Chapter 8
maxSIMhealth: An Interconnected Collective of Manufacturing, Design, and Simulation Labs to Advance Medical Simulation Training

maxSIMhealth Group

Abstract maxSIMhealth is a multidisciplinary collaborative manufacturing, design, and simulation laboratory at Ontario Tech University in Oshawa, Canada combining expertise in Health Sciences, Computer Science, Engineering, Business and Information Technology, aiming at building community partnerships to advance simulation training. It focuses on existing simulation gaps, while providing innovative solutions that can change the status quo, thus leading to improved healthcare outcomes comprised of cutting-edge training opportunities. maxSIMhealth utilizes disruptive technologies (e.g., 3D printing, gaming, and emerging technologies such as extended reality) as innovative solutions that deliver cost-effective, portable, and realistic simulation catering the high variability of users and technologies, which is currently lacking. maxSIMhealth is a novel collaborative innovation with aims to develop future cohorts of scholars with strong interdisciplinary competencies to collaborate in new environments and to communicate professionally for successful medical-tech problem solving. The work being conducted within maxSIMhealth will transform the current health professional education landscape by providing novel, flexible, and inexpensive simulation experiences. In this chapter, a description of maxSIMhealth is provided along with an overview of several ongoing projects.

Keywords Medical simulation · 3D printing · Immersive technologies · Serious gaming · Gamification

8.1 Introduction

Simulation “allow[s] persons to experience a representation of a real event for the purpose of practice, learning, evaluation, testing, or to gain an understanding of systems or human actions, [57].” Simulation has been positively disrupting the traditional education model in healthcare. Evidence in support of this change is solid for
learning outcomes, patient outcomes, and safety [13]. Simulation provides a viable alternative to practice with actual patients, providing medical trainees the opportunity to train until they reach a specific competency level. One of the prevailing arguments for using simulation in the learning process of trainees is the ability to engage the trainee in the active accumulation of knowledge by doing with deliberate practice, while it also allows for careful matching of the complexity of the learning encounter to the trainees’ current level of advancement [41]. Further, there are several studies indicating that ‘hybrid’ clinical placement curricula—whereby part of the time is spent in simulation and part in the clinical setting following a preceptorship model—are as effective as traditional clinical placement curricula, while reducing the resource strain on clinical placement sites (see, for example [1]). However, despite these proven advantages, simulation faces limitation within several training programs for allied health professionals, or in rural and remote settings due to commercial unavailability, high development costs [19, 17], and the inability to address many of competencies requiring specialized facilities.

We believe that disruptive technologies will help us create and establish novel simulation solutions that will provide an alternative model to better train future cohorts of health care professionals [7], and to equip practicing professionals with the tools and knowledge required to function within their complex and rapidly changing work environments [6]. To this end, we have recently established maxSIMhealth, a synergistic multidisciplinary collaborative (laboratory) whereby multiple professions work together to address simulation challenges in training and education. This is made possible given that maxSIMhealth is an academic-public-for-profit collaborative based at Ontario Tech University where access to several different manufacturing, design, and simulation labs is leveraged. A blended funding model supports maxSIMhealth with institutional support for labs and infrastructure, Canadian Foundation for Innovation, Canada Research Chair in HealthCare Simulation (through the Canadian Institute for Health Research), Natural Sciences and Engineering, and Social Sciences and Humanities Research Councils (NSERC, and SSHRC respectively).

maxSIMhealth combines expertise in faculties across the university, including Health Sciences, Business and Information Technology (computer science, game development, etc.), Engineering and Applied Sciences, Education, and Social Sciences. Furthermore, the collaborative builds upon existing and new community partnerships: Lakeridge Health Hospital, Durham Region Department of Health, Canadian Society for Medical Laboratory Sciences, Collaborative Human Immersive Interaction Laboratory (CHISIL), and Simulation Canada. In addition, maxSIMhealth actively seeks and establishes research partnerships with not-for-profit and for-profit organizations as commercial channel partners and stakeholders in order to advance simulation training globally. Finally, maxSIMhealth acts as an idea-seeding mechanism for local startup incubator and experiential learning hub, Brilliant Catalyst.

This multi-sectoral collaborative allows for the connection and cross-pollination of multiple professions and areas of expertise for discovering existing simulation gaps, providing innovative solutions that change systems that lead to improved
healthcare outcomes. Specifically, maxSIMhealth utilizes disruptive technologies including, but not limited to, 3D printing, gamification (including serious gaming), and emerging technologies including extended reality (XR), as innovative solutions that allow for cost-effective, portable, and realistic simulation. Thus, it provides health professionals with innovative, consumer-level, flexible, and highly adaptable simulation solutions that will work in tandem with, and augment the preceptor-ship model (this is currently lacking in medical-based simulation education), while equipping each member of the healthcare team in every point of care setting.

With its increasing popularity and effectiveness of simulation, it is now imperative to integrate simulation throughout entire curriculums (e.g., nursing, surgery) [22]. Programs can no longer rely on this ‘add-on’ notion since simulation opts as a replacement for traditional, and often rare, clinical experiences, and allows learners to develop skills, clinical reasoning, and care competency [26]. With its foundation in technology, sciences, and professional practice, maxSIMhealth thrives on this growing acceptance and enthusiasm of simulation in medical professions education. In doing this, it is able to fulfill its vision of advancing the discovery and application of knowledge that revolutionizes health by providing innovative solutions for simulation training and clinical application. In the following section (Sect. 11.2), we provide a brief overview of several ongoing maxSIMhealth research projects aimed at solving specific medical education needs and problems. In Sect. 11.3 a discussion regarding the “Ideate. Create. Disseminate” approach we follow in maxSIMhealth is provided while concluding remarks are provided in Sect. 11.4.

8.1.1 Immersive Technologies

The technologies of video games, virtual worlds and social networks have become collectively known as immersive technologies because of their ability to engage users of all ages, driving massive investment into technologies to attract, capture and retain our attention [94]. The continuous increase in computational processing power and accompanying decrease in the size of electronic components has led to the decreasing cost and rising availability of consumer-level immersive technologies have helped advance the adoption of virtual simulation in recent years. A definition of various immersive technologies follows below.

- **Virtual reality**: An interactive computer simulation, which senses the user’s state and operation and replaces or augments sensory feedback information to one or more senses in a way that the user obtains a sense of being immersed in the simulation (virtual environment).
- **Augmented reality**: The addition of computer-generated objects to the real physical space to augment the elements comprising it.
- **Mixed reality**: The integration of computer-generated graphics and real objects seamlessly.
• **Extended reality**: A term referring to the synergy of virtual, augmented, and mixed reality technologies, in conjunction with motion capture, user data acquisition, and maker space has been gaining momentum thanks to recent technological advances in electronics miniaturization, image processing, and motion capture system [24].

• **Serious games**: Video games whose primary purpose is education, training, advertising, simulation, or education as opposed to entertainment.

• **Gamification**: The application of “game-based elements, aesthetics, and game thinking to engage learners, motivate action, promote learning, and solve problems” [50].

### 8.2 maxSIMhealth Projects

In this section, an overview of several research projects and initiatives currently underway (or will begin shortly), within the maxSIMhealth lab is provided. All of the projects are interdisciplinary, at the very least, consist of at least one content expert (medical/health sciences professional and/or trainee), at least one technology expert (engineer/computer scientist and/or trainee), and access to experts in medical education. The experts may be academics or practicing professionals from the various maxSIMhealth partner institutions.

