, *n*=68), and the second highest theme was design (18%, *n*=17), followed by engagement (11%, *n*=11). The greatest number of learning-related comments referred to the extent to which students could exercise control over their learning (30%, *n*=29) and included comments on place, time, pace, flow, and having the ability to review and learn independently throughout the process of bacterial identification. Nineteen percent of the comments (*n*=18) related to the students' ability to recall information and remember how to perform a procedure while using the virtual lab. Another 19 percent of the comments (*n*=18) related to the design, and 11% (*n*=11) related to general engagement (see Table 11 for sample comments).

Table 11. Sample Comments of the Benefits of the Virtual Lab from the Think-Aloud Protocol Data (*n*=97)

Category	*n*	%	Sample comments
Learning			
Learner control	29	30	"No, I want to choose this one." "It leaves me a trail, if made a mistake, I can always go back and select a different option." "Actually I'm going to do this instead." "[I'm] not going to open it now." "Watch it again."
Remembering	18	19	"I'm reminded of the first test." "I remember how to do this." "[It's] brain training."
Visual	9	9	"Better idea, how they [bacteria] should look like under the microscope." "Video better than just images."
Authenticity	6	6	"[It's as] if it was in the lab."
Reflective	6	6	"Oh no, [it's] wrong." "I made a mistake".
Design			
Organization	8	8	"[I]really like [having the] results are on the same page." "Download my pathway that I took."
Graphics	5	5	"[I]really liked [the] video, short and concise."
Ease of use	3	3	"[It is] pretty easy to navigate."
Interactivity	2	2	"[It is] interactive."
Engagement			
General Engagement	11	11	"Wow." "I like it a lot."

4.2 Challenges of the Virtual Lab

To answer the second research question, "What are the perceived challenges of using the virtual lab to prepare students for hands-on laboratory sessions?" data was collected from two open ended questions (see Appendix B, Items 2 and 4) and a think-aloud protocol. Thematic analysis was performed on the open-ended questions and the think-aloud protocol.

4.2.1 Open-Ended Questions

A total of 39 responses were collected from students regarding the challenges of using the virtual lab (see Appendix B, Item 2). Most challenges were related to learning (56%, n=22) and the design of the virtual lab (36%, n=14); few comments were offered regarding engagement (8%, n=3).

Within the learning theme, the lack of learner control (21%, n=8), difficulties in understanding the material (15%, n=6), and content issues (13%, n=5) were the most challenging for students. Learner control issues were related to not being able to skip forward to the end and the inability of the program to save the students' progress (e.g., "We needed to start from the beginning of the flow chart every time if we closed the browser," and "Having to go through the whole sample path when you just wanted to quickly view a certain procedure," and "It couldn't save our progress"). The need to access the Internet to use the virtual lab was also noted as a challenge (e.g., "I didn't find any challenges while using the virtual lab, except lack of internet connection occasionally."). Students reported issues with understanding, commenting that the virtual lab forced them to study and that they needed to understand the material in order to use it effectively (e.g., "Some tests you just need to do them to understand," "[the] challenges are related to what your understanding of the material is," and "[the virtual lab] forces you to study in order to get there correctly"). Students also remarked that not all tests and organisms were represented in the virtual lab (e.g., "Not every organism was mapped out," and "[Organism] incubation times would be appreciated"). Comments (8%, n=3) regarding authenticity included: "There were maybe a few discrepancies between some procedures performed in the virtual lab compared to the hands-on lab."

With respect to design challenges, organization issues (23%, n=9) were the most common. For example, students disliked not being able to retrieve information quickly and being required to go through entire identification pathways (e.g., "Sometimes it could be a little difficult to find what I was looking for" and "It was difficult to get to the flowcharts, [I] had to go through many pages first"). Some students found the pathways confusing at times and had difficulty finding what they were looking for (e.g., "The pathways sometimes are confusing" and "navigation was tangled at times"). See Table 12 for a summary of the challenges of the virtual lab. Students offered few comments regarding the graphics (5%, n=2), ease of use (5%, n=2), and interactivity (3%, n=1) of the virtual lab.

Students offered minimal comment with respect to engagement with the virtual lab. The few comments related to engagement (5%, n=2), "feels a little unnecessary," and comparisons to other methods (3%, n=1), "Sometimes the step is different from what it says on the SOP [Standard Operating Procedures], for example, the number of drops of adding reagent for MR test is different."

Table12. Summary of the Challenges of the Virtual Lab (*n*=39)

Category	*n*	%
Learning		
Learner control	8	21
Understanding	6	15
Content	5	13
Authenticity	3	8
Design		
Organization	9	23
Graphics	2	5
Ease of use	2	5
Interactivity	1	3
Engagement		
General engagement	2	5
Comparison	1	3

Students also were asked: “If you could change anything about the virtual lab what would it be?” (see Appendix B, Item 4). Students submitted a total of 40 comments. Suggested changes related to the addition of content (75%, *n*= 30) and organizational design features (25%, *n*=10) into the virtual lab. Comments included: “Adding in the important information that can be found in the SOP [Standard Operating Procedures] but having a simplified box which explains the principle of the test,” “Expanding into the obscure organisms would be much more helpful,” “Add quiz questions,” and “Add in a troubleshooting section”.

4.2.2 Think-Aloud Protocol Data

Of the 97 recorded comments made by the four students in the think-aloud recordings, 7% (*n*=6) related to the challenges of using the virtual lab. All comments offered referred to the students wanting additional content added to the virtual lab (e.g., "I wish there would be a motility video," "extra stuff would help," "it would be cool to have a quick summary," and "[I]wish there was a written summary- quick reference").

4.3 The Perceived Impact of the Virtual Lab

To answer the third research question, "What is the perceived impact of the virtual lab on the development of students' practical skills?" data was collected from eight Likert scale items (see Appendix A, Items 7 to 14) and two open ended questions (see Appendix B, Items 5 and 6). Data analysis on the Likert scale items included mean, standard deviation, and percentage of agree, neutral, and disagree. Thematic analysis was performed on the open-ended questions.

4.3.1 Likert Survey Data

The mean scores for questions addressing the impact of the virtual lab (see Appendix A, Items 7 to 14) ranged from 6.7 to 6.1 (out of 7). The two highest means (6.7 and 6.6 respectively) indicated that the students would use the virtual lab again and that being able to view the procedures ahead of their hands-on laboratory sessions was very helpful. Students also agreed that the virtual lab helped them to prepare and assisted in completing practical hands-on laboratory sessions (means of 6.4 and 6.3 respectively). Students stated that they completed the pre-laboratory exercises (mean 6.1). Students' attitudes also indicated that the virtual lab made acquiring skills faster (6.1) and easier

(6.1) and that they achieved greater success in learning (6.1) by using the virtual lab (see Table 13 for the summary).

