Development and Initial Testing of a Virtual Simulation Training Module to Teach Microtomy

by

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A thesis submitted to the
School of Graduate and Postdoctoral Studies in partial
fulfillment of the requirements for the degree of

Master of Health Sciences in Health Informatics

Faculty of Health Sciences

University of Ontario Institute of Technology (Ontario Tech University)

Oshawa, Ontario, Canada

August 2022

THESIS EXAMINATION INFORMATION

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Master of Health Sciences in **Health Informatics**

Thesis title: Development and Initial Testing of a Virtual Simulation Training Module to Teach Microtomy

An oral defense of this thesis took place on August 8th, 2022, in front of the following examining committee:

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The above committee determined that the thesis is acceptable in form and content and that a satisfactory knowledge of the field covered by the thesis was demonstrated by the candidate during an oral examination. A signed copy of the Certificate of Approval is available from the School of Graduate and Postdoctoral Studies.

ABSTRACT

Background: Microtomy is a procedure that medical laboratory technologists (MLTs) use to cut tissue samples. The aim of this thesis is to use the think-aloud protocol to develop a virtual simulation training module for students to learn microtomy.

Methods: A think-aloud protocol was conducted with an MLT expert to generate the steps of the microtomy procedure. Eight experts rated the criticalness and provided feedback on the steps. Once the module was developed, nine undergraduate students completed the module and provide feedback.

Results: The think-aloud protocol generated 10 steps for the microtomy procedure and experts concluded that all ten steps are critical. Students who completed the module provided a positive response and considered the module as a useful tool to practice microtomy.

Conclusions: The 10 steps of the microtomy procedure have been validated by MLT experts. Students completed the virtual simulation training module and viewed it as a user-friendly tool for learners of the medical laboratory sciences program.

Keywords: microtomy; simulation-based education; gamification; justice; simulation

AUTHOR'S DECLARATION

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STATEMENT OF CONTRIBUTIONS

This thesis has been organized into chapters with chapter one being the introduction, chapter two as the theoretical underpinnings, chapter 3 as the general methodology, chapter four and five are the two studies, and ending with chapter six as the general discussion of the work.

Chapter 4 has been published as:

Wahab, S., Buttu, D., Smeetonm,D., & Dubrowski, A. (June 07, 2022). Development of a Hands-On and Virtual Simulation Training Module To Teach Microtomy. Cureus 14(6): e25720. doi:10.7759/cureus.25720

Chapter 5 has been published as:

Wahab, S., & Dubrowski ,A. (June 25, 2022). Adapting the Gamified Educational Networking (GEN) Learning Management System to Deliver a Virtual Simulation Training Module to Determine the Enhancement of Learning and Performance Outcomes. Cureus 14(6): e26332. doi:10.7759/cureus.26332

I performed the participant recruitment, conducted the two studies, performed data collection, analysis, and writing. The virtual simulation training module was developed by Andrei Torres, a PhD student at Ontario Tech University.

Due to the two studies (chapters 4 and 5) being published, I have kept it in the same format as it was when published.

ACKNOWLEDGEMENTS

This work was supported by funding from the Natural Sciences and Engineering Research Council of Canada (NSERC, BK) and the Canada Research Chairs in Healthcare Simulation (CRCHS, AD), and the Canadian Foundation for Innovation (CFI, AD).

I would also like to thank my supervisor Dr. Adam Dubrowski for all his help throughout my graduate program. He has been of tremendous help and guided me along the way with any questions and concerns in my academic journey. I would also like to thank my committee members Dr. Bill Kapralos and Donna Smeeton for being a part of committee and providing me with their support and opinions on my thesis work. Lastly, I would like to thank Andrei Torres, the phD student who developed the virtual simulation training module and brought the vision to life. Without his help and computer science expertise, the module would not have been made so greatly.

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LIST OF ABBREVIATIONS AND SYMBOLS

MLT	Medical Laboratory Technologist
GEN	Gamified Educational Network
MLS	Medical Laboratory Sciences
CLIA	Clinical Laboratory Improvement Amendments Act
IBL	Internet-based learning
VR	Virtual Reality
CBVT	Computer-based video training
MRC	Medical Research Council
SDT	Self-determination Theory
KR	Knowledge of Result
KP	Knowledge Performance
ZPD	Zone of Proximal Development
SUS	System Usability Scale
OTU	Ontario Tech University
CSMLS	Canadian Society for Medical Laboratory Sciences

Chapter 1. Introduction

1.1 Overview of the Profession

Microtomy is a process that medical laboratory technologists use to cut tissues for further examination, making this a critical process for any sample slide examination under the microscope. A microtome is an instrument that is used to cut paraffin wax blocks to create thin tissue sections. A series of steps must be completed in sequential order, along with cautious safety features when handling the instrument. This thesis aims to explore various training technologies and techniques used in health professions education and apply them to the training gaps in the medical laboratory technologist field. Specifically, a virtual simulation training module presented in a video-based format was developed using a research oriented, custom developed learning management system called “Gamified Educational Network” (GEN) to teach microtomy. This introduction describes the profession and the roles of a medical laboratory technologist; the microtomy procedure and required equipment; the training gaps in the medical laboratory sciences setting; the concept of simulation and its types; and the solutions that emerging technologies provide to fill those gaps.

Medical Laboratory Sciences (MLS) is composed of numerous disciplines. Some of these include histology, biochemistry, hematology, microbiology, and transfusion science. These disciplines are an essential part of the healthcare system as they play a significant role in establishing effective preventative measures, predicting disease susceptibility, making diagnoses, and monitoring diseases (Plebani, Laposata, & Lippi, 2019). Medical Laboratory Technologists perform diagnostic testing for patients and interpret laboratory data. Individuals who want to become a part of this profession must obtain a formal education such as a university degree or college diploma in a specific Medical Laboratory program. The profession is not taken lightly by those who have numerous years of experience in the field, and therefore newcomers must dedicate and commit themselves to studying and keeping up with modern developments that have been discovered (Plebani, Laposata, & Lippi, 2019).

MLSs education is to prepare medical laboratory technologists (MLTs) who have adequate critical thinking skills and can work to deliver quality patient care. They are required to be knowledgeable regarding safety precautions and regulations provided in The Health and Safety at Work Act. Some technologists can be exposed to dangerous infected material daily, so they must always be aware of safety precautions (Baker & Silverton, 2014). Recently, governing and regulating bodies in this field made significant action calls to "keep up" with a new generation of learning and laboratory methods. However, these resulted in the re-training of laboratory personnel in the relevant work fields and did not address pre-licensure students. Some of these innovative training solutions focus on improving the confidence of laboratory personnel that order and interpret diagnostic investigations, contribute to reducing diagnostic errors, support the introduction of innovative technologies, and apply them in the clinical setting, and support innovation in teaching laboratory medicine in both medical schools and postgraduate courses (Plebani, Laposata, & Lippi, 2019). These training programs are aimed to reduce the number of errors that occur and building confidence when working in the laboratory.

1.2 Current Medical Laboratory Science Setting

In the medical laboratory sciences setting, there has not been much research or implementation of simulation-based training (Mohammedsaleh & Mohammedsaleh, 2014). A critical issue in the realm of the field of MLSs is the error rates that occur in many fields of the medical laboratory profession. It is a known problem that there is not enough and inadequate training not only in North America but around the world (Mohammedsaleh & Mohammedsaleh, 2014). Different countries have different requirements for certification for clinical laboratories (Mohammedsaleh & Mohammedsaleh, 2014). In the United States, federal standards require all medical laboratories to be certified under the 1988 Clinical Laboratory Improvement Amendments Act (CLIA). However, the qualifications set by CLIA are deemed inadequate because staff qualification requirements for the moderate and high-class laboratories are a high school diploma and some additional training required in the specified field of work (Baker & Silverton, 2014).

The risks are very high, and often, errors occur due to a lack of knowledge and skills among the MLTs, leading to severe consequences to both the staff and the patient (Mohammedsaleh & Mohammedsaleh, 2014). For instance, there has been a rise in the number of errors in pathology laboratories. This is likely due to the training not being well regulated as errors occur in the pre-analytic, analytic or post-analytic stage. The pre-analytical errors include inappropriate specimen collection and inappropriate preparation of the patient. In the analytical stage, most of the errors are caused by laboratory personnel. The post-analytical errors include loss of results and a wrong copy of the results (Mohammedsaleh & Mohammedsaleh, 2014). A study revealed that 75% of errors involved wrong patient labelling (Hammerling, 2012). This leads to significant harm or inconveniences in patient care and translates to considerable costs in the healthcare system. The errors in the pre-and post-analytical stage are when most errors occur of inappropriate patient care. The rate of errors in the laboratory field may be inaccurate as many errors are underreported, making the current statistics present a small portion of the medical errors that occur (Hammerling, 2012). Although all errors in any stage are wrong, there has been an emphasis on trying to reduce the error rates in the pre-analytical and post-analytical stages. This is likely due to the mistake being simpler to keep track of, whereas the errors cannot be detected physically in the analytical stage (Hammerling, 2012). Therefore, there needs to be a reliable and newly established method of recording errors in the laboratory.

A crucial component of medical laboratory science training is clinical experience. The lack of consistency in the microtomy procedure displayed in the literature demonstrates that MLTs are all learning differently because some MLTs might be trained to skip a crucial step of the procedure. Therefore, this thesis's main objective was to create an online video-based simulation training module for the microtomy procedure that will train a large number of students before using the physical microtome and face-to-face training.

1.3 Overview of Microtomy and the Microtome

One of the fundamental procedures in MLS is microtomy, which has a high degree of risk due to a lack of skill when cutting is first initiated. Microtomy is recognized as an important procedure as it is the process of cutting tissues into very thin sections and creating a slide used to identify abnormalities under the microscope. Biological specimens are embedded into paraffin wax blocks. Dempster conducted a detailed study examining if improper microtomy techniques resulted in poor slides, and results were further confirmed by Heard in 1951, who reported similar findings. The method they proposed to reduce tissue distortions was to treat the knife facets chemically (Jones & Milthorpe, 1994). The conclusion that was discovered after conducting all of these studies was that tissue distortions were primarily due to incorrect cutting technique of the section in the microtome's direction.

The microtome is the instrument that is used to cut the tissue blocks during microtomy. The oldest type of microtome is the rocking microtome, where the paraffin block moves through an arc while the blade remains stationary (Sy & Ang, 2019). This type of microtome is not an optimal choice as it cannot cut serial sections, there is a limit to the size of the block that can be cut, and the angle of the blade cannot be adjusted. Many different microtomes have been introduced into the market over the years, but for histology, the most commonly used microtomes are the rotary microtomes. The device has a rotary motion that is part of the cutting process. The blade is usually fixed in a horizontal position, and the tissue section is placed above the blade. The rotary wheel can be operated manually in many microtomes, but there are generally automated or semi-automated. Automated instruments reduce repetitive movements, which can minimize the risk of developing musculoskeletal disorders (Jones & Milthorpe, 1994).

Figure 1.1. Rocking microtome

A table microtome is a type of microtome used to cut thin sections of microscopic materials such as parts of plants and animals. It is the most basic form of a microtome and is suitable for beginner fieldwork (Radical Equipments, 2020). The instrument consists of a hand-operated microtome that must be attached to the edge of a tabletop surface fixing clamp's support. A feed screw has both fine and long threads, so the material may be inserted at a gradual pace to cut thin sections (Radical Equipments, 2020). Safety is always a concern, and this microtome has a durable glass surface to guide the blade and protect the hand.

Figure 1.2. Table microtome

A cryostat microtome is another form of a rotary microtome; however, this microtome is used for fresh tissues, which allows the tissue to freeze quickly for a frozen section. It is mainly used when there is a need for a rapid diagnosis of suspected carcinogenic surgical specimens. The tissue is then embedded into an optimal cutting temperature compound, allowing it to freeze in the cryostat cabinet. The constant temperature control is valuable for the pathologist because the tissue's quality stays relatively consistent (Nunnally & Abbott, 1961). After frozen, the block is placed in the holder for trimming and cutting and then placed on a glass slide to be stained (Smeeton, 2019).