Our current work is focused on projects whose solutions fall broadly within three major areas: (i) immersive technologies, (ii) gamification and serious gaming, and (iii) 3D printing. Within the immersive technologies domain, a large focus includes the development, testing, and implementation of a novel MLT professional development tool, in the form of a Game-Based Education Multi Technology Platform (GEM-Tech Platform), supported by a combination of serious games coupled with virtual, augmented, and mixed realities (VR, AR, and MR respectively), and physical simulators. We envision the GEM-Tech Platform being used in a number of training applications including several which are described below.

#### 8.2.1 Immersive Technology-Based Solutions

In this subsection, we provide a description of projects whose solutions focus on immersive technologies and virtual reality in particular.

##### 8.2.1.1 Phlebo Sim: A Novel Virtual Simulation for Teaching Professional Medical Laboratory Technologist Skills

Medical laboratory technologists (MLT’s) perform a range of services in the patient sample-testing environment. For example, MTLs are responsible for performing
phlebotomy procedures which consist of taking blood from patients and organizing the samples into proper containers for testing. However, there is a health human resource shortage in the profession, due to higher rates of retiring MTLs compared to MTLs entering the workforce [16]. Although the issue was raised in 2010, there has not been an increase in new MLT graduates to offset the shortage [16]. This shortage is further complicated by the lack of available teachers (who are often working in the field concurrently), to mentor students to a position of confidence [16]. Professional standards have been developed to establish a minimum level of competency for a new entry-level MLT, yet pre-analytical errors still account for up to 75% of laboratory errors [44]. These analytical errors, such as lost or incorrect sample request forms, occur before the sample is tested [44]. These errors are costly and contribute to over one million injuries and approximately 4,400–98,000 deaths in the United States annually [40], making medical errors the eighth leading cause of death in North America, ahead of AIDS, motor vehicle accidents, and breast cancer [40]. One solution previously identified is to increase the efficiency of training and increase MLT’s proficiency, is simulation [44]. While recent studies have shown the potential of simulation, it has yet to be fully integrated into MLT training programs [10].

To further contribute to this work in MLT simulation, an interdisciplinary collaboration between experts in medicine/health sciences, computer science/engineering, and medical education at Ontario Tech University has resulted in the development of a novel, interactive, and engaging virtual phlebotomy (blood-drawing) simulation prototype (known as “Phlebo Sim”), in an attempt to increase the efficiency of MLT training. Currently, Phlebo Sim focuses on the cognitive aspects of MLT training, following guidelines set out by the World Health Organization [93], and the profession’s accrediting body. Sample screenshots are provided in Fig. 8.1.

According to Canadian Society for Medical Laboratory Science, the credentialing body for MLTs, the graduating MLT student must achieve 95 competences [17]. The current version of the simulation (i.e., Phlebo sim) addresses 12/95 competencies.

![Fig. 8.1 Phlebo Sim sample screenshots](a) the player prepping required materials into a tray, and (b) dialogue to guide the player through the procedure
We are porting Phlebo Sim to the GEM-Tech while expanding the scope of Phlebo Sim to address 93/95 competencies set out by the Canadian Society for Medical Laboratory Science (see Fig. 8.2). This will be achieved through the synergy between researchers and research laboratories at Ontario Tech University including the Gamer Lab, HealthTech Lab, Materials Research Laboratory, undergraduate level MLT teaching laboratories, and our Lakeridge Hospital TechEd Living Lab, which together form the maxSIMhealth collaborative. In addition, we will leverage the expertise of our community, and more specifically, the Canadian Society for Medical Laboratory Sciences and Simulation Canada, amongst others.

We anticipate that our updated GEM-Tech Platform-based Phlebo Sim will fulfill at least 98% of the competencies expected from a practicing MLT; serve as a training tool for any new competencies or shifts in the scope of practice; and, consequently, improve the supply of MLT professionals by strengthening education and training pathways, and promote efficient and effective learning. We anticipate that our updated Phlebo Sim will improve the quality and accuracy of laboratory tests and further our understanding of implemented simulation interventions into MLT training.

8.2.1.2 The Anesthesia Crisis Scenario Builder (ACSB): Development of an Anesthesia Crisis Scenario Builder for Virtual Reality Training

An anesthesiologist is a medical professional who practices within the anesthesia field. The job includes perioperative care, developing anesthetic plans, pain-relieving medication during surgical procedures and monitoring the patient’s vitals [47]. Anesthesiologists go through multiple training and education programs to obtain the required knowledge and psychomotor skills to be an anesthesiologist. They are
required to maintain appropriate knowledge of complications during operation by attending lectures or passively learning from journals or textbooks with no feedback [86]. Although knowledge is best retained by actively doing rather than passively learning [4], there is a lack of active methods that are easily accessible to anesthesia trainees [62]. Here, we describe the anesthesia crisis scenario builder (ACSB), developed in an interdisciplinary collaboration between anesthesiologists, computer scientists, engineers, and game developers, and followed an iterative development cycle where a prototype was developed, evaluated, and modified accordingly. The ACSB allows for the creation of multiple anesthesia crisis scenarios and modification of existing scenarios based on the Anesthetic Crisis Manual (ACM) [12]. The manual covers 22 life-threatening crises and provides concise, clear and simple systematic instructions that can be used by any health professional who is leading or assisting in an anesthesia crisis management situation [12]. The ACM has been referenced in recent papers revolving around the evaluation of resident competencies in anesthesia crisis management simulation [25]. The ACM lists each step for the life-threatening crises which have been turned into individual modules. These modules can then be used to create these life-threatening crisis scenarios. The goal of the ACSB is to take these systematic instructions and turn them into modules, allowing medical educators to create their own custom scenarios within each module where trainees can then practice them freely within a safe environment. Currently, the ACSB is in the prototyping phase and does not include all the scenarios found within the ACM. The scenarios are created within the scenario builder portion of the project is shown in Fig. 8.3. The scenario builder can add modules, save and load scenarios, and further customize modules that contain multiple options. Each of the modules contain a description of the task and an overall idea of what needs to be done to achieve the task.

![Fig. 8.3 The scenario builder interface](image)
Fig. 8.4 Virtual operating room modeled after an actual operating room at Sunnybrook Health Sciences Centre in Toronto, Canada

The trainee is “placed into” a virtual operating room (modeled after an actual operating room at Sunnybrook Health Sciences Centre in Toronto, Canada) to immerse user into a real operating room (see Fig. 8.4). Once in virtual reality they can go through the modules that the medical educator or the user has selected. Each module has a different” type”, corresponding to the type of interaction the trainee will have to perform to complete the task. For example, the “Call Help” module requires the trainee to inform the nurse to call for help and the surgeon to stop the operation. This is accomplished using a dialogue wheel (see Fig. 8.5) that requires the user to have the nurse within view to trigger the nurse to call for help and surgeon to stop the operation.

Currently one module has been implemented (the anaphylaxis module was chosen as it is the most common cause of complications during anesthesia [85]), although the goal is to develop modules for each life threatening crises described in the ACM. The final goal is to allow medical educators the ability to create rare anesthesia scenarios that can be created with low levels of technological literacy and be used on multiple hardware devices for accessibility at a low cost. This will allow trainees and current anesthesiologists to actively train for common and rare scenarios.