Table 13. Student Rating of the Perceived Impact of Virtual Lab

Item	*M*[1]	*SD*	Disagree[2]	Agree[3]
I would use the virtual lab again	6.7	0.7	0%	95%
Viewing procedures ahead of the hands-on lab was helpful	6.6	0.7	0%	97%
It helped me to prepare for labs	6.4	1.1	3%	91%
It played a role in completing the hands-on laboratory sessions	6.3	1.2	5%	88%
I completed the virtual lab pre-lab exercises	6.1	1.2	3%	88%
I achieved greater success in learning	6.1	1.0	2%	84%
Easier to learn new skills	6.1	1.0	0%	78%
Develop skills faster	6.1	1.1	2%	77%

Note.

[1] 7-point Likert Scale (1=Strongly Disagree to 7=Strongly Agree)
[2] Includes both Disagree and Strongly Disagree
[3] Includes both Agree and Strongly Agree

4.3.2 Open-Ended Questions

A total of 69 responses were collected from students regarding the key characteristics of the virtual lab they thought were the most beneficial in helping them acquire new skills (see Appendix B, Item 5). Similar to the responses in the open-ended data concerning the benefits, the visual aspect of the virtual lab was identified as the key characteristic (52%, n=36). Similar data was also seen concerning the organizational design of the virtual lab (16%, n=11). All other categories received only a few comments (ranging from 1 to 4). See Table 14 for the summary of the perceived benefits.

Table14. Summary of the Perceived Benefits of the Virtual Lab (n=69)

Category	***n***	**%**
Learning		
Visual	36	52
Learner control	4	6
Content	4	6
Understanding	4	6
Authenticity	2	3
Remembering	1	1
Design		
Organization	11	16
Graphics	3	4
Ease of use	2	3
Interactivity	1	1
Engagement		
Comparison	1	1

Students also offered 10 comments regarding which key characteristics of the virtual lab they perceived as being least beneficial in helping to acquire new skills (see Appendix B, Item 6). The 10 comments were spread evenly over six different categories (visual, authenticity, understanding, organization, ease of use, and content) with no individual category receiving more than two comments. The few comments offered were similar to those mentioned in the challenges.

5 Discussion

5.1 Overview

Health care education is in a state of flux as it moves towards enabling adaptive learning and transforming educators into facilitators of learning (Ruiz et al., 2006). Virtual learning environments must be evaluated if they are going to be accepted by allied health educators and students. The best way for competency-based programs to respond to the calls for change is to evaluate the integration of virtual learning environments and to identify which features students perceive as leading to effective learning. This study aimed at examining the attitudes of allied health students towards using a virtual lab by identifying its benefits, challenges, and perceived impact on hands-on laboratory preparedness.

5.2 Benefits of the Virtual Lab

Triangulation of the data in this study suggests that the overall attitudes of medical laboratory students towards the virtual lab as a tool for facilitating pre-laboratory preparation were positive. The categories which students rated highest included visual learning, authenticity, learner control, organizational design, and scaffolded learning. Each of these categories will be discussed in turn.

5.2.1 Visual Learning

Students struggle to visualize laboratory expectations from written or verbal instructions (Jones & Edwards 2010). Triangulation of the Likert scale, open-ended responses, and the think-aloud protocol data suggests that the greatest benefit of the virtual lab was the ability for students to visualize results and procedures outside the traditional laboratory. This result is not surprising as the literature suggests that the majority of students prefer visual learning resources (Lehmann et al., 2013) over traditional written laboratory manuals (Gregory & Di Trapani, 2012; Jones & Edwards, 2010). The mean scores of the Likert survey questions referring to the videos and images were the highest. When asked which key characteristic of the virtual lab students found most beneficial, nearly half of all comments made reference to the visual aspects. Students also identified the visual aspects as the most beneficial to prepare for laboratory classes. The visual aspects received the highest number of comments and had the greatest total impact (55) of all the categories. The visual benefits of the virtual lab were also mentioned during the think-aloud protocol. The virtual lab was able to provide an illustrated representation of the key procedures and concepts required in the hands-on laboratory. As one student stated in this study, "it's fantastic to have a visual way of preparing for the labs."

5.2.2 Authenticity

Authentic learning is not restricted to traditional laboratory work (Lombardi, 2007). Carefully designed virtual reality learning environments may provide students with real-life laboratory scenarios. While the authenticity of the virtual lab was not included as a Likert scale item, this category had the second highest number of comments (27%, n=32) from the open-ended questions on the benefits of the virtual lab for preparing for laboratory classes. The total impact for authenticity, the mean rating multiplied by the total number of comments, was 35. Measuring total impact indicated that the category had a high percentage of positive comments as well as a high mean. This result contradicts Scheckler's (2003) perspective that virtual laboratories do not embody the reality of the hands-on laboratory. Virtual labs are reported to be unable to provide varied and incorrect experiences (Lewis, 2014). On the other hand, Lombardi (2007) supports this study's results that a virtual laboratory may help students apply knowledge to new situations, thereby providing authentic learning. The realistic layout of the virtual lab mimicked the bacterial identification performed in the hands-on laboratory and may have contributed to supporting the concept of providing real experiences. The ability for students to make mistakes and arrive at wrong conclusions allowed students to experience incorrect and varied data. The virtual lab used in this study appeared to have offered some opportunity for experiential learning similar to traditional laboratory sessions.

5.2.3 Learner Control

The literature supports the importance of students being able to control the learning process (Gibbons et al., 2004; Issenberg et al., 2005; Ruiz et al., 2006). The learner control category was not included as a Likert scale item. However, the third highest number of comments (14%, *n*=17) from the open-ended questions referred to the students' ability to learn independently at their own pace, and when and where they want. The results of the think-aloud protocol supports the value that students place on personalized learning, as the learner control category received the highest number of student comments (30%, *n*=29). Comments included the ability to learn independently while using the virtual lab and to choose their own learning path. As one student mentioned, "It gave me the opportunity to go back and review what I had missed." This result is consistent with Gibbons et al. (2004), who noted that control over learning pace led to a more personalized learning process. To promote learner-centeredness, competency-based programs should permit learner flexibility by allowing students to adjust the time they spend on each outcome, as students learn different sections of the curriculum at different rates (Frank et al., 2010). The virtual lab may enable students to move through material at their own pace, allowing for repetitive practice, and encouraging them to own their learning path and education milestones.