Figure 1.3. Cryostat microtome

Another type of microtome is the high-speed ultra-microtome, which is used for electron microscopic study. The existing rotary microtomes cannot produce sections thin enough for electron microscopy. This limitation of cutting a tissue section extremely thin has limited its use where a high-resolution image would be an advantage (Fullam & Gessler, 1970). A high-speed microtome can cut a section extremely thin, required for electron microscopic study (Fullam & Gessler, 1970). It is operated by inserting a tissue sample into the feeding mechanism at the corrected height. The knife blade is placed in the split plug, which is rotated to obtain the sample's clearance angle. There are two types of motors on the microtome, and they are wired so that both motors can turn off together by one switch. The speed of the cutting motor is selected by setting the transformer according to the calibrated voltmeter. The feed motor's speed is selected depending on the desired thickness of the section (Fullam & Gessler, 1970).

Figure 1.4. Ultramicrotome for electron microscopy

When conducting the microtomy procedure, it is vital to understand all the parts of the instrument; as well as additional safety features regarding the procedure. Understanding the microtome and its components is required for cutting to minimize the damage of distortion to the tissue sample (Mohammed, Mohamed & Arishiya, 2012). The type of microtome that will be used in my thesis research is the manual rotary microtome. There are numerous parts to this microtome, and some are more crucial to the safety and quality of the procedure. All microtomes contain a knife and knife holder base, which connects the knife holder to the microtome stage. The base can be moved towards or away from the block, but it must stay locked during microtomy (Smeeton, 2019). Another key part of the microtome is the coarse and fine trimming wheels. These are the wheels that move the block holder either towards or away from the knife. Specifically, coarse trimming is where the excess wax from the block's face is trimmed away, exposing the tissue in preparation for fine trimming of thin uniform sections (Smeeton, 2019). Another part of the microtome is the specimen thickness gauge, which is used to set the desired thickness for tissue cutting. The microtome also has a wax tray where the paraffin residue and excess wax fall. This tray must be dusted and cleaned each time after completion of the procedure. Important to the safety of the MLTs are the microtome locks and knife guard. Figure 1.5 and 1.6, highlight all the parts of the manual rotary microtome.

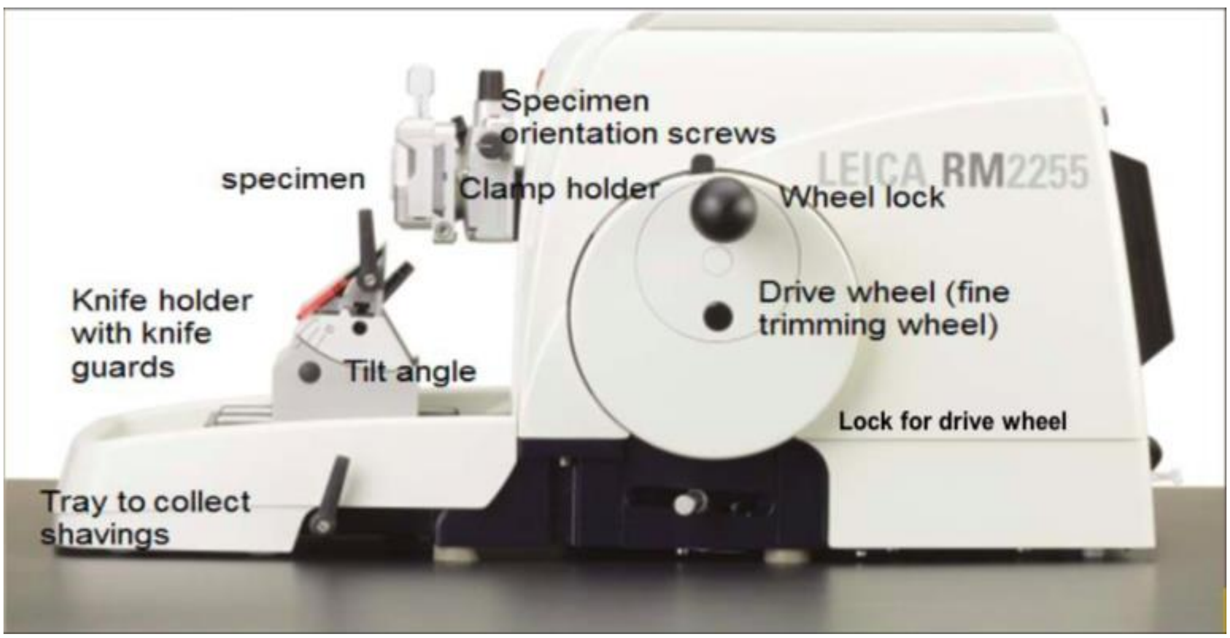

Figure 1.5. Side profile of the labelled rotary microtome

Figure 1.6. Front profile of the labelled rotary microtome

The knowledge and awareness of safety during the microtomy procedure are crucial. If the safety measures are not taken appropriately, an individual can seriously cut themselves with the blade. Disposable stainless-steel blades are used for cutting the tissue blocks. There are comparable to razor blades; however, this type of blade is thicker and more refined (Mohammed, Mohamed & Arishiya, 2012). An important safety feature is to make sure a used blade is carefully disposed of in the sharp's container, never leaving the blade in the microtome when not in use, and always using the knife guard and locking the microtome when not cutting. The microtome wheels and the main lock at the microtome base must also always be locked when not in use. After completion of the microtomy procedure, several steps need to be taken for cleaning up. This includes ensuring the microtome is locked, then carefully removing the blade before starting the cleaning process, then removing the paraffin and tissue debris with a brush, checking to see that there is no wax buildup in the specimen holder, and ensuring all moveable parts are tightened and locked (Smeeton, 2019).

1.4 The Microtomy Procedure

The Rolls (2019) article on specimen processing, states ten general examples of what is appropriate and what is not when completing fixation, tissue processing and embedding (Rolls, 2019). There are no specific guidelines to follow in terms of the microtomy process. An example provided was the importance of adequately filling the mold with wax. Overfilling the mold with wax requires scraping the edges of the cassette before microtomy. An over-filled wax block does not sit well in the microtome and can damage the tissue during microtomy (Rolls, 2019). An under-filled block may lack support during cutting. The literature also describes the tissue sectioning process vaguely and focuses on the cutting process, specifically the blade. It highlights the importance of the blade and its type on the microtome. Disposable blades are more advantageous than non-disposable blades because the blade holder can clamp it more tightly, providing consistent and even cutting. The literature also contains a more in-depth process consisting of 24 detailed steps when performing the microtomy process. Following the 24 steps is a list of items that may go wrong during the procedure, an explanation of why it happened, and a solution to fix the issue. The Leica microtome manual describes the series of steps of the microtomy process. The process starts with setting up the microtome correctly by setting the clearance angle and utilizing the safety features, using the correct instruments when handling the tissue sections. Next, the manual discusses tissue thickness. The actual thickness of the first few sections may be thicker due to thermal expansion (Rolls, 2019). Cold wax better supports hard elements in a tissue block, thus achieving thinner sections. The following step explains how to float out tissue sections carefully onto a water bath by setting the temperature correctly and making sure the water is free of bubbles. Finally, the last step explains how to dry the tissue section to prevent it from lifting during staining. Overall, the literature describes numerous variations of the steps required for the microtomy procedure, and there is no consistency in the steps of the procedure. Thus, demonstrating the gap in this procedure.

1.5 Simulation Training

Simulation-based education is an educational practice that introduces learners to an extensive learning environment allowing them to develop knowledge and receive feedback without the pressure and cost of errors. It is defined as “the imitation or representation of one act or system by another” (Society for Simulation in Healthcare, n.d). Healthcare simulations consist of four main areas: education, assessment, research, and health system integration in facilitating patient safety, with my thesis firmly rooted in the area of education. Trainees can develop the skills required at their own pace with unlimited repetition of specific scenarios catered to the skill (Rojas, Kapralos & Dubrowski, 2014). Simulation learning can be thought of as an activity that mimics or ‘recreates’ reality in a controlled environment with fully immersive or guided experiences and tasks (Grant, 2008). As the literature emerged, many types of simulation activities have been created such as 1) concept simulation using computer-based animation 2) virtual patient simulation to reproduce clinical scenarios 3) part-task training for procedural or psychomotor skills, and 4) high-fidelity patient simulation using computerized mannequins (Grant, 2008). Many studies explore if technical skills training on simulated models improves technical performance in the operating room, and research suggests that technical skills training on simulated models enhances technical performance. Traditional education methods are limited due to patient safety, work hours restrictions, instructor availability, and the cost of operating room time (Rojas, Kapralos & Dubrowski, 2014). In the healthcare field, patient safety and complications are always a concern. Many patients are put at risk when regular training occurs, and skills are practiced on live patients. In a simulated setting, trainee surgeons can practice the procedure any number of times without the need of a live patient.

Learning is generally categorized into three domains: cognitive, affective, and psychomotor (Hoque, 2016). Within each of these learning domains, multiple levels progress from more basic to more complex and deeper learning (Hoque, 2016). The cognitive domain consists of learning skills related to the thinking process. This domain involves numerous skills involving processing information, constructing understanding, applying knowledge, solving problems, and conducting research. Skills associated with lower-level processes should be introduced in earlier stages, whereas skills associated with higher-level processes should be introduced later. The affective domain involves feelings, emotions, and attitudes. It is based on how individuals deal with things emotionally, such as feelings, values, appreciation, enthusiasm, motivation, and attitude. The learning objectives vary from simple attention to more complex qualities of character and conscience. The domain is also categorized into five sub-domains including receiving, responding, valuing, organization, and characterization (Hoque, 2016). Lastly, the psychomotor objectives are physical functions, reflex actions and interpretive movements. This learning type involves movements where the gross and fine muscles are used for expressing or interpreting information or concepts (Hoque, 2016). It also refers to natural, autonomic responses or reflexes.

These learning domains can all be developed with different types of simulations. The psychomotor learning domain can be developed in simulations measuring accuracy or speed (reaction time). The affective domain can be applied to simulations involving healthcare professionals. For instance, the levels of affective domain learning can be observed in high-fidelity nursing simulations for student nurses. The training regarding the microtomy procedure is based on student safety and proper microtomy technique which mainly revolves around the cognitive domain of learning. Therefore, the tools that are useful for these types of simulations are: virtual and video based.

Internet-based learning (IBL) is associated with using electronic media, information and communication technologies in education (Rojas, Kapralos & Dubrowsk, 2014). This learning method has been widely applied across many levels of education such as high school, university, and health professions education. The literature presents simulation in health professional education as video interactions, computer-based learning modules, online activities, virtual reality applications and mannequins, replacing the need for live patients. A recent survey showed that among all the various types of simulation used by health professional educators, mannequins were the most common (used by 80% of participants) (Grant, 2008).

Virtual Reality (VR) medical simulators are diverse in that it can be tailored to different professions and learning styles in ways that cannot be equivalent to traditional teaching methods. VR medical simulation has numerous advantages over traditional teaching methods. Instead of exposing the live patient to severe risks, trainees can practice and develop the skills required in a safe setting before attempting it live on the patient (Ruthenbeck & Reynolds, 2015). It also allows the trainee to gain these skills at their own pace without the added pressure of time.

Another way simulation training can be applied is through computer-based video training (CBVT). This type of training is advantageous because trainees can practice independently in a self-paced manner, which ultimately maximizes their operative experience. CBVT has been widely used for surgical skill training as it is equally effective as faculty instruction in various settings (Kumins et al., 2020). Students and trainees are provided with instructions and watch videos demonstrating the procedure and skill required to be learned. It is usually followed with an assessment method of a quiz or recording themselves performing the skill. Studies have shown that medical students improved their scores significantly in all six knot-tying methods and suturing skills after participating in CBVT (Kumins et al., 2020).