8.2.1.3 Development of a Simulation-Based Solution to Related Musculoskeletal Disorders (WRMSDs) Amongst Canadian Sonographers

Sonography, “the statiscope of the future,” is a diagnostic ultrasound that non-invasively and effectively allows for patient diagnoses through the creation of bodily structure images using high-frequency sound waves [59]. The field of ergonomics suggests that any multi-joint movement requiring awkward body positions, and
application of forces (common in sonography), may result in work-related musculo-skeletal disorders (WRMSDs). Therefore, it is not surprising that recent studies found 84% of respondent sonographers suffer from pain associated with their ultrasound practice, and that one in five workers in the province of Quebec, experienced a non-traumatic WRMSD in at least one body region over a one year period [2]. Another recent study validates this issue where, out of 567 sonographers, 99.3% of them reported WRMSD symptoms within the last year [96]. Statistics predict that in just nine years, 18,000 additional diagnostic medical sonographers will be needed in the U.S. alone, exceeding the average growth of all occupations [88]. However, it will be challenging to meet this demand while maintaining skill within the workforce with these exceptionally high injury rates. Due to their chronic nature, individuals can live with painful and debilitating WRMSDs for years, which will require rehabilitation and mitigation efforts. These disorders along with their resulting physical inactivity pose as risks for developing other illnesses and for increasing long-term
health issues [49]. Not only is the health of most sonographers compromised, but also the costs of these WRMSDs are increasingly high as injuries arise. WRMSDs are estimated to cost the Canadian economy $15 billion per year, in addition to the $22 billion cost it faces from musculoskeletal diseases alone [49]. The Ontario Workplace Safety and Insurance Board receives reports of WRMSDs as their number one type of lost-time work injury (in the province of Ontario). In addition to direct physical costs of pain and suffering and economic costs of absence and lack of productivity, there are also indirect costs that should be noted. When an employee suffers from a WRMSD, their employer also faces many economic burdens including overtime or replacement wages, workstation and equipment alterations, administration, employee replacement training, lost productivity, and lowered quality [68]. The expected increase in the prevalence of WRMSDs will bring a high expense to the Canadian economy as well as a reduction in Canadians’ overall quality of life.

The most significant causative factors of WRMSDs in sonographers include force, repetition, sustained, awkward, or poor positioning, grip and pressure, stress, and workload [96]. A study conducted by Zhang and Huang [96] demonstrated the percentage of musculoskeletal symptoms over four different times in 15 body regions. The most concerning regions include the neck, right shoulder, right hand, and back. Most recommendations and solutions that exist today to reduce risks of these WRMSDs involve:

1. **Guidelines**: Following posture guidelines and ergonomic techniques.
2. **Improved equipment**: Despite significant improvements, not all worksites are equipped with state-of-the-art equipment since more exams are being done at the patient’s bedside [65].
3. **Workload**: workforce shortages caused by WRMSDs lead to less coverage and insufficient break periods; an essential risk-reducing strategy that allows muscles and tendons time to re-cover [45, 65].
4. **Assistive devices**: recent developments involve alterations or re-imaginations of the ultrasound machinery itself since most scanning environments do not promote proper ergonomic techniques. The three main approaches to this challenge include: (i) autonomous robotic imaging that does not use a human operator, (ii) remotely operated sonography, or telesonography, and (iii) human-robot cooperation with a human physically present [82].

However, a study conducted by Al-Rammah et al. [2] revealed that amongst a group of 100 sonographers, there were low levels of awareness regarding best practices and safety measures. Thus, despite guidelines and preventive measures, WRMSDs are still occurring and affecting a vast majority of sonographers.

In summary, there are several causes for WRMSDs in sonographers, and several solutions have been proposed. Unfortunately, the problem persists despite these solutions. The field of simulation-based education may provide another effective method of decreasing the risks of WRMSDs in sonographers. The short-term goal of this research is to examine the WRMSDs in sonographers through a “simulation-based education” lens. Specifically, risks will be evaluated with the goal of using
simulation-based education as an adjunct solution to other currently deployed solutions. To achieve this, several observational (in a clinical setting), think-out-loud (in a simulated setting), and ergonomic (in a laboratory) investigations and evaluations will be utilized to determine the preventable causes of these injuries. The long-term goal of this work is to develop and test solutions that utilize simulation to drastically reduce incidences of WRMSDs in sonographers in Canada. It is anticipated that the completion of this WRMSD study in sonographers will reveal:

- The underlying causes of WRMSDs amongst sonographers.
- Sonographers’ awareness of faulty/risky posture and movements, if any.
- The reasoning(s) for failing to follow strict guidelines.
- A reduction of WRMSD incidence amongst sonographers through utilization and implementation of simulation.

### 8.2.1.4 Cultural Competency Training for Long-Term Care Professionals

Currently, Canada’s population is reported at 37.6 million people (as of July 1, 2019) [81], with an expected growth to 52.6 million by 2061 [80]. However, Canada has an aging population; in 2019, the population of Canadian’s seniors (aged 65 and over), was 6,592,611 (approximately 18%). More locally, the Durham Region in Ontario (where the proposed work/study will take place), is reported to be one of the fastest growing regions in the world [33]. In 2016, Durham’s population was 673,000, and in 2018 it reached a population of 683,600 [27] (immigration is a significant factor for this population increase). As the baby boomer generation ages, the seniors’ population is estimated to be 100,976 (approximately 15% of the total Durham Region population) [27]. The city of Oshawa is the biggest municipality in Durham Region, with a total population of 169,509, 16.7% (or 28,385 people), of which are seniors (age 65 and older).

The growing number of seniors live in their community, assisted living, or group homes. As their abilities to care for themselves independently deteriorate, and home care services become insufficient to meet their needs in their own homes, seniors move into Long Term Care (LTC) homes. The LTC homes, also known as nursing homes, are defined by the Ontario Ministry of Health and Long Term Care, as a place where adults live, receive all aspects of personal care, nursing supervision, and assistance with activities of daily living [20]. LTC settings operate following a “24/7” schedule and LTC homes are considered the residents’ space and home.

In 2014, Ontario had 627 LTC homes across the province, for 78,000 beds in total. Yet, there were 26,495 seniors on a waitlist to enter a home [67]. Accordingly, the demand for LTC beds surpasses the supply [66]. In 2018, the government of Ontario allocated 5000 new LTC beds across the province with 270 beds allocated to the Durham Region [32]. This was part of the Ontario government’s initiative to build 15,000 new beds and redevelop 15,000 existing beds over five year [20]. However, additional beds will require similar growth of trained professionals to ensure that seniors are well taken care of, yet there is a pre-existing shortage of healthcare
professionals nurses and personal support workers (PSWs) in LTC. This is further compounded by the fact that our current training of healthcare professionals does not meet the growing demands. Two solutions may address this gap as follows: (a) training of qualified immigrants, and (b) accelerated retraining of workers from other lines of work.

**Objective:** Given the increasing senior population, the increasing ethnical diversity in the Durham Region; and the fact that the healthcare system is moving towards a person-centered model of care, it is critical that seniors receive appropriate and cultural-centered care and service, that better meets their needs and increases their satisfaction and health outcomes. In other words, developing and enhancing cultural competencies in LTC workers is urgent to meet the cultural care needs of a growing diverse population. Although retraining programs for both internationally trained professionals, and local individuals who require retraining exist, we aim provide extended teaching and learning opportunities to develop or enhance cultural competencies in LTC workers. Adapted from the CanMEDS framework, the cultural competencies will include communication, collaboration, professionalism, and health advocacy.

**Purpose:** We propose a solution, where the newly retrained LTC workers will develop cultural competencies using serious gaming, and more specifically, using our proposed Senior’s Cultural Competency Game (SCCG).