5.2.4 Organizational Design

Triangulation of the data indicated that students found the design elements of the virtual lab to be beneficial. From the Likert scale survey and open-ended questions, students reported that the virtual lab was easy to use (M=6.2). This result is consistent with Limniou and Whitehead's (2010) support of the importance of online resources being easy to use. If students could access information quickly and easily, they were more likely to use and enjoy the pre-laboratory resource (Flint & Stewart, 2010; Limniou & Whitehead, 2010).

Students in this study also valued the helpful feedback (M=5.9) provided by the virtual lab. Issenberg et al. (2005) supported the idea that effective learning environments must facilitate learner feedback. This study corroborates the findings of Chittleborough et al. (2007), which stated that students valued immediate feedback because they are better able to reflect on their comprehension of the material. Limniou and Whitehead (2010) also reported that student motivation to study increases when pre-laboratory resources provide immediate feedback.

Finally, the virtual lab was reported to have a helpful layout (M=6.2) for bacterial identification. The layout of the virtual lab mirrored the procedures of the physical laboratory and was rated highly by students. This finding was seen as well in studies by Flint and Stewart (2010) and Dalgarno et al. (2009). The organizational design of the virtual lab also received (n=16) positive comments within the open-ended questions and

(n=8) positive comments in the think-aloud protocol. The interactive algorithmic flowcharts were well received by students, with comments such as "I like the flowcharts; they make identification easier."

5.2.5 Scaffolded Learning

Kirschner et al. (2006) noted that student learning is more effective through guided instructions. Results from the Likert scale survey were consistent with this claim and indicated that most students (81%) found scaffolded learning in the virtual lab to be helpful. In addition, the majority of students (88%) reported that they used the virtual lab to complete pre-laboratory exercises, providing tangential support for the notion that laboratory preparation went beyond just reading a set of instructions. O'Brien and Cameron (2008) stated that the integration of pre-laboratory activities with the written laboratory manual solidifies the connections to hands-on laboratory sessions. Scaffolded learning may empower students to individualize their own pre-laboratory preparation (O'Brien & Cameron, 2008; Rollnick et al., 2001) and expose them to the requirements and challenges of the hands-on laboratory (Dalgarno et al., 2009). However, scaffolded learning was not mentioned by students in either the open-ended questions or the think-aloud protocol. The virtual lab may provide students with the ability to construct their own pre-laboratory foundational knowledge on which to build their practical laboratory skills.

5.3 Challenges of the Virtual Lab

Though virtual laboratories may overcome many of the constraints of physical laboratories (Johnson & Gedney, 2001), they come with their own inherent limitations (Lewis, 2014). Data from the Likert scale survey did not indicate any challenges as all item means were very positive. However, 39 comments were offered by students from the open-ended questions and six comments from the think-aloud protocol regarding challenges. Identified challenges included the organizational issues, lack of learner control, difficulties in understanding concepts, and the need for additional content.

5.3.1 Organizational Design

Students reported some challenges concerning the organizational design of the virtual lab. Though organizational design of the virtual lab was rated highly as a benefit (80%), it was also viewed as a challenge for some students in the open-ended questions (23%, *n*=9). Most comments related to students having difficulties finding what they were looking for and sometimes being confused and lost. In this study, the layout mimicked the processes of bacterial identification in the microbiology laboratory. Students were required to go through the entire process of identification rather than just look at a specific procedure or test result, therefore students were required to navigate the virtual lab as if they were in the laboratory. One student commented:

> "The challenges were more related to the student's knowledge regarding the tests as each result brought [you] to the next option down the [flow] chart. If you are not as familiar [with] what the tests are targeted for, it may not be as fruitful."

It is important to note the cognitive load theory when designing virtual laboratories, otherwise students will encounter the same cognitive difficulties as in hands-on laboratories. The targeted skills in virtual laboratories must not be too demanding or else they risk overloading the students' working memory. Flint and Stewart (2010) reported similar results with their virtual lab, in which organization received the highest rating as both benefit and challenge. Flint and Stewart (2010) suggested that a short training exercise prior to use would be beneficial. The virtual lab in this study did have a navigation tutorial, however, given the results of this study, it may be beneficial to perform a careful review of the resource.

5.3.2 Learner Control

While learner control was reported as a benefit in the open-ended questions, (14%, *n*=17) and think-aloud protocol (30%, *n*=29), it also was reported as a challenge in the open-ended comments (21%, *n*=8). Challenges referred to a student's lack of control over the flow and sequence of the virtual lab, which included being unable to skip forward and backward through processes and not being able to save the student's progress. While previous research highlighted the benefits of virtual laboratories in enabling flexibility over pace (Mantovani et al., 2003), time, and location of learning (Gibbons et al., 2004), few studies used qualitative research to investigate what students disliked about virtual laboratories. In the study conducted by Flint and Stewart (2010) as well as in this study, students were asked open-ended questions about what they liked least. Flint and Stewart (2010) said that although students reported their virtual laboratory exercises to be well-mapped, they cited navigation and screen layout as areas for improvement. This study also highlighted possible design improvements for the virtual lab. Such improvements could include redesigning the system to have the ability to detect how far students have progressed, allowing them to stop and then resume later without having to start over, and also enabling a hyperlink feature that would allow students to jump around the site.

5.3.3 Understanding

Some students (*n*=6) reported in the open-ended questions that they had trouble understanding concepts within the virtual lab. Rollnick et al. (2001) found that issues with comprehension impacted student performance in pre-laboratory exercises. Limniou and

Whitehead (2010) also stated that students often lack foundational knowledge which impacts their ability to construct accurate and true data. If students lack theoretical knowledge, we can assume they would struggle in both the virtual and physical laboratories. This reinforces the notion that high cognitive load may affect students' understanding and ability to complete tasks in both types of laboratories. Therefore, it is important to design virtual laboratories in such a way that they remain aligned with students' cognitive load and level of understanding. These goals may be difficult to achieve, as students' abilities range widely. Consequently, the virtual lab was designed to present content in a flexible learning environment, enabling learners to choose text, audio, images, and/or videos to accommodate their own learning styles and needs. The virtual lab also was scaffolded with traditional lectures, pre-laboratory checklists, hands-on laboratories, and post-laboratory learning checks. In this way, students were given opportunities to process and build connections between theoretical concepts and required tasks. Research supports the scaffolding of virtual environments to offer students the ability to construct the previous knowledge required to use virtual laboratories successfully (O'Brien & Cameron, 2008; Rollnick et al., 2001).