In the past two decades, there has been an increased involvement in simulation in health professions education, specifically medical education. The main reason for introducing simulation in this field is a concern for patient safety. In the medical laboratory sciences setting, the interest in simulation-based learning, so the reliance on clinical partners is decreased (Grant, 2008). However, due to limited research, educators are unsure how to approach simulation as an educational strategy for medical laboratory programs.

Although simulation-based learning has been introduced into medical laboratory sciences, simulation is under-utilized in this field of learning, especially for microtomy training. It is evident that simulation training is recommended as an educational tool in the healthcare profession (Grant, 2008). In the United States, there has been an increased interest in simulation laboratories in the medical laboratory programs due to difficulties finding and re-training clinical sites that will train their students (Grant, 2008). The recent COVID-19 pandemic has affected the entire world, and we must adapt to a new way of living. A high focus has been shown on remote learning, replacing the more traditional face-to-face method of learning. This shift should also be applied to MLT training and education to assist MLT educators in educating students and trainees. It has emphasized the need to develop programs and training material for remote self-directed education.

1.6 Gamified Educational Network (GEN)

Gamified Educational Network (GEN) is a learning management system that was developed by incorporating gamification principles (usage of game-based elements in a non-game context to engage learners and promote learning), peer-to-peer reviews, and expert feedback into a learning system (Torres et al., 2019).

Online collaborative learning has existed since the 80s, and the increasing advancement of technology has allowed e-learning to stay relevant. Since then, there have been many frameworks and practices developed to contribute to online collaborative learning. My master's research will use GEN to promote collaborative learning by allowing learners to participate in online activities that incorporate a game element. The network consists of a point-based system that ranks the learners participating in a specific activity (Rojas et al., 2014). The leaderboard system is beneficial by allowing students to keep track of their progress and letting them know what rank they are relative to their peers, motivating them to do better (Torres et al., 2019). Video games are becoming increasingly popular, and there has been a demand for applying game-based technologies to teaching and learning (Haji et al., 2014). This is due to “game-based mechanics, aesthetics, and game thinking to engage people, motivate action, promote learning, and solve problems” (Torres et al., 2019). Specifically, GEN will be the network that I will be using for my online safety module. This safety module contains safety content regarding microtomy prior to starting the actual procedure. The module will consist of videos that will be uploaded to the network, followed by questions pertaining to the content in the videos. Students will watch the videos, and, in the end, take a quiz. The student must receive a score of 100% before moving forward and starting the microtomy procedure. This feature of uploading the safety module onto GEN, followed by an assessment quiz will ensure that students have learned and understood the microtomy procedure’s safety rules and precautions.

1.7. Piloting

The Kirkpatrick Model was used to construct tests of acceptability and feasibility from the end point users. This model is best known for analyzing and evaluating the results of training and educational programs and is based on four criteria levels (Kurt, 2016). Level 1, *Reaction*, measures how participants react to the training, such as their level of satisfaction. Level 2, *Learning*, analyzes whether the participant understood the training and if they gained knowledge, skills, or experience. Level 3, *Behaviour*, determines whether the participant has implemented what they learned from the training in their work. Lastly, Level 4, *Results*, identifies if the training had a positive impact on the business or organization (Kurt, 2016). However, this thesis implements only Level 1 (Reaction). The participants will complete a virtual simulation training module that will measure the participant's reaction to the module and their learning. The participants are tested as they complete the module, thus, learning levels can be determined.

1.8. Summary

In summary, there is currently no existing simulation-based learning method that students and trainees in the medical laboratory sciences program can learn and develop the skills required of them. This involves all the training and skills they need to learn in a laboratory setting. There is especially no simulation research regarding the microtomy procedure. With GEN being the online learning platform that I have used in my master's thesis, I proposed a solution for students and educators in the medical laboratory sciences program to train in the simulated setting. The main research question explored in this thesis is 'what are the contents and technological needs to build the virtual simulation training module?' and secondly, 'to what degree are students satisfied with the module with respect to acceptability and feasibility of this approach?'

Chapter 2. Theoretical underpinnings

2.1 On-line, Virtual Learning

Online collaborative learning has existed since the 80s, and the increasing advancement of technology has allowed e-learning to stay relevant. Since then, many frameworks and practices have been many frameworks and practices developed to contribute to online collaborative learning. The Gamified Educational Network (GEN) was developed in our laboratory by incorporating the technologies coupled with gamification principles (usage of game-based elements in a non-game context to engage learners and promote learning), peer-to-peer reviews, and expert feedback. My master's research will use GEN to promote collaborative learning by allowing learners to participate in online activities that incorporate a game element. GEN is an appropriate learning management system that meets the educator and user's needs. The network consists of a point-based system that ranks the learners participating in a specific activity (Rojas et al., 2014). The leaderboard system is beneficial as it allows students to keep track of their progress and lets them know what rank they are relative to their peers, motivating them to do better. Video games are becoming increasingly popular, and there has been a demand for applying game-based technologies to teaching and learning. This is due to game-based mechanics, aesthetics, and game thinking to engage people, motivate action, promote learning, and solve problems (Torres et al., 2019).

Augmented feedback is another important concept as it provides feedback from an external source and can be provided as knowledge of result or knowledge of performance. Feedback gives learners an insight to maximize their strengths and work on their weaknesses to become more effective. It has been demonstrated to show improvement in performance outcomes (Wälchli et al., 2016). More specifically, feedback is essential in an online learning environment because students are more likely to be disconnected from the learning environment than attending face-to-face courses (Wälchli et al., 2016). Therefore, providing feedback to students allows them to feel engaged in the learning process. Expert feedback involves feedback provided by the educator or instructor. This allows students to become more self-aware of both their strengths and areas for improvement. All of these theoretical underpinnings are implemented within the GEN learning management system.

In addition, the theoretical underpinnings that support this research also include video-based instructions and levels of analyses, and augmented feedback that contains peer-to-peer feedback and expert feedback. Computer-based video training (CBVT) is advantageous because trainees can practice independently in a self-paced manner, which ultimately maximizes their operative experience (Kumins et al., 2020). Students and trainees are provided with instructions and watch a video or series of videos demonstrating the procedure and skill required to be learned (Kumins et al., 2020). It is usually followed with an assessment method of a quiz or recording themselves performing the skill. Evaluation is widespread in the simulation world when using a tool because it needs to be validated first before it is used to measure and assess a skill. This learning approach allows learners to practice the procedure’s skills at a relaxed pace that can be transferred to a real-life setting. Typically, participants watched an instructional demonstration and were asked to perform the four tasks. Traditional education methods are limited due to patient or student safety, work hours restrictions, instructor availability, and the cost of operating room time (Dunphy, 2016; Rojas, Kapralos & Dubrowski 2014). Simulation-based training, specifically CBVT, must be uploaded on a platform or learning system where trainees can access this information to a) watch the videos or b) perform the simulation. Once again, traditional educational methods are costly due to the economy, faculty time, and operating room time. Thus, technology for learning and training becomes a viable alternative approach.

The theoretical underpinnings for this educational network come from the Levels of Processing model, created by Fergus I.M. Craik and Robert S. Lockhart in 1972. The model suggests that it is not the intention to memorize something, but the stimulus-encoding process that is important for future retrieval of the stimulus. In the encoding stage, there is a series of processing hierarchies. During the shallower processing level (perceptual processing), the subject initially perceives the physical and sensory characteristics of the stimulus (Ekuni, Vaz & Bueno, 2011). The deepest level (semantic processing) is related to pattern recognition and extraction of meaning, with an emphasis on semantic analysis rather than shallow processing (Ekuni, Vaz & Bueno, 2011). It was proposed that semantic analysis (i.e., the deeper processing) is associated with higher retention levels and long-term memory traces. The deeper processes also require more attention than shallow processes demonstrating that the learner is more engaged when presented with tasks that require deep processing. Therefore, when using the GEN learning management system, learners not only watch videos but watch a series of videos to identify mistakes that seem to look the same in the task or skill they are learning. The repetition of an item encoded only at a sensory level does not improve memory performance (Craik & Lockhart, 1972). However, when using GEN, learners can also repeatedly watch the videos, leading to repetition. The task that is being asked to perform involves more than sensory processing; this results in an improvement in memory performance. This allows the learners to engage in a deeper level of analysis (semantic analysis), which would result in more profound levels of learning. This type of learning is known to be associated with higher levels of retention and long-term memory, ultimately increasing the outcomes of performance.

2.2 Video-based Instructions and Level of Analysis

Currently, medical laboratory technologist students are required to develop the technical skills that are needed to conduct the microtomy procedure. Teaching these skills can become complex and a large undergraduate classroom imposes greater demands and time and teaching faculty resources (Dubrowski & Xeroulis, 2005). One way to address this issue is to utilize self-directing using computer-based video training (Dubrowski & Xeroulis, 2005). Over the years, computers and communications technology have revolutionized educational delivery methods. Computer-based video training is advantageous because trainees can practice independently in a self-paced manner, maximizing their operative experience. Students and trainees are provided with instructions and watch a video or series of videos demonstrating the procedure and skill required to be learned (Kumins et al., 2020). It is usually followed with an assessment method of a quiz or recording themselves performing the skill. Evaluation is widespread in the simulation world when using a tool because it needs to be validated first before it is used to measure and assess a skill. The computer-driven method allows for an objective assessment of technical skills, permits data interpretation by a laboratory technologist, and has a low-operating cost, all of which promote it as a reliable, highly replicable, and inexpensive competency assessment method (Dubrowski & Xeroulis, 2005). This learning approach allows learners to practice the procedure’s skills at a relaxed pace that can be transferred to a real-life setting. Traditional education methods are limited due to patient and student safety, work hours restrictions, instructor availability, and the cost of operating room time (Kumins et al., 2020; Rojas, Kapralos, & Dubrowski, 2014).

Computer-based instruction also reduces geographic and temporal constraints on training (Xeroulis et al., 2007). The advantages of training in a skills lab include decreased stress of learning when compared with the operating room, the opportunity for repetitive and deliberate practice, participatory rather than observational learning, and the ability to tolerate and correct performance errors (Xeroulis et al., 2007). Simulation-based training, specifically CBVT, must be uploaded on a platform or learning system where trainees can access this information to a) watch the videos or b) perform the simulation. Once an application has been set up, trainees are not constrained by laboratories being booked for a certain amount of time. On an online platform, students can repeat, interrupt, and resume training at will, which may have advantages for weaker students (Xeroulis et al., 2007). The use of CBVT promotes self-directed learning, which is important in medical education as there is limited faculty or staff availability and time allocated for students and trainees. It also allows trainees and students to personalize their learning according to their schedules. This type of computer training can also be modified, customized, and updated to meet the needs of the curriculum of the traditional teaching approach. Thus, technology for learning and training is becoming a viable alternative approach.

Video-based instructions are also used in combination with “spot the difference” approaches. Trainees watch a series of videos of the skill they are required to learn. Some of these videos are right and some are wrong. The objective is for students and trainees to identify which video is done incorrectly and look for the mistakes in these series of videos that seem the same. This method reinforces and allows the learner to engage in a deeper level of analysis resulting in deeper learning levels.