**Research:** Once implemented and incorporated into professional practice, the SCCG will allow providers to be culturally competent when providing care to seniors. The training will be computer-based, freely available, and available at any given time for all healthcare providers’ access. Using a previously developed cultural competency game framework [51], we propose to build the SCCG for LTC workers. Initially, the SCCG will be part of the orientation process for new staff, and staff returning from an extended leave of absence. Furthermore, the SCCG will be added to the yearly mandatory education for all staff in the facility. Once implemented as part of the orientation process, in the next phases, the SCCG will be augmented to include remediation and education modules where providers who failed the competency threshold will have a chance to acquire these competencies in a safe and flexible learning environment. The research and development process will be completed in five phases:

- **Phase 1 (Scenario Development):** Four scenarios will be developed by a content expert to address four cultural competencies: communication, collaboration, professionalism, and health advocacy.
- **Phase 2 (Face and Content Validity):** Using expert consensus building methods (e.g., the Delphi method), experts will assess the face (realism) and content (appropriateness) of the SCCG.
- **Phase 3 (Imbedding the Scenarios into the Game Framework):** this will be completed by computer scientists and serious game developers.
• **Phase 4 (Implementation):** An initial installment of the game during an orientation session for new staff at a single institution (Sunnycrest Nursing Home in Durham Region, Canada).

• **Phase 5 (Evaluation):** Novice and experienced staff at the Sunnycrest Nursing Home will be asked to participate in a study to examine the usability and effectiveness of the SCCG. It is expected that the experienced staff will have higher scores than the novices (construct validity evidence). At the same time, the user experiences will be assessed using previously validated metrics.

### 8.2.1.5 Integrating Immersive Technology and Neurophysiological Techniques to Evaluate Optimal Learning Environments in Medical Simulation Training

Medical errors are the third leading cause of death in the United States, following cardiovascular disease and cancer [58]. Although there is no single solution to fix this problem, simulation is one approach [9]. Educators generally favor more realistic simulations, based on the assumption that they are more representative of the real world, and therefore more effective in training. High-fidelity simulators are expensive, and research suggests these simulations are not more effective than low-fidelity options [64]. Additionally, evidence suggests that it is not only the realism of the simulator, but also the level of immersion within the environment that leads to improved learning outcomes and skill development [15, 29, 64, 91]. In VR, a form of simulation, one way to enhance the perception of immersion is to provide multiple sensory cues (such as vision, audition, and haptic sensations). Currently, the field of healthcare simulation has not addressed what immersion means from the neurophysiological point of view, the impact of immersion on learning, and how multiple sensory inputs influence the level of immersion.

With the use of blended research paradigms from neurophysiology [36] and behavioural sciences [14], this work aims to understand if more realistic simulators are more immersive and more effective, compared to lower-fidelity training environments. More specifically, how different forms of sound and touch feedback can influence a trainee’s perception of a drilling task, and whether these sensations promote motor learning and skill transfer. By integrating neurophysiological techniques, such as electroencephalography (EEG), we will examine brain activity during a drilling task with progressive levels of immersion. Using frequency analysis and source localization, we will also seek evidence of a neural signature of optimal immersion in a training environment. Utilizing other physiological measures, including surface electromyography (sEMG) and heart rate variables, we will assess trainee responses to different immersive stimuli, and potentially identify physiological differences in top- and bottom-performers.

Our prior work has established that low-fidelity haptic force-feedback combined with realistic audio input can enhance subjective realism and accuracy in a simulated drilling task, compared to audio alone [39]. We will continue this work by examining how auditory and haptic sensations affect motor learning, skill transfer, and associated
brain activity during a simulated task. We will have separate groups of volunteers participate in the simulated drilling task with either (a) no audio or haptic sensations, (b) audio sensations, (c) haptic sensations, or (d) audio-haptic sensations, and a transfer session 24 hours later. With a between-group design, we can hypothesize that the participants in the audio-haptic group will learn the drilling task more efficiently, and perform better during the transfer test, as compared to the other groups.

8.2.1.6 Customization of Pick and Place Tool for Cardiac Auscultation Tasks in Virtual Reality Employing User Ergonomics

Virtual reality (VR) applications in medical training allow for the reproduction of realistic scenarios depicting procedures for developing cognitive and psycho-motor skills, performed in seated, standing, and room-scale settings [79]. However, given the recent widespread application of commodity VR, on-size-fits-all solutions lack support for the variability of users in terms of their ergonomics (e.g., height, reach, mobility), which can lead to usability issues [60]. For example, VR sensitivity can be affected by speed and height changes within the scene mismatching their own [90].

In this section we present the development of a tool for customizing pick and place tasks within a virtual cardiac auscultation scenario employing user ergonomics. Cardiac auscultation is a routine examination that allows diagnosing heart conditions to determine proper care and treatment if needed [8]. With respect to cardiac auscultation training, practices are moving away from using the cost-effective stethoscope toward employing multimedia resources, manikins, and various diagnostics tools such as the echocardiography [8]. Although simulation has proven gained more popularity it is leading to concern regarding the loss of cardiac auscultation skills using the stethoscope [8]. This scenario in conjunction with current consumer-level virtual simulation is leading to the development of complementary training tools for addressing this problem [69].

The VR-based auscultation training tool is being developed using the Unity game engine, and SteamVR. The tool combines tracking scripts attached to all in-game objects that record the user’s actions in order to obtain ergonomic measures. This allows us to define the best placement and scene scale with the goal of overcoming the limitations of one-size-fits-all default interactions in VR software development kits. Before examining the virtual patient, the user is required to pick and place tasks by interacting with objects on a table to obtain the user’s ergonomics (see Fig. 8.6a). Once completed, the user can examine the patient by placing the virtual stethoscope on the mitral, tricuspid, aortic, and pulmonic areas. To provide quantifiable feedback to the trainee, metrics from the interactions include completion time, number of attempts, and motion paths are gathered during the virtual examination and displayed at the end of the simulation. In addition, the framework allows instructors to review the sessions within the scene to evaluate performance and identify areas where the trainee had trouble (e.g., auscultation areas, completion time, examination responses, and gaze areas). The recorded data can be reproduced to conduct debriefing sessions with the trainees to discuss their decision-making. The framework also provides
Fig. 8.6 Auscultation scenario view. a User calibration. b Virtual cardiac auscultation

an additional view on a monitor for instructors and other trainees to spectate the examination being performed with the HMD.

Data obtained from a preliminary testing of the Vive controller and the Vive Tracker over 30 examinations, allowed us to observe that the trackers can be easily occluded by the trainee’s body during the interactions, resulting in 25 faulty interactions between the stethoscope and the auscultated area, affecting the examination and the metrics being recorded. Figure 11.6b shows the virtual examination with the Vive Tracker, the spectator’s view, and auscultation with the Vive controller.

In this Section, we have briefly presented our ongoing work that is seeing the development of a VR framework that adapts the scene based on anthropometric measures captured within the virtual examination for cardiac auscultation. The preliminary assessment of its use across numerous examinations allowed us to identify problems with the Vive Trackers and their reliability for the developed training tool. Moreover, during the development of this project, a SteamVR update introduced inconsistency to our system provoking continuous tracking dis-connection. A problem later solved with an update by the developer.

Future work will study the effects of ergonomics measures on usability, presence and performance within the virtual auscultation.