5.3.4 Content

Students reported that they would have liked the virtual lab expanded to include additional content. Triangulation of the data from two open-ended questions (*n*=5; *n*=30) and the think-aloud responses (*n*=6), suggests the need for additional content to be included in the virtual lab. Comments referred to adding obscure bacteria, and additional procedural videos and images. Students also mentioned that they would like to have brief theoretical descriptions of the tests below the images. Dalgarno et al. (2009) also stated that incorporating additional theoretical content from laboratory manuals and textbooks may increase their students' perception of the usefulness of their virtual laboratory. The content of virtual laboratories must be aligned to the intended learning outcomes (Lewis, 2014). O'Brien and Cameron (2008) stated that the addition of more support information was an initial step in improving issues with their virtual laboratory. While more research is needed to explore areas of improvement, assessing the attitudes of student users could highlight important aspects of future improvements to virtual laboratories.

5.4 Perceived Impact of the Virtual Lab

Triangulation of the data in this study suggests that student attitudes towards the virtual lab as a resource for both laboratory preparation and performance were positive. This study found that the virtual lab enabled students to become familiar with tasks before hands-on laboratory sessions, it supported visual learners, and students were intrinsically motivated to adopt it. The virtual lab may have impacted performance by decreasing cognitive load in the hands-on laboratory, thereby allowing them to acquire new skills faster and easier and aiding in completing the hands-on laboratory sessions.

5.4.1 Student Preparation

The virtual lab gave students an opportunity to become familiar with the material prior to laboratory sessions. Data collected in the Likert scale survey indicated that 91% of students agreed that the virtual lab helped them prepare for hands-on laboratory sessions. This finding is consistent with previous studies that found student preparedness increases with the use of pre-laboratory virtual resources (Gregory & Di Trapani, 2012; Jones & Edwards, 2010).

Ninety-seven percent of students agreed that viewing laboratory procedures ahead of time had a positive impact on the hands-on laboratory sessions. Illustrating laboratory tasks may have provided students with the opportunity to process information at their own pace. This pre-constructed knowledge may have enabled them to focus only on the tasks in the hands-on laboratory, thereby reducing cognitive load. This benefit has been widely reported in research (Chittleborough et al., 2007; Limniou & Whitehead, 2010).

This study further reported that students readily adopted the pre-laboratory exercises despite the virtual lab having no associated assessments or other extrinsic motivational factors. Students indicated that they used the virtual lab (88%) and that they would use it again (95%). This finding contradicts some previous studies in which researchers professed a belief students would engage in preparation only if educators used extrinsic motivation such as grades (Meester & Maskill, 1995). For instance, Dalgarno et al. (2009) reported low participation in their preparation exercises, which they believed could be rectified through linked assessments. A number of studies included marked assessments to ensure obligatory participation in pre-laboratory preparation (Carnduff & Reid, 2003; Chittleborough et al., 2007; Rollnick et al., 2001).

Internal motivational factors were apparent in the Likert scale items where students reported that the virtual lab helped them to prepare (91%) and that they achieved greater success in learning (84%). Jones and Edwards (2010) reported the same findings; their students adopted online pre-laboratory exercises without any associated assessments. A study by Limniou and Whitehead (2010) also supported this study’s findings that students would participate in well-designed virtual learning environments without external pressures. Konetes (2010) reports that mandatory usage requirements may actually diminish students' interest and activation to participate. This study may aid in solidifying the concept that students are intrinsically motivated to participate in pre-laboratory preparation.

5.4.2 Student Performance

In this study, 84% of students agreed that the virtual lab helped them to achieve greater success in learning. Prior exposure to material through the virtual lab may have led to a reduction in cognitive overload as students were not being asked to absorb new knowledge and develop hands-on skills simultaneously. These findings align with a number of other studies in which virtual pre-laboratory exercises provided students with a better understanding of laboratory expectations (Johnson & Gedney, 2001; Jones & Edwards, 2010; Limniou & Whitehead, 2010). Other studies have reported on the benefits of pre-laboratory preparation that allows students to practice cognitive skills (Johnson & Gedney, 2001), thereby reducing cognitive load in the hands-on laboratory (Limniou & Whitehead, 2010).

Over three-quarters of the students reported that the virtual lab made it easier and faster for them to develop and learn new skills. This finding is supported by Jones and Edwards (2010), who found that student performance improves when educational tools support their learning preferences. Sancho et al. (2006) also found that students gained competence using a virtual lab. The virtual lab gave students the opportunity to review procedures whenever they wished, allowing them to spend more time practicing bacterial identification outside of traditional laboratory classes. This ability to review and practice bacterial identification is a key process in gaining mastery of a necessary skill (Raineri, 2001).

Virtual laboratories may allow students to use their time more efficiently in the hands-on laboratory. Eighty-eight percent of students reported that the virtual lab played a role in completing the hands-on laboratory sessions. In their study, Gregory and Di Trapani (2012) found that students were able to use their time in the physical laboratory more efficiently after the implementation of pre-laboratory exercises. This may link the benefits of pre-laboratory preparation and the occurrence of meaningful learning (Jones & Edwards, 2010). Students cited the same characteristics — the visual aspects and organizational design — as being most beneficial in helping them learn new skills to prepare for laboratory classes. The perceived impact of the virtual lab is that it helped prepare students for the physical laboratory and that it aided in skill development and acquisition.

5.5 Summary

Triangulation of the data indicated that, overall, students rated the virtual lab positively. The virtual lab was designed to illustrate laboratory procedures and expected reactions in a flexible any time, any place format. Students were given options to learn by either images, video, audio, or text. The organizational layout of the virtual lab mimicked the reality of bacterial identification performed in the hands-on laboratory. Students were given the opportunity to make mistakes and arrive at wrong conclusions, while being offered immediate feedback. By using the virtual lab, students could adjust the time, pace, and sequence of their required learning outcomes. The virtual lab was not used in isolation, but rather it was fully integrated within other resources, including pre and post laboratory exercises, traditional lectures, and hands-on laboratory sessions.

While students' attitudes regarding the virtual lab were positive, some students reported limitations. Challenges included difficulties with the organization, where students reported being lost or confused at times. Another reported challenge was the students' inability to skip forward and backward through the virtual lab and not being able to save their progress. A few students reported difficulties with understanding concepts within the virtual lab. Consequently, if students lacked theoretical knowledge, it is possible that the virtual lab may have led to cognitive overload, particularly if the content was not aligned to their level of understanding. Research also indicated that students would like additional content and functionality included in the virtual lab.

This study indicated that students used the virtual lab of their own volition, without extrinsic force applied by educators. The current study found that students perceive the virtual lab as a benefit to their own learning and as such, do not need to have their efforts rewarded. Students may have been motivated to use this learning tool because it afforded learner control, visual and authentic learning, and was well designed.