2.3 Augmented Feedback

Augmented feedback is defined as feedback from an external source and can be provided as knowledge of result (KR) or knowledge performance (KP) (Wälchli et al., 2016). It is important to note that augmented feedback is not only effective when applied to long term training, but it is also effective in short-term performance gains. Feedback provides learners with an insight to maximize their strengths and work on their weaknesses to become more effective, an essential aspect of becoming an expert at a practiced skill (Ronsse et al., 2011). It has been demonstrated to show improvement in performance outcomes by producing motivation, supplying reinforcement for correct actions, and dissuades incorrect actions (Ronsse et al., 2011). More specifically, feedback is essential in an online learning environment because students are more likely to be disconnected from the learning environment than attending face-to-face courses (Wälchli et al., 2016). Augmented feedback might enhance motivation by encouraging participants to outplay their foregoing or maximal performance. This comparison with their own foregoing performance is believed to enhance the intrinsic motivation (Dubrowski & Xeroulis, 2005). The ideology is that augmented feedback needs to provide information for learning and whoever provides this information must have more extensive knowledge. This brings upon the theory of the Vygotsky Zone of Proximal Development (ZPD) (Dunphy, 2003). The use of feedback can demonstrate what a learner can do with help, with the support of the environment, of others, and of themselves (Dunphy, 2003). In ZPD this information is provided by the teacher, the expert, and the more capable peer

(Dunphy, 2003). Learning with ZPD can be divided into four stages. Stage one is where performance is assisted by more capable others. Stage two is when the performance is assisted by itself. This does not necessarily mean the performance is fully developed or automatized (Dunphy, 2003). Stage three is when the performance is developed, and the learner has emerged from the ZPD (Dunphy, 2003). Lastly, stage four is where de-automatization occurs, and the learner is engaged in other assistance to self-assistance for the development of new capacities (Dunphy, 2003). In the early stages of learning, the learner has a limited understanding of the task and experts offer direction or modeling. Therefore, providing feedback to students allows them to feel engaged in the learning process.

Expert feedback involves feedback provided by the educator or instructor. This allows students to become more self-aware of both their strengths and areas for improvement. When an expert provides feedback during the performance of the skill it is referred to as concurrent feedback, and when provided on completion of the skill it is referred to as summary feedback (Xeroulis et al., 2007). With that being said, the nature and timing of feedback influences the effectiveness of this learning strategy. For instance, feedback timing can produce different effects when performance is measured immediately after practice compared to a rest period. All of these theoretical underpinnings are implemented within the GEN learning management system.

Chapter 3. Methods

3.1 Overview

The studies outlined follow the Medical Research Council (MRC) framework to develop complex interventions (Haji et al., 2014). The two studies outlined below will start with a robust theoretical scan of the literature, which will result in the development of the most relevant education content (e.g., learning modules). The initial content will be developed based on expert opinions (study one), followed by the development of the most suitable virtual simulation platform to deliver the content, which will follow Kirkpatrick's program evaluation model (study two). Study two will focus on testing learners' reactions to the module, including aspects of acceptability and feasibility.

3.2 Research Framework

The studies will follow the Medical Research Council (MRC) framework for the development of complex interventions. The framework proposes a nonlinear approach that emphasizes both piloting and implementation studies, integrates process and outcome evaluation, and highlights the importance of understanding the intervention's context (Haji et al., 2014). Complex interventions are developed from numerous components that may act both independently and interdependently (Haji et al., 2014). These interventions are characterized by a multitude of active ingredients that make standardization of intervention delivery difficult, long casual chains linking them with intended outcomes, and features that mutate upon local contexts (Haji et al., 2014).

The framework encompasses cycles such as theory and modelling, piloting, evaluation, and implementation. For this thesis, the first two cycles, theory and modelling, and piloting will be addressed. It promotes research that seeks to understand the relationship between an intervention, its context, and its outcomes. This research thesis uses simulation as an intervention for microtomy training to compare its outcomes with traditional training methods. The first cycle *theory and modelling* cover the development phase which comprises 2 subphases known as theory identification and intervention modelling (Haji et al., 2014). To achieve this, gaps in the literature must be identified, generate a hypothesis, identify suitable outcomes, and outline the simulation intervention to be studied. It also involves mapping out the content, structure, and delivery of the intervention and its components and then linking them with anticipated outcomes stated in the methodology. The second cycle consists of *piloting* which investigates the feasibility and acceptability of the intervention. Potential barriers must be addressed to ensure the simulation is appropriate. It also involves identifying and designing the protocol for a comparison group, to which the primary intervention may be compared in the evaluation phase (Haji et al., 2014). The methodology of this thesis has been designed and positioned around the basis of the MRC framework. It considers the first two cycles of the framework into consideration as they have all been addressed in the two studies described previously.

Qualitative methodologies are used to explore why or how a phenomenon occurs, to develop a theory, or describe the nature of an individual's experience, while quantitative methodologies address questions about causality, generalizability, or magnitude of effect (Berman, 2017). A mixed methodological approach draws on the strengths of both qualitative and quantitative research. The design of this study follows a mixed methodological approach with both qualitative and quantitative approaches. Specifically, it will be an explanatory design as study one follows a quantitative approach and study two follows a qualitative approach. In reference to action representation, study one will identify the actions that will be used as the basis to conduct study two. Study two will consist of adjusting actions to be better represented in the GEN LMS. A researcher first collects and analyzes the quantitative data. The qualitative data is collected and analyzed second in the sequence, and helps explain, or elaborate on, the quantitative results obtained in the first phase (Ivankova, Creswell & Stick, 2006). The purpose of this approach is the quantitative data, and the subsequent analysis is to provide a general understanding of the research problem (Ivankova, Creswell & Stick, 2006). The qualitative data and their analysis refine and explain those statistical results by exploring participants' views in more depth (Ivankova, Creswell & Stick, 2006).

More specifically, the qualitative research portion will follow a phenomenological research design. A phenomenological study describes the common meaning for several individuals of their lived experiences of a concept or phenomenon (Creswell, 2018). The purpose of phenomenology is to reduce individual experiences with a phenomenon to a description of the universal essence (Creswell, 2018). The inquirer or researcher collects data from individuals who have experienced a phenomenon and develops a composite description of the essence of the experience for all the individuals (Creswell, 2018). The description generally consists of "what" they experienced and "how" they experienced it. There is a common philosophical assumption that the study of these experiences is a development of descriptions, not an explanation or analysis. Phenomenological studies typically include several features that define this approach. There is an emphasis on a phenomenon to be explored and is phrased into a single concept or idea. The exploration of this phenomenon involves a group of individuals who have all experienced this phenomenon, which generally ranges from 1 to 4 individuals to 10 to 15 (Creswell, 2018). The data collection procedures that are involved in this approach include interviewing individuals who have experienced the phenomenon. This is not universal, as there is a variety of data collection such as poems, observations, and documents. The data analysis can follow systematic procedures that shift from the narrow units of analysis (e.g., significant statements), to broader units (e.g., meaning units), and then to detailed descriptions that summarize the two elements of "what" the individuals have experienced and "how" they have experienced it. Lastly, phenomenology generally ends with a descriptive passage that discusses the 'essence' of the experience for individuals incorporating the 'what' and 'how'. The essence is the culminating aspect of a phenomenological study (Creswell, 2018).

Phenomenology also consists of subtypes known as hermeneutic phenomenology and empirical, transcendental, or psychological phenomenology. Hermeneutic phenomenology is described as oriented toward lived experiences and interpreting the "texts" of life. It is not only a description, but it is also an interpretive process in which the researcher interprets the meaning of the lived experiences (Creswell, 2018). Conversely, empirical, transcendental phenomenology is developed by analyzing the data to produce significant statements and combine them into themes. Following that, a textual description referring to the 'what' they experience was developed, and a structural description of 'how' they experienced it.

This research study will follow a descriptive approach which differs from hermeneutic phenomenology, in that an interpretive approach is. Descriptive phenomenology is the requirement to explore, analyze and describe a phenomenon while maintaining its richness, breadth, and depth to gain a 'near real picture' (Matua & Van Der Wal, 2015). The reasoning behind choosing a descriptive approach over an interpretive one is to generate knowledge that emphasizes what it is like to undergo a particular experience. To achieve this, the experience must only focus on describing the experience without mentioning any of the participants' social, cultural or political contexts. The outcome of the research is to 'unveil' how a particular experience presents itself, with nothing added and nothing subtracted (Matua & Van Der Wal, 2015)

3.3 Study Specific Procedures

3.1.1 Study One

Study one encompasses the theory and modelling cycle of the framework. It employed a think-aloud method to decompose the microtomy procedure into subtasks. The think-aloud method asks people to think aloud while performing a task and analyzing the verbal protocols (Someren, Barnard & Sandberg, 1994). The protocols provide a clear insight into how individuals reach the solution and solve a problem step by step (Someren, Barnard & Sandberg, 1994). A single teaching faculty expert participated. The expert was asked to perform microtomy while being video recorded and talk through the procedure while providing reasoning and thinking. Collecting knowledge from an expert is called *knowledge elicitation* (Someren, Barnard & Sandberg, 1994). These recordings were used to map the entire microtomy procedure.

Next, a modified Delphi method was used by generating an initial concept document (Haji et al., 2015). The Delphi method is recommended for use in the healthcare setting as a reliable means of determining consensus for a defined clinical problem (Eubank et al., 2016). Eight experts participated, and consensus was built from two separate rounds. A comprehensive list of items was identified, and each expert completed a questionnaire and provided comments on each item on the list. At the end of the two rounds, a consensus was made using the experts' data. The decision to follow the modified version of the Delphi method was made because we had access to a local expert who prepared the initial concept document.

3.1.2 Study Two

Study two involves adapting the GEN LMS to deliver the virtual simulation module. This study encompasses the piloting cycle of the framework which investigates how the GEN learning management system can be adapted to enhance the user experience. The participants completed the module and provided feedback to try to understand the virtual simulation training module's needs and the changes required to the existing virtual GEN learning management system. The GEN learning management system includes gamification elements to better engage and motivate students in the learning process, emphasizing peer-to-peer assessment and feedback (Torres et al., 2019). The educational content developed in study one was used to create a series of videos that participants were then tested on. Using a survey, the participants were asked to provide their reactions using open feedback to the system's educational value and usability.

Selecting participants is vital as individuals are typically chosen based on their experience or lack of experience related to the topic (Longhurst, 2003). Purposeful sampling was used as it is generally used in qualitative research (Creswell, 2018). The researcher selected MLT students because they can purposefully inform an understanding of the research problem and central phenomenon in the study (Creswell, 2018). The participants were accessible through access from a local expert and educator. The System

Usability Scale (SUS) is the survey that was used to ensure an understanding of the participants' needs and experiences so the GEN LMS can be adapted to suit the needs of the MLT students. The SUS is a 10-item questionnaire with five response options using a Likert scale (1; strongly disagree, 5; strongly agree) (Sauro, 2011). Ultimately, it measures how useable a system is.

A group of MLT students were asked to engage in the virtual simulation module, which was held on the GEN system that supported and administered the module. Students were be asked to navigate the module by reading the safety precautions, watching videos and being assessed on the content. After completing the simulation module, students were asked to provide their feedback on the module using the SUS questionnaire, which allows us to assess their a) perceptions in relation to the module’s content, b) the module’s potential to serve as an educational tool, and c) provide possible improvements to the module. The purpose of this is for the participants to describe their experiences of the content and interactivity of GEN and the participants’ perceptions of the educational value of the module.

Chapter 4. Study One: Development of A Hands-on and Virtual Simulation Training Module to Teach Microtomy

Abstract

Background: Microtomy is a risky procedure that medical laboratory technologists (MLTs) use to cut tissue samples for microscopic examination. Due to the safety concerns and the potential to destroy tissue samples, it is critical for learners to perform the procedure correctly. To allow for safe and controlled learning, this procedure should be acquired in a safe and controlled simulated setting before attempting on human tissues. The overarching purpose of this work is the development of a virtual training module for undergraduate students to learn from. However, because of the heterogeneity in the steps required to successfully complete the procedure from the MLTs as well as in the literature, the aim of this study was to reach a consensus from a panel of experts about identifying the steps of the procedure using the think-aloud and modified- Delphi method.

Methods: First, we conducted a think-aloud protocol with a single MLT expert trained in microtomy to generate the list of steps of the microtomy procedure objectively. In order to remove any idiosyncratic steps, next, we asked eight experts that were trained in histology to rate the criticalness of each step using a (1-5) Likert scale and provide evaluative feedback.

Results: The think-aloud protocol generated 10 steps for the microtomy procedure. During the subsequent two rounds of the Delphi exercise, the experts agreed to modify one step of the 10 steps.