8.2.1.7 Guiding User Vision in Virtual Reality Environments

With the increase in demand for graphical fidelity, as well as the increase in display resolution and refresh rate, graphics performance is once again a concern for developers. This problem is most apparent in the field of Virtual Reality (VR) where framerates and response times must be kept high to avoid motion sickness and other unwanted effects such as delay when using techniques like foveated rendering [3]. This is made worse by the nature of current virtual reality hardware which requires rendering a display for each eye, doubling the graphics compute cost of VR games. The current trend in VR hardware is also leaning towards standalone systems, with reduced Graphics Processing Unit (GPU) compute capability compared to their
desktop counterparts. Many methodologies and techniques have been developed for optimizing rendering performance in VR, such as Multiview outputs and foveation. Many of these are also relevant to the traditional rendering pipeline (where the vertex stream is rasterized to a single display), especially when combined with newer technology like high-performance eye tracking. One of the current leading areas of research in this field is perception-based rendering, where the GPU compute resources are allocated to areas that have a higher impact on user perception, such as areas of high contrast or in the foveal region (the area of highest visual acuity in the human eye) when eye-tracking hardware is used.

**Perception-Based Rendering:** Perception-based rendering has been a goal of graphics researchers for many years due to its ability to efficiently allocate rendering resources [70]. It refers to a set of methodologies and techniques that aim to reduce the computational cost of rendering by leveraging the limitations of the human visual system [37]. This field of research borrows heavily from research into the psychophysical aspects of the human visual system, with some simplifications and generalizations made, such as using discrete foveal regions based on averages of human foveal regions. The human eye visual field spatial resolution can be categorized into three main regions: the foveal, inter-foveal and peripheral regions [89]. The foveal region has a high density of color-receiving cones, and a lower number of rods (contrast sensitive photoreceptors), which leads to the fovea excelling at visual acuity and color accuracy. The inter-foveal region is marked by a sharp decrease in cone density, with a large increase in rod density. These two regions constitute ‘central vision’ and are responsible for the majority of visual acuity. Beyond these regions there are no cones, and rod density falls off steeply and this is referred to as the peripheral region [89]. It is also worth noting that the periphery shows no decrease in ability to detect motion, which may have applications when attempting to guide user attention. Perception-based rendering aims to leverage these attributes and limitations of the human visual system to provide shortcuts for rendering techniques. The most promising of these fields is foveation, where rendering resources are allocated mainly in the foveal region, but there have been some promising results using contrast to guide rendering to higher-contrast areas [30].

**Driving User Attention:** Our area of research is in leveraging the findings of perception-based rendering research to drive user attention in a way that does not impact immersion. Foveation uses gaze information to guide rendering resources to the user’s area of focus, but there is little research done on reversing this, and having the simulation guide the user’s attention. Work has been done on guiding user vision in VR and Augmented Reality (AR) using more traditional approaches, such as arrows, object highlighting, and halos [72]. Our research will focus on whether it is possible to leverage contrast, movement, and aliasing in a way that guides user vision without impacting immersion in the virtual scene. Our current approach will be to artificially introduce aliasing or contrasting the inter-foveal region to induce a saccade response and move the artificially salient region until the user’s gaze aligns with the point of interest.
Current Applications: This could provide guidance to the user in high-complexity virtual environments in video games and training simulations and may have a positive effect on immersion. Our current research involves guiding user vision in a full-immersion VR environment for cardiac auscultation training, as well as guiding vision on a more traditional display in reminiscence therapy for patients with dementia (see Fig. 8.7 for a sample screenshot of our current application). We also plan to examine how guiding vision impacts skill transfer to non-guided and real-world tasks.

8.2.1.8 Force Feedback for Precision Tool Grasping

Although virtual simulation is being applied across a wide range of medical training applications, currently the majority of these applications focus on the cognitive aspects of a procedure only typically ignoring the technical components given the complexities associated with generating the haptic cues required to simulate them. The aim of this project is to improve the medical training simulation by providing haptic feedback in virtual medical skills training. We are focusing on simulating the grasping and manipulating of precision tools (e.g., a scalpel, etc.) similar to commonly available haptic gloves (see Fig. 8.8).

We determined the force required to lift an object at rest with a known mass based on Newton’s law of gravity. Grasping and manipulating precision tools such as a scalpel involves the thumb and the index finger. According to Nataraj [54], the difference between the magnitude of the forces applied by the thumb and index finger is negligible. Taking this into consideration, we distributed the forces equally between the thumb and the index finger. The haptic device then goes through a series of conversions of these forces to provide equal and opposing force. The user must then overcome this force in order to lift the virtual object. The motion of the object
is detected using a Leap motion sensor connected to a Unity application connected to an Arduino Uno as microcontroller communicating with the driver board.

8.2.2  **Gamification- (and Serious Gaming-) Based Solutions**

In this subsection, we provide a description of projects whose solutions focus on gamification and serious gaming.

8.2.3  **The Gamified Educational Network (GEN)**

Interacting online daily using social networks has become ubiquitous while “educational networking” (the use of social networking technologies for educational purposes [46, 71]), has also gained popularity. A prominent strategy is the adoption of gamification concepts to motivate, engage, and enhance the participant’s experience, thus positively impacting its academic achievement and social connectivity [95]. Gamification refers to the process of applying game elements (such as levels or points) to non-game contexts to stimulate learners to engage in collaboration, friendly competition with peers, and achieving the positive learning outcomes [95]. Online educational platforms, including massive online open courses (MOOCs), have applied gamification to entice participation and engagement by exploring the learners’ intrinsic motivation (e.g., socializers want to interact with others, killers
are engaged by competition and challenges with others) [61]. Within this context, the Gamified Educational Network (GEN) was born, to explore the application of gamification concepts to an educational network by using game elements as intrinsic motivators and aiming to engage and motivate learners and to promote a collaborative learning process.

The GEN builds upon the Observational Practice and Educational Network (OPEN) that was initially designed to support health professions education by allowing a community of trainees to access educational and instructional content, communicate with peers and subject-matter experts, and provide/receive feedback asynchronously [76]. OPEN was previously used to study the role of Internet-based learning in clinical skill acquisition and medical-based cultural competence training for novice health professional trainees [21, 52]. More specifically, medical trainees were video-recorded practicing suturing and knot tying techniques [21] and interacting with a virtual simulation of an elder patient that does not feel comfortable with her doctor [52]. The resulting videos were uploaded to OPEN, where other users (e.g., peers or experts) provided constructive feedback by commenting on these videos. Furthermore, Khan et al. [52] demonstrated that the use of an Internet-based educational platform could encourage trainees to prepare for learning sessions, and video-based activities provided a fun and engaging experience. GEN aims to offset the low engagement identified in OPEN by applying gaming elements, and it has been designed from the beginning to be used by any field of study, not only health education.

The game elements employed in the GEN were determined after a series of formal focus group sessions that were conducted with an equal mix of 15 participants (game developers, game designers, and medical trainees), recruited from the Game Development and Entrepreneurship at Ontario Tech University and from the faculty of Medicine of the University of Toronto, who interacted with the original OPEN platform [75]. That work identified three game elements that were implemented in the GEN and, with badges, are the most used in education [95]:

- **Point-based system**: implemented in a manner similar to the “Reddit” entertainment, social networking, and news website which supports peer-based assessment where-by peers rate the quality of other comments or interactions.
- **Leaderboard**: this social comparative feedback component provides learners with information regarding how well they are doing with respect to their peers. Such comparative information is provided both individually and in a general context by showing the learner position on a private individual leaderboard (e.g., ‘Forum likes: #2’) ensuring that the learners do not have access to the scores of their peers, avoiding comparisons that could be a detriment to motivation. Learners also get access to how many points they received in each course section through an individual scoreboard.
- **Module division**: implemented as a segmented progress bar that allows learners to track their progress in each course and each course component.