The virtual lab was perceived to impact the amount of preparation students engaged in as well as their performance. The majority of students reported that they used the virtual lab and that they would do so again. They believed that the virtual lab helped them to prepare for and complete the physical laboratory sessions. Students perceived that the virtual lab allowed them to acquire skills easier and faster and that it helped them to achieve greater success.

The requirements of demonstrated skills in competency-based programs drives educators to adapt teaching and learning to improve health care pedagogy, and this study contributes to the body of literature suggesting that learning with a virtual lab is an important instructional method. There still exists a pressing need to provide and evaluate active learning experiences in health care education. Virtual learning environments may provide a solution to ready students to competently perform the laboratory tasks expected of them.

5.6 Educational Implications

Several educational implications emerged for allied health programs. Firstly, that virtual labs can be effective learning tools within the allied health education field. Students' attitudes revealed that they perceived the virtual lab as supporting their learning process. Students believed the virtual lab helped to prepare them for hands-on laboratory sessions and that it made skill acquisition easier and faster. Previously, few studies that investigated the impact of a virtual laboratory in allied health education had existed. The use of virtual labs in allied health education should be increased and virtual labs should be scaffolded alongside traditional resources.

Secondly, virtual laboratories should be carefully designed to prevent cognitive overload, and content needs to be aligned with students' level of understanding. The virtual lab may reduce cognitive overload as it provides students with the opportunity to familiarize themselves with the material prior to laboratory sessions. The majority of students agreed that the virtual lab played a role in completing the physical laboratory sessions, however, some students did have difficulty using the resource. These difficulties may have stemmed from a lack of understanding, as the virtual lab was designed to mimic the real-world bacterial identification process. These students may, therefore, have felt the same cognitive load in the virtual lab as in the physical laboratory. In light of this finding, educators should strive to design virtual learning environments in a way that reduces the cognitive load experienced by students and fits their level of understanding.

Thirdly, virtual learning environments are tools educators can use to support a wide range of learning modalities. Students within this study reported that the visual aspect of the virtual lab was its most beneficial characteristic, both in preparing for hands-on laboratory sessions and in developing new skills. Virtual labs should be designed in a way that supports the visualization of material. In addition to the visual aspect, many students also believed that the organizational design of the lab was beneficial. Student comments focused on the fact that the virtual lab was designed in a way that mirrored how bacterial identification is performed in the hands-on laboratory. This study also found that virtual labs should offer students timely feedback and control over learning. The implication is that when designing a new virtual learning environment, allied health educators should attempt to support different learning modalities, offer feedback, and learner control while mirroring the hands-on laboratory.

Lastly, this study demonstrated that students will use a preparatory resource of their own volition if they feel it will help them achieve greater success and is user-friendly. Other studies have reported that it is necessary to motivate students extrinsically to use a preparatory resource through the use of linked assessments or grades. In the courses involved in this study however, there were no such requirements and, despite this, 88% of respondents used the virtual lab. The majority of students also agreed that the virtual laboratory was easy to use. The implication of this finding is that when students feel they are gaining personal benefit from an easy to use virtual learning environment, they will more readily adopt it.

5.7 Limitations and Future Research

The study's purpose was to investigate student attitudes towards their experiences using a virtual lab for laboratory preparedness and skill acquisition. While careful attention was directed to collecting multiple sources, using frequency analysis to detect missing or incorrectly entered data, and determining inter-rater and internal reliability, there were at least seven limitations that, if addressed, could guide future research.

Firstly, the researcher in this study was also the participants' teacher for the 2nd year cohort of students. While the researcher did not offer any extrinsic motivation for the students to participate, it is possible that the teacher/student relationship may have affected the students' responses. There also existed a potential concern for participants around confidentiality. Future research should investigate virtual laboratories from more of an objective perspective.

Secondly, the population size was relatively small (N=97) and lacked complexity. Medical laboratory science students are a unique population within a unique program in Canada. More research needs to be conducted on a more diverse population from a wider range of higher education institutions focusing on allied health programs, to determine the generalizability of the results.

A third limitation of the study was the small sample size (n=4) within the think-aloud protocol, although it can be difficult to support a large sample size in this research activity (Charters, 2003). Future research using the think-aloud protocol should consider decreasing the demands on the participants' time, and the requirements of downloading computer software by investigating the use of simpler capture methods in an attempt to increase the number of participants.

Fourthly, a think-aloud protocol requires the researcher to draw inferences from the comments uttered (Charters, 2003). Also, participants may have experienced cognitive load while simultaneously speaking and performing data manipulation. Future research should consider including a post interview (Fonteyn, 1993) or allowing participants to review their transcript to aid in overcoming the inherent limitations of think-aloud protocol (Charters, 2003).

Concerning the study design, a fifth limitation was apparent. The Likert scale items were developed by the researcher, and testing and retesting the reliability of the scale items was not conducted prior to being administered. Internal reliability of the Likert scale r=0.67 (learning attitude scale) and r=0.69 (design attitude scale) could have been improved by increasing the number of items in each construct (Gliem & Gliem, 2003).

A sixth limitation was that the Likert scale did not include questions regarding authenticity, learner control, and content, which were significant categories that emerged during the open-ended questions and the think-aloud protocol. Increasing the number of Likert scale items to include categories found to be impactful through the open-ended questions and think-aloud protocol would add to determining the significance of these categories for future research.

A seventh limitation was that this study targeted only the benefits, challenges, and perceived impact of using a virtual lab and did not measure actual usage or student performance. Future research could be enhanced by including a pre-and-post study to compare usage and performance. The virtual lab helped students acquire skills, but whether those skills could fully transfer to the real world without the laboratory sessions is a question that needs to be addressed. Continued research into learning tools such as virtual laboratories may encourage those engaged in allied health education to consider the adoption and the evaluation of a virtual learning environment.

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Appendix A – Survey

Demographics

a. Please indicate your gender: Male or Female
b. Is English your first language? Yes or No
c. Which range contains your age? 17-20; 21-24; 25-30; or 30 and up
d. Please indicate which academic year you are presently enrolled in : 2nd; 3rd; or 4th

Likert Survey Questions

Instruction; Please circle a number indicating how much you agree or disagree with each of the statements.