Conclusions: The 10 steps of the microtomy procedure have been validated by experts in the field through this work. Following that, a virtual simulation training module was built to instruct learners on the microtomy procedure. The virtual simulation training module may be used for further research in microtomy.

Keywords: Microtomy, Simulation, Training, Delphi

4.1 Introduction

Microtomy is a process that medical laboratory technologists (MLTs) use to cut tissue samples for further examination, making this a critical process for any sample slide to be examined under a microscope. A ‘microtome’ is a specialized cutting tool used to cut extremely thin slices of tissue samples. When conducting the microtomy procedure, it is vital to understand all the equipment parts and the safety features needed to perform this procedure accurately and safely to minimize damage or distortion to the tissue sample [1]. A series of steps must be completed in sequential order and learners must become aware of the cautious safety features when handling the microtome instrument.

Ensuring that an MLT correctly prepares a sample is critical because if not done correctly, the entire tissue sample is tarnished, and must be re-prepared because the tissue specimen can be cut and get damaged resulting in a poor sample. Using simulation-based education, our overarching aim is to build a virtual simulation training module where the students can practice the procedure multiple times in a safe and controlled environment. However, currently, the literature does not validate the content of the microtomy procedure or provide consistency in the required steps of the microtomy procedure. The inconsistency of the microtomy procedure demonstrated in the literature [1,2] exhibits that MLTs are being trained differently, which could potentially result in some MLTs being unaware of crucial steps of the procedure [2].

This study is part one of two, in which the objective is to develop a virtual simulation training module to teach the microtomy procedure. To do so, we need to validate the sequential steps to execute the microtomy procedure safely and efficiently, which is the first and current objective of part one of the study. Doing this will contribute to the validation of the steps needed to create the virtual simulation module.

4.2 Methods

This study employs a think-aloud method to decompose the microtomy procedure into subtasks. The think-aloud method asks people to think out loud while performing a task and followed by analyzing the verbal protocols [3]. These protocols are used to decompose complex tasks or procedures into steps known as actions. However, verbal protocols are another term often used as a synonym for thinking aloud. Verbal protocols can be concurrent (thinking aloud) or retrospective, referring to short reports after the completion of a task. They can be subject to individual biases and habits. To ensure that the verbal protocols (i.e., actions) are representative of an MLT standard, we employed a Delphi methodology to reach consensus among experts about the criticalness of the protocols (i.e., actions needed to perform the procedure) and their sequence. The Delphi method is recommended for use in the healthcare setting as a reliable mean of determining consensus for a defined clinical problem [4]. It begins with experts completing a survey in round one where they can suggest revisions. The changes would be made, and the survey with any revisions would be sent to the same experts in round two to achieve consensus. If consensus cannot be made in round two, subsequent rounds would occur until consensus is reached [5]. A modified version of the Delphi was prepared prior to it being brought to the other experts. The purpose of this was because we had access to a local MLT expert who could prepare the initial concept document.

4.1.1 Participants

Expert participants consisted of MLTs from the faculty of Medical Laboratory Sciences at Ontario Tech University (OTU; two participants) and MLTs from the Canadian Society for Medical Laboratory Sciences (CSMLS; six participants) who had previous and/or current experience with performing the microtomy procedure.

4.1.2 Procedure

For this study, a single teaching faculty expert from OTU participated in the think-aloud protocol. The expert was asked to perform microtomy while simultaneously being video recorded and talked through the procedure while providing reasoning and thinking. This is also known as knowledge elicitation [3]. These recordings were used to decompose the entire microtomy procedure into subtasks.

Next, a modified Delphi method was used [5]. Eight participants were asked to complete a survey that asked them to rate each of the initial subtasks (i.e., steps of the procedure) as critical (5/5) or not critical (1/5) [5]. Steps with an average of 3.75/5 or above on the scale were considered critical, and therefore they were retained in the list. Those that fell below 3.74/5 were reviewed for variability in the responses. High variability in ratings (criterion 1-point standard deviation (SD)) indicated that the expert may be interpreting the step in various ways [5]. Therefore, more clarity needs to be added to the wording about the step. In this case, written feedback about ways to improve the interpretation of these steps was considered and reviewed. Steps that fell below the 3.74/5 threshold and showed low variability were considered not critical and therefore removed. Based on this algorithm, a new list of steps was generated and submitted to the participants for round two of the modified Delphi method. Typically, using this methodology consensus is reached within 2-3 rounds [5]. Figure 4.1 demonstrates the methodology in a flow diagram to visualize the steps before the virtual simulation training module is developed.

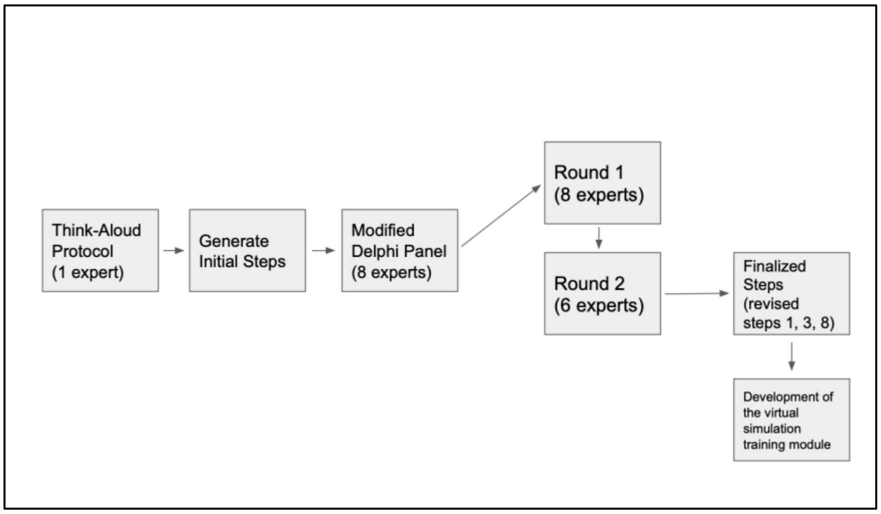

Figure 4.1: Flow diagram of the methodology to develop the virtual simulation training module.

4.3 Results

During the think-aloud protocol, the single expert generated 10 steps (Table 4.1). These steps served as an initial survey for the subsequent modified Delphi method.

Step	Description
1.	Place the tissue on a cold surface prior to cutting (cold wax make the tissue easier to cut).
2.	Fill the water bath and warm to approximately 46 degrees Celsius
3.	Ensure the microtome is locked and adhere to microtome safety. Place the blade in the blade holder and cover with the knife guard.
4.	Calibrate the microtome (clearance angle should be at 5, tissue thickness at 4 µm).
5.	Insert the paraffin wax block, lower the knife guard, unlock wheel and coarse trim all blocks (15-30 µm) and place trimmed blocks back on ice to cool.
6.	With one paraffine wax block, start to cut sections at a thickness of 4µm. After obtaining a good ribbon, lock wheel and cover blade with knife guard.

7.	Pick up tissue ribbon using tweezers and gently place onto water bath surface to remove wrinkles and then stand the clean slide in an upright position to allow the water to drain from the slide.
8.	Remove unused sections and clear water surface regularly.
9.	Label slides.
10.	Place slides into staining basket. Place basket into drying oven and set at 60 degrees Celsius for one hour.

Table 4.1: List of the 10 steps generated from the Think-Aloud method

In round one of the modified Delphi methods, only one step fell below the mean of 3.75 at a value of 3.63, with high variability (SD of 1.69; see Table 4.2). Eight experts completed a survey that asked them to respond yes or no to whether the step is critical or not, rate the importance of each step using a (1-5) Likert Scale, and provide open feedback on each item on the list [4]. The purpose of this was to validate the steps of the procedure from multiple experts. This is important to ensure there is no bias from a single expert. A thematic analysis was conducted from the open feedback that was provided for each of the steps in the procedure and synthesized to create a general theme for each step. These themes were then used to alter any steps that fell below the threshold.

Steps	Round 1 (scale 1-5) # of Participants: 8	Round 2 (scale 1-5) # of Participants: 6
1.	3.63±1.69	3.83±1.69
2.	4.25±1.17	4.25±1.17
3.	4.75±0.71	4.75±0.71
4.	4.00±0.93	4.00±0.93
5.	4.88±0.35	4.88±0.35
6.	4.75±0.71	4.75±0.71
7.	4.50±0.54	4.50±0.54
8.	5.00±0.00	5.00±0.00
9.	5.00±0.00	5.00±0.00
10.	4.00±1.41	4.00±1.41

Table 4.2: Ratings from the modified-Delphi method in round 1 and round 2
The average rating for each step of the microtomy procedure (scale 1-5) is expressed as mean ±SD.

When examining the open feedback from round one, there was heterogeneity in the interpretation and therefore perceptions of the criticalness of step one were due to the language used by stating that there was a need for ice, instead of stating that any cold surface would work. Revisions were made to step one of the microtomy procedure. The revised step was changed from ‘placing the tissue face down on ice’ to ‘placing the tissue on a cold surface prior to cutting’. In addition, the analysis of the written feedback from round one highlighted additional changes. More specifically, the participants commented regarding steps three and eight. For step three, which states to lock the microtome and adhere to microtome safety, the feedback that was consistently provided was to ensure the microtome is locked before inserting the blade as it is a high safety risk and doing so will prevent any serious accidents. Step three now reads 'ensure the microtome is locked and adhere to microtome safety. Place the blade in the blade holder and cover with the knife guard to prevent serious accidents. For step eight, which asks to remove unused sections and clean the water surface regularly, the feedback was that cleaning the water and removing unused sections, prevents cross-contamination between patients and misdiagnosis. Step eight now reads 'remove unused sections and clear water surface regularly to prevent cross-contamination'. The language for all three steps was altered based on the feedback and the new steps were submitted to the participants for review in round two.

Six experts completed round two of the survey. The new rating for step one was 3.83, exceeding the 3.75 value, and was accepted (Table 4.2). The consensus was built on two rounds, eliminating the need for round three. The consensus is that all ten steps of the procedure will be kept and are indeed critical. The revised and finalized list of the ten steps is shown in Table 4.3.

Step	Description
1.	Place the tissue on a cold surface prior to cutting (cold wax makes the tissue easier to cut).
2.	Fill the water bath and warm to approximately 46 degrees Celsius
3.	Ensure the microtome is locked and adhere to microtome safety. Place the blade in the blade holder and cover with the knife guard to prevent serious accidents.
4.	Calibrate the microtome (clearance angle should be at 5, tissue thickness at 4 μm).
5.	Insert the paraffin wax block, lower the knife guard, unlock the wheel and coarse trim all blocks (15-30 μm) and place trimmed blocks back on ice to cool.
6.	With one paraffin wax block, start to cut sections at a thickness of 4μm. After obtaining a good ribbon, lock the wheel and cover blade with the knife guard.
7.	Pick up tissue ribbon using tweezers and gently place onto the water bath surface to remove wrinkles and then stand the clean slide in an upright position to allow the water to drain from the slide.
8.	Remove unused sections and clear the water surface regularly to prevent cross-contamination.
9.	Label slides.
10.	Place slides into a staining basket. Place the basket into the drying oven and set at 60 degrees Celsius for one hour.

Table 4.3: Finalized list of the 10 steps after round 2 of the modified-Delphi method

Again, the open feedback from round two step one was synthesized and used to refine and adjust the steps for round two of the study. After round two consensus was reached, the feedback from step one in round two was analyzed to generate the main theme of the feedback.

The main theme of the feedback that was received in round two after sending the revised version of the steps was that a cold surface will support the tissue structure which will ultimately produce better overall sections. The main difference between the feedback provided in round one and in round two was the participants did not think that placing the tissue on ice was necessarily required, rather any cold surface would be sufficient.