A preliminary between-subjects study with 10 participants was conducted using the QUIS (Questionnaire for User Interaction Satisfaction), and the SUS (System
Usability Scale) questionnaires and four open-ended questions requesting general feedback to examine the usability and satisfaction perception of the GEN in two versions: with and without gamification elements [84]. Both versions achieved a SUS score above 80, which indicates a highly usable system, and the QUIS questionnaire also implies that the GEN interface is extremely easy to use, although not very stimulating. Concerning the open-ended questions, users provided constructive feedback regarding both versions of GEN. Here are a couple of answers when asked about the gamified version “Do you feel that GEN fosters a collaborative experience?”

- “GEN has the potential for user collaboration, but I think areas like the comments section could use more functionality (i.e., up-voting, direct replies, etc.).” (Anonymous participant).
- “I think it is possible, I noticed a couple social motivators on the comments for example, however I am unsure if collaboration can be better encouraged by the system somehow or if it falls primarily on a course instructor to direct.” (Anonymous participant).

Furthermore, given the preliminary nature of the data, definitive conclusions cannot be drawn regarding the superiority of one version over the other.

For future work, based on open-ended questions feedback, we will improve the comments functionality, quiz collaboration, integration with social media to allow users to share their accomplishments, and also study more methods to improve peer-to-peer interaction. Additional testing will also be conducted to examine the engagement and motivation of both versions, in addition to their educational effectiveness (knowledge transfer and retention).

8.2.3.1 Assisting Medical Lab Technicians Using a Modified Objective Structured Assessments of Technical Skills (OSATS) Tool to Test Content Validity on the Microtomy Procedure

Histological techniques are a highly valued skill in the medical laboratory sciences (MLSc) program because it is the basis for all microscopic examination of tissues under the microscope [83]. A microtome is a tool that is used to cut paraffin wax blocks to create tissue samples. It involves the use of a sharp knife for tissue cutting and several safety precautions that students must be aware of. The most commonly used microtomes in histology are the rotary microtomes (see Fig. 8.9). The device has a rotary motion that is actually part of the cutting process. The blade is usually fixed in a horizontal position and the tissue section is placed above the blade. In many microtomes, the rotary wheel can be operated manually, but they are generally automated or semi-automated. Automated instruments reduce repetitive movements, which can minimize the risk of developing musculoskeletal disorders.

There are a series of steps that must be completed in sequential order along with cautious safety features when handling the instrument. Rolls [77] states ten general examples of what is and is not appropriate during tissue processing and fixation.
Although the literature illustrates the microtomy procedure using several steps, there is still a lack of tool that defines the most essential steps of the procedure.

The Objective Structured Assessment of Technical Skills (OSATS) is a tool that will be used to validate the microtomy procedure. It was initially used by the University of Toronto in the 1990s to examine surgical residents’ skill competence. The checklist identifies tasks that must be performed correctly. The global rating scale consists of seven general competencies and the examiner rates the level of each competency on a five-point Likert Scale that is anchored with a behavioural description [5]. The OSATS tool has been implemented in evaluating surgical skills of residents and the reliability and validity of the assessment. The assessment identifies residents who may need additional training and provides a mechanism to ensure the competency of surgical skills. Thus, OSATS is a reliable and valid tool for assessing technical skills such as the microtomy procedure.

The current learning methods consist of students following a stepwise procedure from a lab manual or a procedure written by the professor. These manuals all have variations between the sequence of steps, along with what steps are included in the procedure [77]. The biggest issue is when students aren’t aware of all the safety features, it can lead to accidents such as cutting themselves. The lack of adequate amount of time prevents students to confidently develop the technical skills of the microtomy procedure. Simulation provides an alternative method for health care professionals such as medical laboratory technicians, and future health care professionals such as students to develop their skills until they reach a specific competency level [28]. Therefore, a game-based simulation will be designed to improve the learning outcome of the medical lab students because it will allow for students to practice the technical skills outside of the lab.
**Purpose:** use a modified version of the OSATS tool to (a) develop the stepwise procedure, (b) provide evidence of content and construct validity of the microtomy procedure.

**Research:** The research questions we will be examining include (i) Can we break down the skills of microtomy into component skills using task decomposition methods and expert opinions. (ii) Does the modified OSATS tool show evidence of content and construct validity for the 10-step microtomy procedure?

For both phases outlined below we will use a modified Delphi method as outlined in [42], by generating an initial concept document. Experts are recruited and consensus will be built from separate rounds. Each expert will complete the questionnaire and provide comments on each topic. At the end, a consensus will be made using the data provided by the experts. This is different from a full Delphi method, which starts with preparing the concept with an expert. We have selected to follow the modified version because we have access to a local expert who can prepare the initial concept document.

Phase 1, “Development of the instrument”, will consist of the use of the OSATS tool to validate the content of the 10 key steps for successful microtomy completion. Data collection will be obtained using expert consensus methods (e.g., the Snowballing method), and experts will assess the stepwise procedure to provide content validation.

Phase 2, “Assessment of content validity”, will require the MLSc content experts to complete a questionnaire regarding the OSATS tool and provide feedback on each of the dimensions.

Phase 3, “Imbedding Safety Module into the Gamified Education Network”, which consists of an online safety module that students must complete prior to the simulation-game starting the microtomy procedure. Students must pass the module to demonstrate an understanding of the safety component of the microtomy procedure.

The long-term objectives are to enhance the learning outcomes of MLSc students with microtomy techniques using simulation. The key deliverable will include a working simulation-game (beta version) that will consist of a virtual microtome, pre-game safety module, pre-game description of the skill, in-game information and feedback, in-game scoring, post-game feedback to the learners about their performance, and the game will balance educational and fun practices. The collaboration between experts in health sciences and computer science/engineering at Ontario Tech University will allow for the development of the simulation-game. We anticipate that this game will:

- Improve the knowledge of all safety components of the microtome.
- Improve MLT confidence.
- Increase safe practices to ensure individuals are not cutting themselves.
- Improve sample slide tissues for more accurate microscopic examination.
8.2.3.2 The Autism Serious Game Framework (ASGF)

Autism spectrum disorder (ASD) has a variety of causes, and its clinical expression is generally associated with substantial disability throughout the lifespan of the affected individual. It is characterized by impaired social communication and interaction, and by restricted, repetitive interests and behaviors [97]. Mentalizing, which involves the ability of a person to attribute beliefs, thoughts, feelings, plans, and intentions to themselves and others, can be a struggle for those with ASD [73]. The mean clinical age of diagnosis is 4–5 years, despite advances in knowledge regarding early signs of the disorder [97].

Serious games (SGs) are games that do not have entertainment, enjoyment, or fun as their primary purpose [23]. Serious games are often designed and developed to address one specific problem/scenario that cannot be easily modified. Changes to scenarios require the serious game’s source code to be modified, which is a difficult and time-consuming process.

Within the scope of this project, working collaboratively with ASD experts, we developed an Autism Serious Game Framework (ASGF) that allow therapists with limited, if any programming experience, to create new (or modify existing), serious games intended to assist children with autism (we are targeting children between 3 and 7 years of age). The ASGF provides a more usable, flexible structure than traditional gaming engines, as it allows a non-programmer to develop serious games and modify their parameters while overcoming the single scenario problem inherent. The ASGF includes a graphical user interface (GUI) that follows a WYSIWYG (what you see is what you get) approach whereby users (therapists) are able to drag and drop (and assemble) components associated with each game. The framework allows users to import 2D, 3D graphical assets (with or without animations), and sound assets to configure the different types of games. We are in the process of conducting a series of experiments to test the effectiveness of the ASGF and several games developed with it. However, preliminary testing with childhood autism experts are promising and indicate that the ASGF will allow for the simple development of autism-based serious games and assist and help children with autism to develop skills and obtain functional gains, such as recognizing faces.