Item	**Strongly Disagree 1**	**Disagree 2**	**Slightly Disagree 3**	**Neutral 4**	**Slightly Agree 5**	**Agree 6**	**Strongly Agree 7**
Learning							
1. The pre-laboratory checklist exercise helped me to prepare for labs. (RQ1)	1	2	3	4	5	6	7
2. The videos in the virtual lab helped me to learn. (RQ1)	1	2	3	4	5	6	7
3. The images of the reactions in the virtual lab helped me to learn. (RQ1)	1	2	3	4	5	6	7
Design							
4. The virtual lab was easy to use. (RQ1)	1	2	3	4	5	6	7
5. The virtual lab gives helpful feedback. (RQ1)	1	2	3	4	5	6	7
6. The layout of the virtual lab was helpful for bacterial identification. (RQ1)	1	2	3	4	5	6	7
Perceived Impact							
7. I completed the virtual lab pre-lab exercises when applicable. (RQ3)	1	2	3	4	5	6	7
8. The virtual lab played a role in completing the hands-on laboratory sessions. (RQ3)	1	2	3	4	5	6	7

9. The virtual lab helped me to prepare for labs. (RQ3)	1	2	3	4	5	6	7
10. The virtual lab resulted in me achieving greater success in my learning. (RQ3)	1	2	3	4	5	6	7
11. Using the virtual lab made it easier to learn new skills. (RQ3)	1	2	3	4	5	6	7
12. Being able to view the procedures ahead of the labs was helpful. (RQ3)	1	2	3	4	5	6	7
13. Using the virtual lab helped me to develop skills faster. (RQ3)	1	2	3	4	5	6	7
14. I would use the virtual lab again. (RQ3)	1	2	3	4	5	6	7

Appendix B – Open-Ended Questions

1. What were the benefits of the virtual lab for being prepared for hands-on labs? (RQ1)

2. What were the challenges of the virtual lab for being prepared for hands-on labs? (RQ2)

3. Which key characteristics of the virtual lab were most beneficial for preparing you for laboratory sessions?(RQ1)

4. If you could change anything about the virtual lab what would it be? (RQ2)

5. Which key characteristics of the virtual lab were most beneficial for helping you to acquire new skills? (RQ3)

6. Which key characteristics of the virtual lab were least beneficial for helping you to acquire new skills? (RQ3)

Appendix C – Virtual Lab

Appendix D – Pre-Laboratory Checklist

Week 6

Indicate which tasks have been completed or not completed.

#1 Please read the MLSC 2131 SOP Manual, Section 3, Biochemical and Other Identification tests. It is only necessary to study the tests to be performed in this laboratory session (see list below). The SOP will cover the principles of the tests.

- Mannitol salt – Media section
- DNase- Media section
- Tube Coagulase
- Staph latex agglutination
- Novobiocin
- Catalase

Completed Not completed

#2 Visit the virtual lab. Follow this breadcrumb trail to get to the videos on *Staphylococcus*.

- Make sure to watch the videos and look at the positive and negative reactions.
- Click on Gram-positive→ Gram-positive cocci→ Gram-positive cocci in clusters. You are there! Explore the *Staphylococcus* genus.

Completed Not completed

#3 Textbook of Diagnostic Microbiology, Read Chapter 14, Fourth Edition

Completed Not Completed

#4 Pre read through the entire laboratory exercise before the first laboratory session

Completed Not Completed

#5 Attended Lecture

Yes No

Always bring your MLSC 2131 SOP Manual **and** Laboratory Work Book to every laboratory session.

The checklist must be filled out prior to the start of the first laboratory session.

Comments and questions:

Appendix E – Letter of Invitation for Survey

Dear Student,

We warmly invite you to participate in the study entitled "***Assessing a Virtual Lab in an Allied Health Program***" designed to reveal the attitudes medical laboratory science students have towards the use of a virtual lab for enhancing laboratory preparedness and skill development. Your participation consists of completing an online Likert survey and open-ended questions using the online domain, *SurveyMonkey*. The survey and questionnaire will take approximately 15 to 20 minutes to complete.

Please note:

Participation is voluntary and you are free to decline without explanation or consequence. Your participation in this study is purely voluntary and as such, you may choose not to answer any item you wish and skip to the next question. You may also withdraw from the questionnaire at any time simply by closing the browser window or clicking on the "exit survey" link. However, once data is submitted, it can no longer be withdrawn due to the anonymity of the questionnaire.

Your academic program or instructor(s) will not know whether you have participated or not and your results will be kept anonymous. Your results will be reported in summary form so that no individual information can be identified. No data will be stored or reported which will link your responses to you.

By consenting to participate in this research, participants do not waive any legal rights.

Participation in the study will have no bearing or influence on your academic status/standing within the Medical Laboratory Science program at UOIT.

All survey data collected is anonymous and will be available only to the researchers of this project: Dr. Jia Li, Dr. Robin Kay, and Helene Goulding. Although *SurveyMonkey* uses US based servers, and as such is subject to US laws and/or the Patriot Act, NO personal or identifiable information is collected in this survey, and as a normal procedure, all data is deleted from *SurveyMonkey* immediately after the data collection period. The data will then be stored in digital form and secured by password-protected encryption on computer hard drives at UOIT. Complete anonymity of your responses is assured.

> The results of this study will be used as data for our research, and may be shared with the greater research community through publications and conference presentations.
>
> Given these safeguards, this research has been reviewed and approved by the Research Ethics Board of UOIT as well as UOIT's Ethics and Compliance Officer. REB number: 14-085
>
> If you would like to consider participating please read the attached consent form. By opening this attachment you are not consenting to participating.

If you have further questions regarding any aspect of this study, please respond to helene-marie.goulding@uoit.ca

Please contact the UOIT Ethics and Compliance Officer (9057218668 Ext. 3693 or compliance@uoit.ca) if you have any questions or concerns about the ethics of this study.

Regards,

Appendix F – Letter of Consent for Survey

Title of study: ***Assessing the Impact of a Virtual Lab in an Allied Health Program***

Principal investigator:
Helene Goulding, BAHSc, MLT, Faculty of Health Sciences.

Research Supervisors: Dr. Jia Li & Dr. Robin Kay, Faculty of Education.

Purpose of this study

The objective of the online survey is to collect participant's attitudes of the virtual lab. Participants will be sent an invitation via their UOIT.net email accounts to participate in the online survey. The research study will be voluntary.

Participant responsibilities

If you volunteer to participate in the survey study, you will be asked to fill out an online evaluation survey of the virtual lab.

Possible risks

The potential risks to study participants would be no greater than that encountered during normal everyday life. Participation in the study will have no bearing or influence on your academic status/standing at UOIT.
You may also be worried about the privacy of the information you provided. If you have these concerns, you may contact helene-marie.goulding@uoit.ca .