4.4 Discussion

Upon completing the think-aloud protocol, followed by a modified Delphi study, experts concluded that all the steps of the procedure are indeed critical. The experts' consensus validating the steps of the microtomy procedure is a critical first step in the development of any simulation exercise [4]. Current literature does not provide a universal standard of the microtomy procedure [1,2], and this was exhibited among the participants based on the responses provided in the open feedback section of the [6]. Although after two rounds all experts were unanimous in their decision on whether the ten steps were indeed critical, the feedback demonstrated variability among the steps in terms of preference of tools, times, and temperatures. Therefore, this initial study provides two unique contributions to the field of simulation-based education in MLT training. First, to the best of our knowledge, this is the first study showing expert-based consensus on the steps necessary to perform microtomy. Second, this is the first study in the realm of MLT training and education to use a combination of the think-aloud protocol and Delphi methodology to generate educational content to build subsequent simulation exercises.

Traditional education methods are limited due to patient safety, work hours restrictions, instructor availability, and the cost of operating room time [7]. In the healthcare field, patient safety and complications are always a concern. Simulation-based education is an educational practice that introduces learners to an extensive learning environment allowing them to develop knowledge and receive feedback without the pressure and cost of errors. It is defined as “the imitation or representation of one act or system by another” [8]. When practicing in a simulated setting, the trainees can develop the skills required at their own pace with unlimited repetition of specific scenarios catered to the skill [7]. However, before a simulation can be adequately and accurately developed, the content of the simulation must be accurate and validated. The result of this study is the first step to developing a virtual simulation training module to address the need to develop procedural knowledge (knowing how) related to protocols and safe handling of equipment used during microtomy. The Delphi methodology was used by obtaining experts from MLTs to validate the steps of the microtomy procedure that was produced from the think-aloud method. The Delphi method has been used in numerous studies for simulation curriculum development [4].

A couple of limitations to this study should be noted. Firstly, the experts that were used were limited to a single Canadian society, CSMLS. This may make the findings based on a single expert group rather than experts from various medical laboratories. Thus, the results may not have accounted for MLTs who may conduct the procedure differently in a different medical laboratory society.

Secondly, the modified Delphi process was conducted via email in an asynchronous manner, which may have limited the opportunity to resolve any miscommunications among the experts. For instance, the main theme generated from the open feedback was in step one regarding the differences between whether placing the tissue face down on ice is critical or not, or if any cold surface is sufficient. Step one was revised after the feedback that was provided from round one, and although some experts may still have found it not critical, it did pass the 3.75 value, deeming it as a critical step. In addition, only six out of the eight initial participants from round one chose to complete the survey for the revised steps in round two. Due to this, there were less participants in round two than in round one.

Future research should focus on implementing a universal procedure for medical laboratory science procedures in not only microtomy but other procedures such as histological staining. This will prevent MLT training from being inconsistent which leads to differences in producing a tissue sample for microscopic examination. Ultimately, this process could lead to a medical diagnosis, and it is critical for the tissue sample to be prepared consistently across various healthcare laboratories. Further efforts regarding this study will focus on the development of the virtual simulation module, which will be held on a learning management system known as Gamified Educational Network [9]. This type of simulation-based training may be advantageous because trainees can practice independently in a self-paced manner, which ultimately maximizes their clinical experience.

4.5 Conclusion

The objective of this study was to validate the steps of the microtomy procedure in order to develop a virtual simulation module to teach microtomy. This study provides researchers and educators with a consistent number of steps for the microtomy procedure. Although simulation-based learning has been introduced into medical laboratory sciences, the methods used to develop simulation in this context are not well developed yet. This study has generated a stepwise list of the microtomy procedure. Therefore, this study offers two unique contributions to the growing field of simulation-based education in medical laboratory sciences training. First, it provides an expert-based consensus on the steps that are necessary to successfully complete a microtomy procedure. Second, it introduces a tested methodology that can be employed to build a similar consensus for other skills and procedures to be simulated.

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Chapter 5. Adapting the Gamified Educational Networking (GEN) Learning Management System to Deliver a Virtual Simulation Training Module to Determine the Enhancement of Learning and Performance Outcomes

Abstract

Microtomy is a medical laboratory sciences procedure that medical laboratory technologists (MLTs) use to cut tissue samples for microscopic examination. Due to the safety concerns and the potential to destroy tissue samples, it is critical for learners to perform the procedure correctly. In order to allow for safe and controlled learning, this procedure should be conducted in a simulated setting before attempting with human tissues.

This objective of this study is to describe the development and user-based evaluation of the virtual simulation training module. A research group developed the virtual simulation training module's content and design, and a local MLT expert provided the content. Nine students enrolled in a university-based medical laboratory sciences program provided feedback about the module. The results demonstrated that the virtual simulation training module was an effective and user-friendly learning tool for the medical laboratory sciences program. Although more validity and efficacy testing are required in the future, the students indicated a potential use to use this module to prepare future students for hands-on exercise in a simulation laboratory setting.

5.1 Introduction

Medical laboratory technologists (MLTs) perform the microtomy procedure to cut tissue samples for further examination, making this a critical process for any sample slide examination under the microscope [1]. When conducting the microtomy procedure, it is vital to understand the procedure's steps and safety features. If a tissue sample is prepared incorrectly, part or the entire tissue sample can get damaged and must be prepared again [2]. In a clinical setting, this could have serious ramifications for patient diagnosis. A series of steps must be completed in sequential order, and it is crucial that learners become aware of the cautious safety features when handling the instrument [2].

Simulation-based education is an educational practice that introduces learners to an extensive learning environment allowing them to develop skills and receive feedback without the pressure and cost of errors [3]. When practicing in a simulated setting, the trainees can develop the skills required at their own pace with unlimited repetition of specific scenarios catered to the skill [3].

Despite simulation-based learning being introduced into medical laboratory sciences, its systematic use is under-utilized [3]. Simulation methods are ideal for optimizing the knowledge and skills of trainees with guided experiences before they are trusted with real patients' samples [3]. However, simulation is expensive and logistically difficult to organize [4]. Literature suggests that pre-simulation preparedness leads to more effective simulation [4]. Although didactic and/or reading assignments-based preparations are predominant, early evidence from our laboratory suggests that more experiential learning opportunities may be more effective to accomplish this goal [5]. Therefore, this technical report is aimed to describe the design and preliminary evaluation of a pre-simulation, virtual simulation training module that students can complete before coming to the teaching laboratory for hands-on learning.

5.2 Technical Report

Medical laboratory sciences students complete a four-year university-based program to obtain a bachelor's degree. During their program, they must undergo histotechnology courses in their third year to learn the microtomy procedure. The students learn the microtomy procedure in both the lecture and in the laboratory in the first semester of their third year. They are also offered a one revision lesson in practicing their microtomy skills in the second semester of their third year. The virtual simulation module was designed as an educational tool for medical laboratory students who are learning how to perform the microtomy procedure. The intended learners are students of the medical laboratory sciences program who have undergone traditional laboratory learning.

5.1.1 Inputs and design process

The virtual simulation module was initially discussed by the research team that focuses on promoting knowledge using simulation as the approach and a medical laboratory expert regarding the format and layout of the module's presentation. This happened using a series of interviews and iterative redesign cycles. The expert consisted of an MLT who obtained their Medical Laboratory Technology diploma from the Michener Institute of Applied Health Sciences in Toronto, Ontario. The expert has also completed their Clinical Research Associate certificate at Michener Institute, received a Master of Health Studies from Athabasca University, Canada and is currently an associate teaching professor at Ontario Tech University, Oshawa, Canada. Prior to teaching, the expert spent over 25 years as a working MLT in histology. Communication between the researcher and the expert was conducted via email and Google Meets. Email communication was used to set up meetings and Google Meets is where the feedback was discussed regarding the layout and appearance of the module. Once the changes were made, an email was sent to confirm if the changes were appropriate and if further edits needed to be made. However, after the first edits, the virtual simulation training module was deemed appropriate by the expert. The total time of the study took a few months from developing the module and completing the testing.

The virtual simulation module is held on a gamified educational network (GEN), an online learning management system that supports and administers training programs and educational courses. The platform provides gamification elements such as a leaderboard system where participants can rate the quality of others' comments and interactions [6]. The leaderboard system shows the ranking in a private version that does not show the rest of the users who are at each position, which avoids comparisons that could be detrimental to motivation. GEN also has a feedback feature for the learner to receive constructive feedback, an essential part of an online learning experience. The feedback can consist of peer-to-peer and expert-based feedback [6]. This type of computer-based video training (CBVT) is an emerging method of self-directed learning method that allows learners to take initiative and responsibility for their learning [7]. It is a portable, convenient, flexible, and consistent form of learning that is inexpensive once implemented [7].

Communication with a computer science expert from Ontario Tech University, who was also a designer of the virtual simulation training module, was conducted via email. The requirements of the content and design based on the MLT expert's feedback were written out, and the computer sciences expert completed the task. A link was then created via email to view the module and all of its features, and when providing feedback, it was written out again via email. Once the changes were made, after consulting the MLT expert, another link was provided by the computer science expert to view the module, and the second time, it was deemed adequate. Essentially, the expert was the input of the ideas of the content and visuals of the module, and the computer science expert provided the outputs.

5.3 Products/Outcomes

To assess the usability of the system after the module was completed, all participants provided their feedback using the system usability scale (SUS) questionnaire, which allowed us to assess their a) perceptions in relation to the module's content, b) the module's potential to serve as an educational tool, and c) to provide possible improvements to the module. The purpose of using SUS is that it is an easy scale to administer to small sample sizes with reliable results [8]. The participants were asked to score a list of 10 items (Table 5.11) using a (1-5) Likert scale and provide open-ended feedback about the module and suggestions for possible improvements.

	Educational Value
1.	I think that I would like to use this frequently.
2.	I found this unnecessarily complex.
3.	I thought this was easy to use.
4.	I think that I would need assistance to be able to use with this.
5.	I found the various functions in this were well integrated.
6.	I thought there was too much inconsistency in this.
7.	I would imagine that most people would learn to use this very quickly.
8.	I found this very cumbersome/awkward to use.
9.	I felt very confident using this.
10.	I needed to learn a lot of things before I could get going with this.

Table 5.1: System Usability Scale (SUS) questionnaire

5.4 Virtual Simulation Training Module

The virtual simulation module begins by providing the background and objectives of the module followed by key microtome safety instructions (Figure 5.1-5.5). Once the participants had read through these sections, they moved on to the four learning objectives. Each learning objective begins with a description of what that section is about and is followed by a video that they must watch and a question that they must answer correctly. Once the participants answer the question, the correct answer is shown, along with a description of why the correct answer is correct. If the student chooses the incorrect answer, the correct answer is shown along with an explanation as to why the correct answer is correct. Formative feedback is provided during the course of an assessment, such as the learner completing the quiz portion of the virtual simulation training module. Constructive feedback is provided after each section of the module; thus, the learner is not overwhelmed with the amount of feedback. The participant cannot move through the sections until the previous section has been completed.