8.2.3.3 COVID-19 Serious Game

Coronavirus disease 2019, colloquially known as COVID-19, is an affliction that was first reported back in early January of 2020, and as of March 2020 has been classified as a pandemic [92]. According to the World Health Organization [92], COVID-19 affects different people in different ways, and most infected people will develop mild to moderate illness and recover without hospitalization. The most common symptoms include fever, dry cough, and tiredness while less common symptoms include aches and pains, sore throat, diarrhea, conjunctivitis, headache, loss of taste or smell, a rash on skin, or discoloration of fingers or toes [92]. It is commonly spread by close contact between humans, and as such health professionals around the world have
recommended maintaining at least two meters of social distancing, isolation and the use of face masks by those experiencing flu-like symptoms.

With many workplaces and businesses having to shut down in order to limit the spread of COVID-19, schools and workplaces alike have become more reliant on technology to ensure work and learning can proceed. Those who work on a computer have shifted their work and meeting environment from the office to their home, and educators have had to work diligently to adapt their lessons to be delivered online (see Grant [39] for a discussion on the use of virtual reality to host meetings). While most post-secondary programs have been able to adapt to electronic content delivery, students training to be medical practitioners and other professions that require hands-on experience have suffered from a lack of hi-fidelity simulations in lieu of being in the operating room or other learning environment. Virtual reality in the form of virtual learning environments including virtual simulations, and serious games, can help fill in some of this gap. The use of such tools hasn’t only been seen in professional and academic fields, when dealing with a pandemic the general population requires access to reliable information in an engaging and easy to digest format. In response to this demand, we have begun developing a COVID-19 serious game to be deployed to mobile platforms where the player will step into the shoes of an essential worker, and must go about their day while making the right choices to keep not only themselves and their family safe, but everyone around them to minimize the spread of the disease.

8.2.4 3D Printing-Based Solutions

In this subsection, we provide a description of projects whose solutions focus on 3D printing.

8.2.4.1 Low-Cost 3D Printed Craniotomy Simulator: Developing an Instrument Examining Contextual Factors that Matter in the Implementation of Three-Dimensional Printing and Virtual Reality Simulation in Nursing and Medical

A craniotomy for traumatic intracranial hemorrhage is a common procedure in a neurosurgery residency training program [56]. When a patient suffers a traumatic head injury (THI), such as an expanding epidural hematoma (EDH), or subdural hematoma (SDH), usually, a neurosurgeon will take an urgent operative intervention to relieve pressure on the brain and control hemorrhaging [56, 74]. When this happens in rural and remote areas where neurosurgeons may not be readily available, surgical intervention by community general surgeons (CGS) may be required to prevent progressive neurological impairment or possible death of the patient [34, 78, 87]. Even with the remote assistance by a skilled neurosurgeon through video call, the stress of an emergency and a CGS’s rare hands-on experience may increase the risk of surgical complications [56]. In this case, a CGS is confronted with a difficult decision:
operate in undesirable circumstances with remote assistant from a neurosurgeon, or transfer the patient to a tertiary care center with the potential for adverse consequences due to delay of care [11].

To date, medical simulation has become an excellent addition to healthcare education, as it promotes skill acquisition and maintenance through hands-on experience [74]. Simulation-based training may provide a good training platform to CGSs to “master the critical skills before performing their first craniotomy on a patient” [56]. However, the cost of similar commercially available high-fidelity simulators are magnitudes more expansive, making them potentially prohibitive outside large, well-funded neurosurgical training programs [11].

We have proposed a solution, 3D printing affordable simulators for rural and remote healthcare centers [11]. A three-dimensional (3D)-printed EBHC simulator (see Fig. 8.10) was designed and printed with the purpose of being incorporated into a simulation-based medical education (SBME) curriculum developed collaboratively by neurosurgeons and CGSs, specifically delivered in rural and remote areas. The direct cost for each EBHC simulator is approximately $12 although this cost can be further reduced if we recycle the 3D printed material.

We have tested the EBHC simulators at hands-on workshop of the 26th Annual Rural and Remote Medicine Conference in St. John’s, NL, Canada. This conference,

![Fig. 8.10](image)

**Fig. 8.10** a The first stage of the simulator construction (base, brain, skull, and skin). b The final stage of the simulation construction (the skin was draped over the skull and secured using the clamps on the base and additional hardware). c Emergent burr hole/craniotomy simulator after a 15 min demonstration by an educator
hosted by the Society of Rural Physicians of Canada, targeted healthcare professionals who are currently practicing, or those who look to practice, in rural and remote areas of Canada. 16 individuals attended the workshop, all of whom indicated that they were rural general practitioners (GP), with two individuals indicating they additionally completed enhanced surgical skills.

Future work will examine the integration of the low-cost EBHC simulator (see Fig. 8.11) into a neurosurgical training program. Future work will also involve further improvements to the design of the EBHC simulator.

8.2.4.2 Developing an Instrument Examining Contextual Factors that Matter in the Implementation of Three-Dimensional Printing and Virtual Reality Simulation in Nursing and Medical Laboratory Sciences Education

There is a rapidly growing body of literature that examines how simulation can be best used in healthcare education [63]. However, a gap has been identified in the area of simulation-based medical education, and more specifically, program directors are struggling with how to successfully implement simulation programs, given a lack of clear guidelines on the matter [53]. Implementation science is a rigorous study of methods that allow for a systematic uptake of research findings and other evidence-based practices [31]. It is intended to guide the implementation of evidence-based programs in various contexts; however, it has not yet been integrated into simulation-based education [31]. This research study aims to use implementation science to
develop an instrument to assess the effectiveness of disruptive technologies in nursing and MLS education.

Commercial simulators are expensive and have limited customizability, therefore restricting educational opportunities in fields such as nursing and MLS. In contrast, innovative 3D printing and VR simulators are cost effective and customizable. Our goal is to implement 3D printing and VR as adjunct options for academic institutions to develop simulators that are low-cost, good quality, and customizable. However, implementation science shows that only a minority of innovations are adopted without proper implementation planning and consideration of the context. This project uses an implementation framework to assess the feasibility and need for developing an instrument examining contextual factors that matter in the implementation of 3D printing and VR simulation in nursing and MLS education. What are the constructs that make up an effective instrument to evaluate readiness and fit for implementation of disruptive technologies to enhance the use of simulation in nursing and medical laboratory sciences education?

The Consolidated Framework for Implementation Research (CFIR) was used to inform the development of the instrument. The CFIR includes 37 constructs that influence implementation, which are within five major domains: (i) inner setting, (ii) outer setting, (iii) intervention characteristics, (iv) characteristics of individuals, and (v) the process of implementation [35]. An online questionnaire will be administered to participants and completed anonymously, and the data collected will aim to reduce the number of constructs to those that are most applicable to simulation in nursing and MLS education. Participants will include thirty experts who are teaching faculty from the Nursing and Medical Laboratory Science (MLS) programs within the Faculty of Health Sciences, at Ontario Tech University in Oshawa, Canada. Each participant will rate the importance of each construct in regard to their specific educational program on a scale of 1–10; 1 signifying the construct is ‘not important’ and 10 signifying the construct is ‘very important’. The data will be analyzed and filtered based on expert ratings. Using the Delphi methodology, the constructs will be narrowed down based on the ratings. Further refinement of the constructs will take place until a feasible implementation instrument to evaluate the effectiveness of disruptive technologies in Nursing and MLS education is formed.