Privacy

Participants are being recruited for this study via Blackboard. All survey data collected will be anonymous and will be available only to the researchers of this project: Dr. Jia Li and Helene Goulding. Although *SurveyMonkey* uses US based servers, and as such is subject to US laws and/or the Patriot Act, no personal or identifiable information will be collected in this survey, and as a normal procedure, all data will be deleted from SurveyMonkey immediately after the data collection period. The data will then be stored in digital form and secured by password-protected encryption on computer hard drives at UOIT. Complete anonymity of your responses is assured. All volunteers will be asked to participate in the Likert surveys and the open-ended questionnaire. All responses will be coded and grouped into general themes and concepts, thus ensuring complete annominity.

Participation

Participation is voluntary and you are free to decline without explanation or consequence. You may choose to withdraw from the study at any time. You will not be affected in any way if you wish to discontinue your participation in the study. If you do not wish to continue in the study, you may discontinue the survey at any point and not submitted any part of the online survey. You are also not obliged to answer any questions you do not want to answer and you can still remain in the study. You have the opportunity to withdraw your data, by simply exiting the browser; whereas by clicking “Submit” you are consenting to let your anonymous data be used. Once data is submitted to the researcher, it cannot be deleted as submitted data is anonymous. There will be a reminder on or near the actual “Submit” button (at the end of the survey), reminding that you still have the opportunity to withdraw your data, by simply exiting the browser; whereas by clicking Submit you are consenting to let their data be used.

Study Sample

Approximately 100 Medical Laboratory Science students may participate in this study due to enrolment capacity. Students will be sent an invitation to participate in the online survey by email.

Possible benefits

Participants in this study will have the opportunity to increase their knowledge about the virtual lab and offer improvements to this online learning tool. Once the research is complete, the results of the study will be made available to the participants, upon request.

Refusal to participate

Participants can choose not to take part in this study. Refusing to participate will not affect you in any way.

Cost

There are no costs to participate in this study.

Contact Information

If you have any questions about the research, now or in the future, please contact Helene Goulding, principal investigator, helene-marie.goulding@uoit.ca , or the research supervisor, Dr. Jia Li, jia.li@uoit.ca If you have any questions regarding your rights as a research participant, please contact the UOIT research office, 905 721-3111 ext. 3693 or compliance@uoit.ca.

Consent Statement

Clicking on the survey link- one does not yet consent to participating in the study. You have the opportunity to withdraw your data, by simply exiting the browser, but rather once the “submit button” is clicked is when consent is implied. Once data is submitted to the researcher, it cannot be deleted as submitted data is anonymous.

TO PARTICIPATE, CLICK ON https://www.surveymonkey.com/r/YZ97XLL

Appendix G – Letter of Invitation for Think-Aloud Protocol

Dear Student,

We warmly invite you to participate in the study entitled "***Assessing the Impact of a Virtual Lab in an Allied Health Program***" designed to reveal the attitudes medical laboratory science students have towards the use of a virtual lab for enhancing laboratory preparedness and skill development. Your participation will consist of speaking aloud your thoughts as you complete a small section of the virtual lab for 5 minutes. Your verbal reactions will be audiotaped in a private setting by using the online free domain, Jing. The audiotaping will take approximately 5 minutes to complete. There will be a short pre-task orientation video available on how to use Jing for the audio recording.

Please note:

> Participation is voluntary and you are free to decline without explanation or consequence. You may refuse to participate or terminate your participation at any time. You may also withdraw from the study at any time. However, once the Jing link is emailed to the independent researcher, it can no longer be withdrawn due to the anonymity of the study. The independent researcher will dissociate the link from the sender's email. Collected links will be re-labelled as Link 1, Link 2, etc. The renamed links will then be sent to the principle researcher (Helene Goulding) for analysis. Once the data is transcribed it will be coded, grouped into concepts and then overall themes. Once data is transcribed the links will be deleted.
>
> By consenting to participate in this research, participants do not waive any legal rights.
>
> Participation in the study will have no bearing or influence on their academic status/standing at UOIT.
>
> There are no potential risks to you in participating in this study. Furthermore, you have the option to withdraw without penalty or prejudice. (Withdrawal may be accomplished, without consequence, at any time during the collection of the data).
>
> All verbal data collected will be anonymous and will be available only to the researchers of this project: Dr. Jia Li, Dr. Robin Kay, and Helene Goulding. Although *Jing* uses US based servers, and as such is subject to US laws and/or the Patriot Act, no personal or identifiable information is collected. The coded data will then be

stored in digital form and secured by password-protected encryption on computer hard drives at UOIT. Complete anonymity of your responses is assured.

The results of this study will be used as data for our research, and may be shared with the greater research community through publications and conference presentations.

Given these safeguards, this research has been reviewed and approved by the Research Ethics Board of UOIT as well as UOIT's Ethics and Compliance Officer. REB number: *14-085.*

If you would like to consider participating please read the attached consent form. By opening this attachment you are not consenting to participating.

If you have further questions regarding any aspect of this study, please respond to helene-marie.goulding@uoit.ca

Please contact the UOIT Ethics and Compliance Officer (9057218668 Ext. 3693 or compliance@uoit.ca) if you have any questions or concerns about the ethics of this study.

Regards,

Appendix H – Letter of Consent for Think-Aloud

Title of study: ***Assessing the Impact of a Virtual Lab in an Allied Health Program***

Principal investigator:
Helene Goulding, BAHSc, MLT, Faculty of Health Sciences.

Research Supervisors: Dr. Jia Li & Dr. Robin Kay, Faculty of Education.

Purpose of the study

The objective of the think-aloud study is to collect participant's verbal reactions and thought processes while using the virtual lab. Participants will be sent an invitation via their UOIT.net email accounts to participate in the think-aloud study- phase two. Participants will be asked to record verbal reactions while using the virtual lab using an online recording tool *Jing*. The "think-aloud" pilot study is completely voluntary.

Responsibilities

If you volunteer to participate in the think-aloud study, you will be asked to record your verbal responses while using the virtual lab. Verbal reactions will be recorded for approximately 5 minutes in length using the free online tool-Jing. There's a 5 minute pre-task orientation video which will briefly explain the data collection process. You will be shown how to make a Jing recording. Once the audiotape is complete- a link is supplied from the recording. The link has no identifiable information. You will then forward the link to an independent researcher, Jia Li. The links will be disassociated from the sender and re-labelled by the independent researcher. The collected links will then be sent to the primary researcher, Helene Goulding. Once all links have been collected- verbal data will be coded. Links will then be destroyed.

Possible risks

The potential risks to study participants would be no greater than that encountered during normal everyday life. There is an extremely remote chance that the researcher could identify the participant voice from a pool of 100 students. The researcher is a lecturer and has limited opportunity and ability to know each of the student's voice from a lecture-based section course and the pool of volunteers span over 3 academic years.