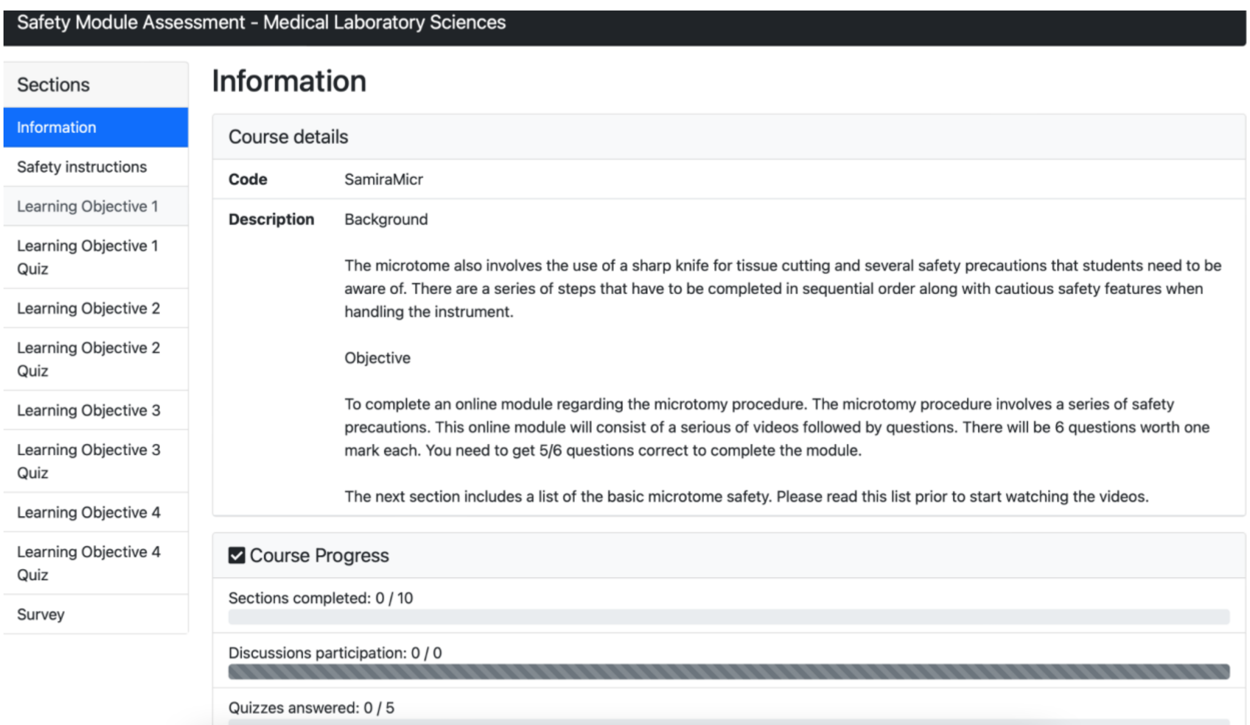

Figure 5.1: Virtual simulation training module introduction and landing page

This figure illustrates the GEN virtual simulation module's introduction and landing page, which is the first page that appears after the participants has logged in.

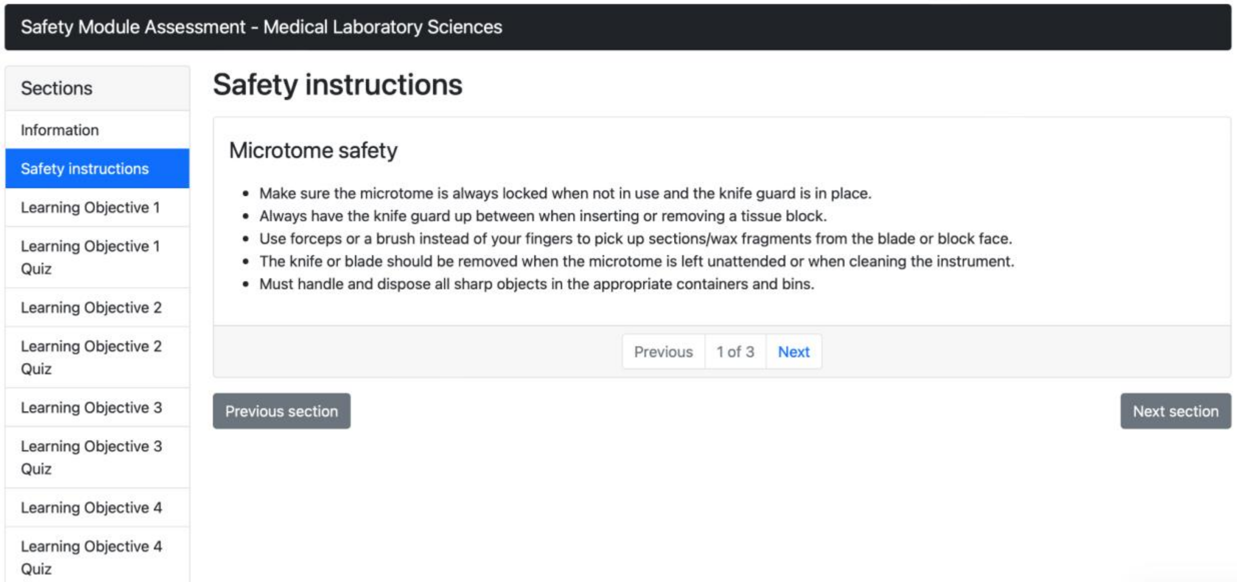

Figure 5.2: Virtual simulation training module safety instructions

This figure illustrates the GEN virtual simulation training module's first of three pages of safety instructions for the microtomy procedure. The first page lists key microtomy safety instructions, the second page shows the labelled diagram of the microtome, and the last page shows the conclusions and the marked completed section.

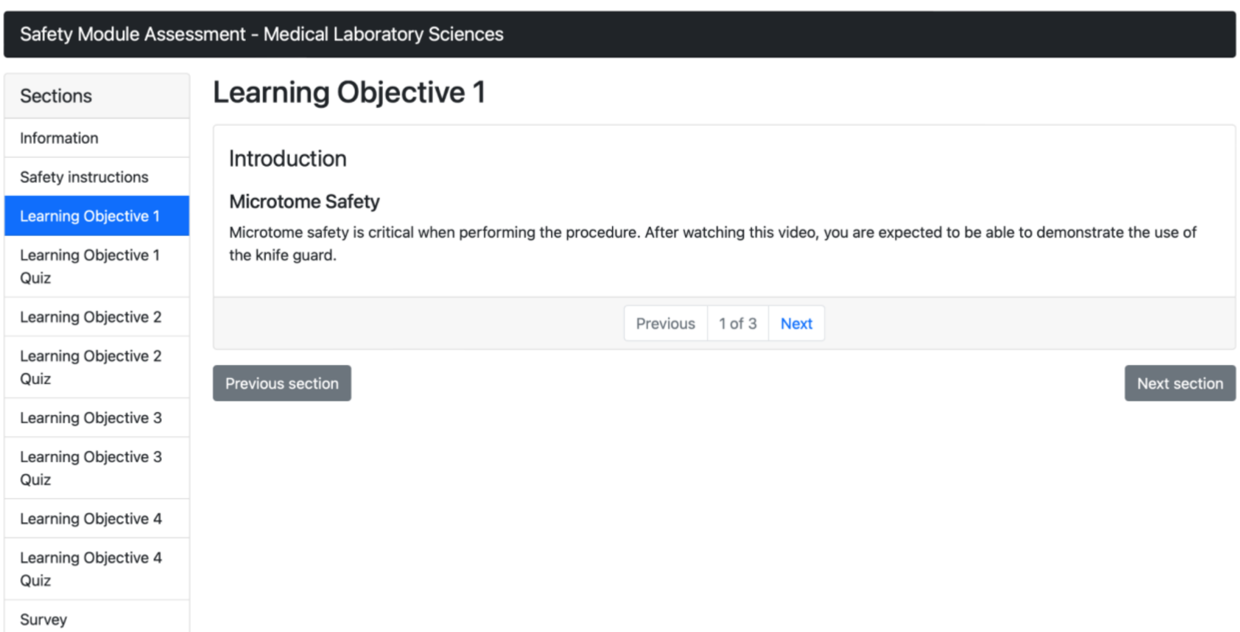

Figure 5.3: Virtual simulation training module learning objectives

This figure illustrates the GEN virtual simulation training module and shows an example of the learning objectives of the module. There are a total of four learning objectives for this module.

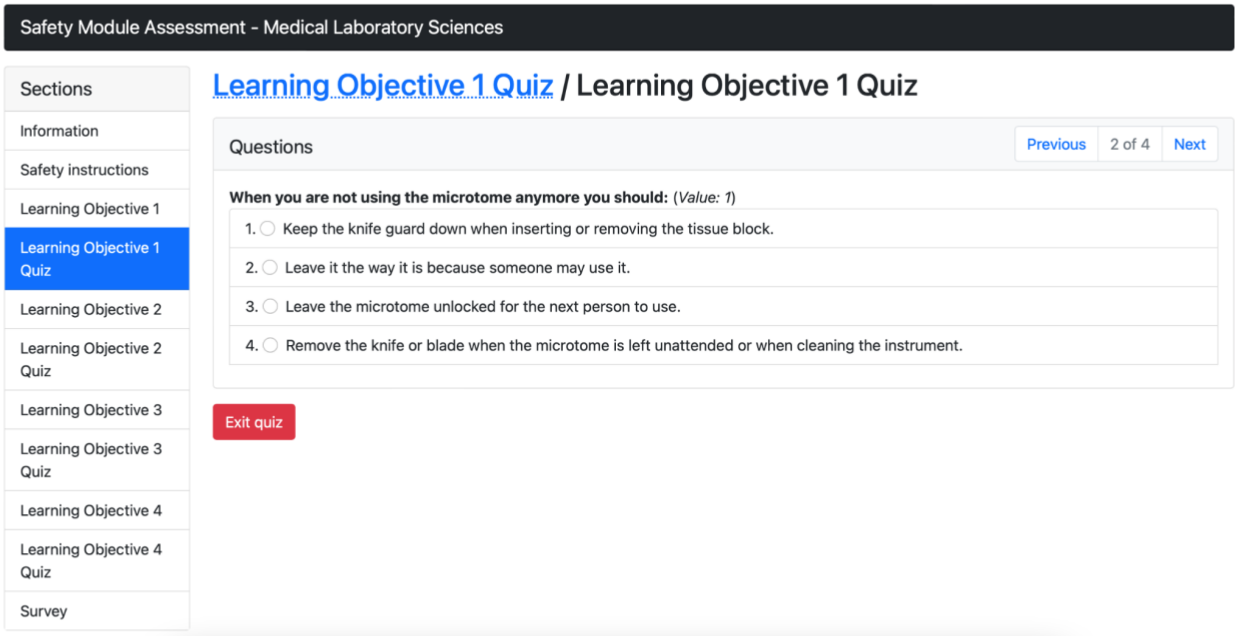

Figure 5.4: Virtual simulation training module quiz example

This figure illustrates the GEN virtual simulation training module and shows an example of the quiz question that appears after the participant has completed the material for the specific learning objective.

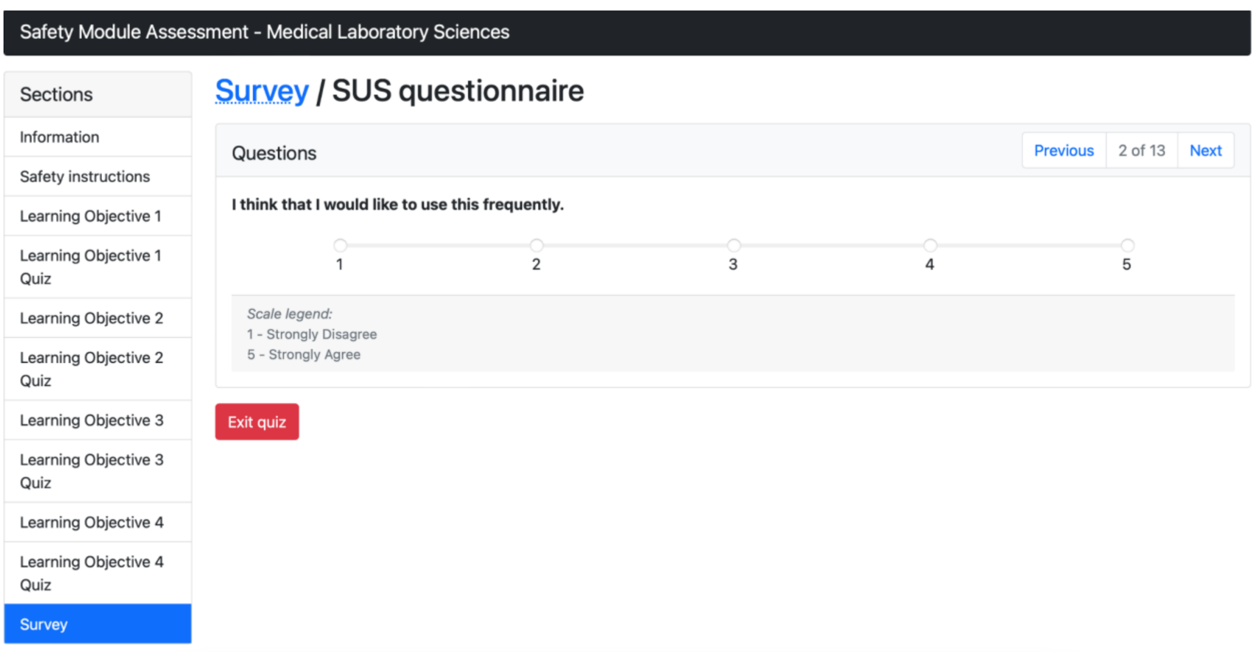

Figure 5.5: Virtual simulation training module SUS questionnaire

This figure illustrates the GEN virtual simulation module and shows an example of the SUS questionnaire, where the participants can rate the module after completion.