Using 3D printing and VR to fulfill simulation requires careful implementation. Implementation frameworks inform this process, but they require adaptation to fit the context. To optimize the success of adoption of 3D printing and VR simulation, the implementation process should focus on the constructs that the experts deem important. With the pool of faculty members from both the Nursing and MLS programs, the Delphi methodology will be used to build consensus among these experts. The process of narrowing the constructs to create a feasible implementation instrument will help evaluate the effectiveness of disruptive technologies in Nursing and MLS education, and may have the potential to be further adapted to other educational contexts.
8.2.4.3 Is the “Floss Dance” Really Enough to Make You Floss?

Approximately 2.2 million Canadians aged 20–64 have lost all of their natural teeth, while 96% of Canadians have or had dental cavities throughout their lifetime [18]. A simple oral hygiene routine could have largely prevented this. Educating the public on proper oral hygiene practices is one of the preventative measures against tooth decay, gum disease, and other common oral health problems. The program dedicated to improving brushing techniques in children resulted in significantly better brushing skills and more frequent brushing [55].

The Oral Health Division of the Durham Region Health Department (DRHD) is interested in acquiring a physical model of teeth and adjacent structures to demonstrate proper dental hygiene techniques to their patients. The model can also be used to explain the symptoms a patient experiences and the underlying oral health problems, as well as, educate children and youth during school screenings.

Low-cost 3D printed dental models were previously evaluated on the face (realism) and content (usefulness) validity by dental students and maxillofacial surgeons and were rated as good or excellent [48]. Within the scope of this project, will create an electronic 3D model from 3D scans of subject volunteers. These will include patients with decaying teeth, deteriorating gum lines, abfraction, and brushing abrasion as a demonstration of these common problems resulting from poor oral hygiene. To further the realism of the model, CT scans of the upper and lower jaw can be used to accurately show the bone structure. We will use 3D printing and a silicone coating to construct a realistic model of the upper and lower jaw including teeth and gums. The teeth, maxilla, and mandible will be 3D-printed in various bone-like plastic materials. We will model gums and oral mucosa by direct application of dyed semi-liquid silicone onto 3D-printed “bone”.

Alternatively, both the bony and soft tissue parts will be 3D printed simultaneously using a dual-filament 3D printer: jaws and teeth will be printed with PLA (for example) and gums will be printed with TPU (Ninjaflex or other). The advantage of the second method is the absence of any post-printing modifications and the possibility of adding periodontal ligament and the innervation commonly used in dental anesthesia.

Working with the Oral Health Division of the DRHD, we will collect feedback from practicing dentists and oral health experts. We also plan to test the resulting product with Ontario Tech University dental club during their educational visit to local elementary school. The created 3D files will be a useful future asset for serious gaming simulations in maxSIMHealth labs as they could be easily incorporated into VR simulations.

8.3 Discussion

**Ideate. Create. Disseminate.** This sums up how maxSIMhealth operates. Through this collaborative, we can take ideas, transform them into existence, and disseminate the final product via partnerships which results in solutions that matter. maxSIMhealth’s work spans a broad spectrum of scholarship from mapping existing gaps, to changing education systems, to improving learning and performance outcomes. In order to achieve this, the maxSIMhealth map is followed using five simple steps when starting new projects (see Fig. 8.12).

**Step 1—Gap Analysis/SKA Selection:** Regards selecting skill, knowledge and/or attitudes (SKA) to focus on and improve through collaboration with content and medical experts at our partners. A key component of this first step involves the utilization of maxSIMhealth’s unique range of established research partnerships with hospitals, professional societies, governing bodies, and the simulation industry. This step follows a methodology adopted from implementation sciences and described in our earlier report [31]. In brief, this step constitutes the formation of core ideas through collaborating with diverse groups of stakeholders outlined above. A needs assessment is a fundamental stage in the educational process, which will lead to

![Fig. 8.12 Five steps taken when starting a project within maxSIMhealth](image-url)
changes in practice and therefore, it is the starting point for designing a formalized educational program. The stakeholders’ contextually appropriate ideas are assessed for their ‘fit’ in the program. The needs assessment identifies gaps which must be addressed by looking at the current position of the stakeholders, current curriculum, and comparing it to the desired level of simulation learning. We employ diverse methods for conducting a gap analysis: individual interviews, focus groups, surveys, questionnaires, self-assessments, and observations. Next, this information is translated into a detailed implementation plan. The implementation plan addresses the ‘what, who and when’ of the implementation, which identifies activities to be performed, schedules, and people involved. Resources are gathered from internal and external talent to build a functional team, and risks and potential roadblocks are identified.

**Step 2—Technology Matching:** This step is designed to determine the best possible and most feasible disruptive technological solution for the selected SKA. Similar to Step 1, this step focuses on involving stakeholders and employs diverse methods for conducting a gap analysis: individual interviews, focus groups, surveys, questionnaires, self-assessments, and observations. The step culminates with the formation of development teams including several students, faculty members and partners. Typical team composition has two students—one technology oriented and one with expertise in health sciences, two faculty advisors, and at least one partner lead.

**Step 3—Piloting and Validity:** Piloting the concept, developing prototypes (where applicable), and conducting preliminary studies occurs to determine its face and content validity.

**Step 4—Efficacy and Effectiveness Testing:** In this step, we aim to determine whether or not the concept works and, if so, how well it works. In steps 3 and 4 we follow an adapted Medical Research Council Framework [43]. This work typically constitutes graduate level scholarship, and therefore it adheres to our funding model emphasizing highly qualified personnel (HQP) training that needs to be imbedded in all activities.

**Step 5—Knowledge Dissemination and Implementation:** This step involves knowledge dissemination of the products once they are shown to be effective as well as implementation into health and/or education systems. To ensure timely and meaningful knowledge translation, maxSIMhealth has also established an institutional channel called Archives of Scholarship in Simulation and Educational Techniques (ASSETS) with the open-access *Cureus Journal of Medical Science* through which our work is freely disseminated as peer-reviewed, PubMed-indexed publications. maxSIMhealth works with our research partners to distribute the solutions for free, at cost or at an affordable price point. To accomplish this, we are encouraging institutions to become members with maxSIMhealth and participate in further implementation and iterative improvement research.

With this five-step map (see Fig. 8.12), students/trainees and experts within the collaborative work together and easily follow a set of guidelines to facilitate the
development and implementation of meaningful and economic simulation solutions that improve healthcare outcomes.

8.4 Conclusions

maxSIMhealth is a novel collaborative innovation at Ontario Tech University in Oshawa, Canada, straddling many professions and settings. Keeping the goals of public health in mind, we collectively aim to develop future cohorts of scholars who will have strong competencies, ranging from technology application, to working with others in new interdisciplinary environments, to communicating professionally and problem-solving. Here, we have provided an overview of several current and planned (future work) maxSIMhealth projects, all of whom are interdisciplinary, bringing together experts, trainees, and various stakeholders from a wide range of disciplines to solve pressing problems. It is anticipated that our work will successfully transform current health professional education landscape by providing novel, flexible, and inexpensive simulation experiences.

Authors’ Contributions At the time of writing this chapter, the maxSIMhealth (www.maxSIMhealth.com) group consisted of (in alphabetical order): Artur Arutunian, Krystyna M. Clarke, Quinn Daggett, Adam Dubrowski, Thomas (Tom) Gaudi, Brianna L. Grant, Bill Kapralos, Priya Kartick, Shawn Mathews, Pamela T. Mutombo, Guoxuan (Kurtis) Ning, Argyrios Perivolaris, Jackson Rushing, Robert Savaglio, Mohtasim Siddiqui, Andrei B. B. Torres, Samira Wahab, Zhujiang Wang, and Timothy Weber.

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