Participation in the study will have no bearing or influence on their academic status/standing at UOIT.
You may also be worried about the privacy of the information you provided. If you have these concerns, you may contact helene-marie.goulding@uoit.ca .

Privacy

Participants are being recruited for this study via their Blackboard email accounts. All data collected will be anonymous and will be available only to the researchers of this project: Dr. Jia Li and Helene Goulding. No personal or identifiable information will be collected in this survey. All audio data will be stored without unique file identifiers on secure servers (behind firewalls) and deleted after one year. Collated data will be stored in digital form and secured by password-protected encryption on computer hard drives at UOIT.

Participation

You may choose to withdraw from the study at any time. You will not be affected in any way if you wish to discontinue your participation in the study. You may withdraw from the study at any time simply by closing the browser window. You are not obliged to submit the voice recording if you wish to withdraw from the study. However, once data is submitted, to the independent researcher, it can no longer be withdrawn due to the anonymity of the study.

Study sample

Approximately 100 Medical Laboratory Science students may participate in this study due to enrolment capacity.

Possible benefits

Participants in this study will have the opportunity to increase their knowledge about the virtual lab and offer improvements to this online learning tool. Once the research is complete, the results of the study will be made available to the participants, upon request

Refusal to participate

Participants can choose not to take part in this study. Refusing to participate will not affect you in any way.

Costs

There are no costs to participate in this study.

Contact information

If you have any questions about the research, now or in the future, please contact Helene Goulding, principal investigator, helene-marie.goulding@uoit.ca , or the research supervisor, Dr. Jia Li, jia.li@uoit.ca If you have any questions regarding your rights as a research participant, please contact the UOIT research office, 905 721-3111 ext. 3693 or compliance@uoit.ca.

Consent Statement

I have read the preceding information thoroughly and understand the terms of the research. By submitting the think-aloud study, I give consent to participate in this study and allow the researcher to use my data for analysis of the study.

To participate:

1. Please download the free online tool Jing: http://www.techsmith.com/jing.html
2. Watch the instructional video on how to take your first capture with Jing: http://www.techsmith.com/tutorial-jing-taking-your-first-capture.html
3. Capture video will using the virtual lab.
4. Once you have finished capturing your video save your video capture by clicking on the screencast option. Your video will be rendered and at the completion you will have a link of your video capture.
5. Email the link to **jia.li@uoit.ca**
6. Dr. Jia Li, the research supervisor will dissociate the link from your email. Dr. Li will then collect all the links and identify as them as Link 1, Link 2, etc. The renamed links will then be sent to the principle researcher (Helene Goulding) for analysis. Once the data is transcribed it will be coded, grouped into concepts and then overall themes. Once data is transcribed the links will be deleted.

Please remember that you have the opportunity to withdraw at any time; whereas by emailing the completed Jing link to the independent researcher jia.li@uoit.ca you are consenting to let your data be used.

By completing the *Jing* video- one does not yet consent to participating in the study, but rather once the link is emailed to the researcher consent is implied.

Appendix I – Themes and Categories

Themes & Categories	Includes reference to:
Learning	
Visual	The mention of the visual aspect of the virtual lab which aids or hinders student learning.
Authenticity	Includes references to degree that the virtual lab can provide hands-on laboratory knowledge and real life experience.
Learner control	The mention of the extent in which students could learn independently by exercising control over content, place, time, pace, and flow while using the virtual lab.
Remembering	Student comments on the ease or difficulty to recall, review or memorize the material involving the virtual lab.
Reflective	Student comments on the ability or inability to learn by making mistakes while using the virtual lab.
Understanding	Student comments on the ease or difficulty of learning bacterial identification, grasping concepts and studying using the virtual lab.
Content	Includes references to the quantity or quality of the concepts covered in the virtual lab.
Design	
Graphics	Refers to the quality of the images and videos.
Organization	Refers to the quality of the flow charts, pathways, layout of the virtual lab.
Interactivity	Refers to the degree of interactivity of the virtual lab.
Ease of use	Student comments on the ease or difficulty of use.

Engagement	
Comparison	Comparison comments between the virtual lab and Internet search, reading or hands-on laboratory sessions.
Confidence	Refers to the degree in which the virtual lab can help or hinder confidence in hands-on laboratory sessions.
Engagement	Student comments on the virtual lab as being or not being useful/enjoyable/necessary.

Appendix J – Research Ethics Board Approval

UNIVERSITY OF ONTARIO INSTITUTE OF TECHNOLOGY

RESEARCH ETHICS BOARD
OFFICE OF RESEARCH SERVICES

Date: March 13th, 2015

To: Helene Goulding (Graduate Student/Faculty), Jia Li (Co-I) and Robin Kay (Supervisor)

From: Bill Goodman, REB Chair

REB File #: 14-085

Project Title: "Assessing the Impact of a Virtual Laboratory in an Allied Health Program."

DECISION: APPROVED
CURRENT EXPIRY: March 1st, 2016

NOTE: Notwithstanding this approval, you are required to obtain/submit, to UOIT's Research Ethics Board, any relevant approvals/permissions required, prior to commencement of this project.

The University of Ontario, Institute of Technology Research Ethics Board (REB) has reviewed and approved the above research proposal. This application has been reviewed to ensure compliance with the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans (TCPS2 (2014)) and the UOIT Research Ethics Policy and Procedures.

Please note that the (REB) requires that you adhere to the protocol as last reviewed and approved by the REB. Always quote your REB file number on all future correspondence.

CONTINUING REVIEW REQUIREMENTS:

- **Renewal Request Form:** All approved projects are subject to an **annual** renewal process. Projects must be renewed or closed by the expiry date indicated above ("Current Expiry"). **Projects that are not renewed within 30 days of the expiry date will be automatically suspended by the REB; and projects that are not renewed within 60 days of the expiry date will be automatically closed by the REB.** Once your file has been formally closed, a new submission will be required to open a new file.

- **Change Request Form:** any changes or modifications (i.e. adding a Co-PI or a change in methodology) must be approved by the REB through the completion of a change request form before implemented.

- **Adverse or unexpected Events Form:** events must be reported to the REB within 72 hours after the event occurred with an indication of how these events affect (in the view of the Principal Investigator) the safety of the participants and the continuation of the protocol. (I.e. un-anticipated or un-mitigated physical, social or psychological harm to a participant).

- **Research Project Completion Form:** must be completed when the research study has completed.

All Forms can be found at http://research.uoit.ca/faculty/policies-procedures-forms.php.