5.1.1 Assessment of the simulator

Nine medical laboratory students from Ontario Tech University were asked to complete the virtual simulation training module delivered through the GEN platform [9]. GEN consists of various features to increase motivation by incorporating game elements and peer-to-peer collaboration [9]. However, for the purpose of this technical report, these features were disabled, and the GEN platform provided the video and quiz features to the participants.

5.1.2 User assessments

All nine participants completed the survey. Overall, the majority of the participants rated the module to be above average. Based on previous SUS score studies, a SUS score of 68 and above would be considered above average, and anything below 68 is below average [8]. Scores above 80.3 are considered to be in the top 10% of scores [8]. Therefore, the scores that were obtained demonstrated that all nine participants rated the module as above average, and six out of nine participants have scored the module in the top 10% of scores.

Participant	Score
1	100
2	97.5
3	90
4	85
5	75
6	82.5
7	97.5
8	95
9	77.5

Table 5.2: SUS scores from each participant

After the participants rated the module by completing the SUS evaluation, they also provided free-text feedback regarding the module. These comments are summarized in Table 5.3. In general, the virtual simulation training module was perceived to be educational and easy to follow. Every participant commented that the module was easy to use. This is very important when the students complete the module as the students are completing the module remotely and in their own time. A couple of the comments suggested to revise some of the wording of the questions so that it reads more clearly.

Free Text Feedback
Awesome. I like it.
These modules are very easy to follow and the quizzes per section helps ensure you understand before moving forward.
It was overall very helpful and solidify my knowledge on the microtome. I liked how the videos were broken up into using the microtome, safety, and how to clean the microtome.
There were some spelling mistakes. The wording was slightly confusing at times, but overall very easy to use and helpful for reviewing for our histo midterm next week.
It was easy to use but the question answers were long to read.
After hitting the 'mark completed' button at the end of a learning objective section, it would send me back to the first slide of that learning objective. It would be more intuitive if that button sent me to the quiz for that section (linking it together so that each time I clicked "next" on the last slide of the previous section, it sent me to the first slide of the next section). The quiz questions were sometimes unclear exactly what was meant. Eq. Purpose of coarse trimming "to remove excess wax from around the tissue" would have been more clearly phrased as "to remove excess wax from around the surface of the tissue" (most of the wax around the tissue is supportive and is not removed). One of the microtomy questions contradicted the video, where the instructor stated the knife guard was not to be up while cutting the tissue or interact with the tissue block at all, but the question claimed the purpose of the knife guard was to protect the tissue while cutting as well as protect fingers. The clearly labelled diagram of a microtome was nicely done. In the video, it was difficult to see where the instructor was indicating from the positioning of the camera, because of her hand/arm was often blocking. The Objectives broke down learning about the microtome into easy to understand pieces and I think this would be a valuable tool to go through once before the first cutting lab. It would be valuable to add seeing how the microtome actually works (demonstrating how the blocks are cut) to put the pieces into context. This module seems most useful for students who have never seen a microtome before.
Very intuitive and easy to use. Feedback for corrections was a nice addition in the quizzes.
This module was designed really well. It was clear, quick, and easy to understand.
I found this platform very nice, and the layout is great for learning.

Table 5.3. Free text feedback from the participants after completing the virtual simulation module

5.5 Discussion

The rationale for developing the virtual simulation training module presented in this technical report is to provide an educational tool for the microtomy procedure so that students can learn and practice the procedure remotely. Numerous studies have suggested that an online learning environment may possess the same learning benefits as face-to-face learning with an instructor present [4,6,10]. Having the learners use this module can increase their training opportunities and ultimately improve learning outcomes. Consequently, this report outlined how the virtual simulation training module can be used as an educational tool for microtomy students.

After the participants used the virtual simulation training module, the module received overall positive feedback. The participants considered it to be a useful tool to learn and practice microtomy. All of the participants reported that the module was above average, demonstrating that it was clear and easy to follow. However, some participants found some minor issues. Specifically, some of the module questions could have been worded differently so that the question is clearer as a few of the participants found them to be confusing. The virtual simulation training module presented microtomy in sections to learn the names of all the parts of the instrument, safety, cutting process, and cleaning. This allowed them to learn one section at a time until they had understood the material and answered the questions correctly before moving on to the next section. Despite some of the shortcomings of the module, all of the participants rated the module as above average and thought it was helpful for their learning process.

The participants collectively agreed that overall, the module was clear and easy to follow, concluding that the GEN platform was a useful platform with a clear layout to navigate. One of the student's open-ended feedback items described that they liked the GEN platform, and that the layout of the module is great for learning. Another participant also commented that they liked how the module was broken down into sections, instead of having all the content provided at once.

The main limitation of the study was that there was no comparison group of learners who had no previous knowledge of microtomy to complete the module. The benefit of comparing the results of learners with no prior knowledge of microtomy is to determine how much learning was gained from the module without the traditional laboratory learning. Due to COVID-19, participant recruitment for this subgroup was non-responsive or declined as the students were overwhelmed with the amount of current online learning they are required to do. Another limitation of the user-based feedback was that some of the wordings of the questions were confusing and could have been worded differently to be clearer of what the question was asking. Despite having these comments on how the module could have been improved, the module was still perceived as useful for student learning. The module's questions and answers are being examined to eliminate grammar errors and any unclear wording of sentences. This change will improve and provide a clearer understanding to the participant of what the question is asking.

Based on the feedback provided by the students, the virtual simulation training module would need some minor modifications before it can be considered for use in training. Although it does reach its objective, which is to allow the learner to practice the microtomy procedure before having to perform it in a clinical setting, the suggested improvements of the module will improve the understanding of the questions.

5.6 Conclusions

The virtual simulation module that was designed as an educational tool was demonstrated to be an effective and useful tool for the microtomy procedure in addition to being the first virtual simulation training module designed specifically for microtomy to our knowledge. We believe our module, with a few minor improvements, could become a valuable educational tool for students to practice the microtomy procedure in a remote environment.

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Chapter 6. General Discussion

6.1 Research Objectives

The aim of this thesis was to develop a virtual simulation training module using a video-based online learning platform known as the Gamified Educational Network (GEN), and test whether the module enhances learning outcomes for the microtomy procedure. Specifically, the objectives of study one was to validate the steps (i.e., content) of the virtual simulation module. Following that, was study two, in which the objective was to test the virtual simulation training module and determine if it enhanced the learning and performance outcomes of the students.

6.2 Research Methodology

To construct and validate the steps of the microtomy procedure, a think-aloud method was conducted by using a single expert talking through while performing the microtomy procedure. The initial 10 steps were developed from the think-aloud method. Next, to minimize bias from a single expert's opinion of the steps of the procedure, the content had to be validated. A modified-Delphi method was conducted using MLTs from Ontario Tech University and the Canadian Society for Medical Laboratory Sciences (CSMLS). After two rounds, the content of the steps of the microtomy procedure have been validated and can be implemented in the virtual simulation training module. When building the module, a computer-based video format was used and held on an online learning management system called GEN. The students watched videos and were assessed on the videos. Undergraduate students began with reading safety instructions and microtome parts before starting the module. The module contained a specific learning objective, video, question, and feedback that corresponded to each section of the module.

Once the module was completed, the students had the opportunity to provide feedback through a System Usability Scale (SUS) questionnaire by rating the module using a (1-5) Likert Scale based on a series of statements. They were also asked to provide open-ended feedback regarding the module.

6.3 Research Outcomes

The general results of the modified-Delphi study demonstrated that all of the ten steps of the microtomy procedure are indeed critical. In round one, steps one, three and eight needed to be revised in order to move on to round two. Once the revisions were made, consensus was reached after two rounds. One the students completed the virtual simulation training module, the overall feedback was positive. The participants considered the module as a useful tool to practice microtomy. From the SUS survey, all of the participants reported that the module was above average, demonstrating that it was clear and easy to follow. A significant detail obtained from the feedback was how the module was set up. The participants were unable to move forward to the next section until they understood the material and answered the questions correctly. This gamification element allows for the student to ensure that they have understood the material before moving on to the next step, a feature that may be limited in a physical laboratory setting.

This thesis contributes to the literature as it provides a universal step-wise procedure of how to perform microtomy in a simulated format. If trainees are not trained correctly or lack knowledge of the microtomy procedure, they can potentially hurt themselves, causing a serious accident. This may also lead to errors and severe consequences can arise for both the staff and the patient sample [1]. Simulation-based education is an educational practice that introduces learners to an extensive learning environment allowing them to develop knowledge and receive feedback without the pressure and cost of errors [2]. By learning the procedure in a virtual setting, it allows the learner to develop their knowledge of the procedure at their own pace with an unlimited repetition of completing the module. Despite simulation-based learning being introduced in medical laboratory sciences education, it is still under-utilized in this field of learning. The module held on GEN incorporates gamification principles to promote learning. Thus, creating and developing a virtual simulation training module provides an educational tool that can be accessed remotely in any setting allows for training to occur at any moment without physically being in the laboratory.

6.4 Limitations

Although the two studies conducted in this thesis met its objectives to develop the content and validate the steps of the microtomy procedure (study one), and to determine user satisfaction of acceptability and feasibility (study two), there were still a few limitations. The MLT experts obtained in study one were from a single organization known as the Canadian Society for Medical Laboratory Sciences, instead of obtaining MLT experts from various organizations. Therefore, the feedback provided from the modified-Delphi method does not account for MLTs that are a part of other organizations and work in laboratories that may potentially conduct the microtomy procedure differently. Secondly, due to the modified-Delphi method being conducted virtually in an asynchronous manner, it may have limited the chance to resolve any miscommunication or questions posed by the experts.

There were also limitations that arose in study two. For instance, the participants that were selected to complete the virtual simulation training module already completed the traditional laboratory learning and had prior knowledge of microtomy, with no comparison group of participants that had no prior knowledge of microtomy. The goal was to use a comparison group of participants with no prior knowledge of microtomy to and compare the results to the participants who already completed the laboratory training to determine how much learning was gained from the module. However, during the period when participant recruitment occurred, the participants with no microtomy knowledge were either non-responsive or declined as it was a busy time and were dealing with a heavy workload.

6.5 Future Directions

As this thesis was built and based around the MRC framework, only the first two cycles, *theory and modelling* and *piloting,* of the framework were addressed. Future research can focus on the evaluation and implementation cycles of the framework. For the evaluation cycle, the efficacy and effectiveness of the virtual simulation training module should be tested using a randomized controlled trial. Having participants with no prior microtomy experience complete the virtual simulation training module can test the efficacy and learning gained from the module. The final cycle is the implementation cycle, which specifically focuses on implementing the virtual simulation training module into a health care education setting, such as an educational institution or a laboratory setting. In an educational institution such as a university, the virtual simulation training module can be embedded into the curriculum for students to complete before attempting the microtomy procedure in the physical laboratory. In a work setting, such as a laboratory, the virtual simulation training module can be accessible for new MLTs entering the workforce, or simply for those who want a refresher of the procedure. In both settings, emphasis needs to be placed on the availability and integration of the virtual simulation training module with other learning management systems. With the module being compatible with other learning management systems, it can be implemented in more places with easier access without the need of using the GEN system.

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