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Using Augmented Reality to Enhance Nursing Education

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Abstract

Augmented and Virtual Reality are proliferating throughout daily life. Everyday utilities, such as Google Maps, deploy Augmented Reality (AR) to improve the user experience and increase its effectiveness. Similarly, Augmented and Virtual Reality have been used in the educational domain, where these applications have been shown to improve the learning curve and retention. In this study, AR is proposed as an innovative method to improve the effectiveness and efficiency of the education of nursing students. We propose to introduce this innovative technology in the education of future nurses. Within this study the researchers use augmented reality (AR) to help nursing students learn about physical assessment techniques for the heart and the lungs. Researchers have demonstrated increased memory retention while using AR [14][15]. In this study, we provide a holographic overlay including the internal organs heart, ribcage, and lungs to increase the understanding of accurate placement of devices required for assessing cardiac and respiratory issues using anatomical landmarks. In addition, the visual aspects are supported with audio sound tracks to enhance learning. The ability to project images accurately placed onto real world physical objects using AR headsets could lead to increased retention and deeper understanding leading to precision performance related to techniques in physical assessment of the patient.

Introduction

Simulation is a recognized adjunct to health care curriculum. Simulations ranging from task trainers, mannequins, standardized patients and virtual training. The use of inter-professional scenarios are increasingly recommended as a method of improving safety in patient care. A recent Institute of Medicine (IOM) report identifies the use of simulation and the training of professionals together as key to long-term success for effective collaborative practice and a dire need for academics and the service sector to assume accountability for the testing of models that can demonstrate an impact on patient outcomes [21]. The complexity of health and disease and the increasing difficulty of health care demands collaboration between health-care professionals and the use of innovative training materials is a necessity to complete this challenging task of inter-professional collaboration [22]. The purpose of this project is to examine the effectiveness of augmented reality (AR) on clinical learning outcomes. It hypothesized that the use of AR increases retention of knowledge and skills. As such, it is expected that the implementation of AR training can potentially improve the healthcare worker's preparedness to provide safe care for patients. The researchers will focus on nursing students cardiopulmonary assessment skills. A hybrid educational approach will be used that includes a didactic component and AR, that address the cognitive, affective (confidence), and psychomotor domains.

Motivation

Patient safety is underpinned by nurses performing appropriate physical assessments. Teaching physical assessment skills to undergraduate nursing students is critical for their professional development. A wide variety of methods have been employed in the effort to teach these skills including manikins, standardized patients, and models. In addition digital methods including simulations have been employed[7]. Alternative approaches have been suggested to aid in the teaching of these core skills to nursing students [7][8]. Potentially, AR offers a powerful method to enhance learning. In this study we propose to develop an augmented reality (AR) application with the eventual goal to study the effects of AR as a teaching method for physical assessment of the human thorax, heart, and lungs performed by students. The AR is delivered using augmented reality headsets to display visual internal landmarks that can be viewed by students wearing the headsets during physical assessment training.

Augmented reality has the power to change medical education [14] [16]. AR also allows educators to circumvent the use of cadavers, which could significantly reduce training cost while still being able to properly prepare nurses and doctors for clinical practice with live patients[17]. There are several studies that demonstrate improvement in memory retention while learning with virtual reality (VR) environments, which aids participants in knowledge retention for content they have learned for a longer periods of time [18]. AR and VR can be applied to almost any area of study for educational purposes. Focusing on a study based on the application of VR in mechanical and electrical engineering, Kaminska et. al. found that VR can be used to successfully convey complex engineering ideas and concepts [19]. High level realism can be achieved in the virtual environment, making it extremely feasible to translate the experience to the real world. Rupasinghe et al. [20] have shown that VR training used for aircraft maintenance has been proven to help students perform better compared to those who have only been taught using traditional training methods. In their paper Leo L. Wang et al. [1] have been able to determine student satisfaction by implemented augmented reality into textbook learning. They developed an application called Gunner Goggles which used Layar on mobile phones and tablets to superimpose 3D models, text, links, and other visual and audio information onto a page of the textbook while students point their phone/tablet cameras to it. Pages from their textbook were uploaded to Layar and image recognition was used to delineate placement of 3D models, figures, videos, diagrams, and links to other websites and YouTube videos that were cited appropriately. 3D models of body parts were created or downloaded in wavefront(.obj) format and edited in Blender. They tested the application on a group of 24 medical students and found that 100% of the students felt that AR enhanced their learning experience. This study shows that AR in all forms contributes to the enhancement of the learning process. This novel technique has been proposed to be implemented in other learning environments and fields of study.

Literature Review

In this section, we discuss some of the other works that relate to our project.

Augmented Reality in Mobile Devices for Medical Learning

Due to various restrictions, it is not always possible to impart all required clinical content in live settings (lack of access to patients, settings etc.) Instead, educators have turned to using simulation methods including AR to assist clinical education. Researchers and scientists have been able to take advantage of the advancements in augmented reality to develop AR systems as an adjunct to the teaching of anatomy, procedural training, and emergency simulations [46]. In their paper, Von Jan et al. [2] present a learning environment powered by AR that can be implemented on mobile phones and tablets to possibly solve this problem. The researchers present an application that built life-like scenarios which are superimposed on physical objects in the real world that display desired aspects for a given training environment. These scenarios were viewed using mobile phones or tablets for which the application is developed. The application they developed is called mARble and reported findings indicate it improves the learning process in medical education for subjects that are visually oriented. They were able to assess the applicability and learning efficiency of the AR application by testing it with the help of ten participants. By providing an interactive learning environment, the authors claim that the application does a better job in capturing the attention of students and enables higher memory retention in them when compared to traditional teaching methods. The effects of learning with AR are compared to traditional education methods in the study conducted by Albrecht et. al [2]. We chose to use headsets that generate separate images for the right eye and the left eye so as to provide a stereoscopic view of the 3D models. Kamphuis et. al. demonstrate the potential uses of using AR in medical education by implementing AR for training laparoscopy skills [26].

Augmented Reality Used in Education

Steve Chi-Yin Yuen et al. [23] have discussed and evaluated the implementations of augmented reality for education and learning. The researchers have thoroughly discussed AR in all its forms as well as its applications in different fields including advertising, architecture, books, entertainment, gaming, medicine, military, and travel. Specifically with regards to applications in medical education, their research demonstrates that AR will be able to enhance surgical procedures and assist clinical activities by improving safety, efficiency, and cost-effectiveness. In their paper the researchers have also stated that AR could help invent new procedures. AR could be used to assist surgeons with orientation and navigation during the course of the surgery. Fischer et al. have integrated the use of AR with existing medical equipments.[28]. AR could also be used in pre-operative imaging studies by allowing doctors and surgeons to visualize the internal anatomy of a patient compiled from CT, MRI and Ultrasound data. Integrated with haptic feedback, AR could be used by medical professionals to visualize as well as feel the patient's condition prior to surgery. Researchers claim that a combination of these ideas would allow surgeries that are traditionally considered to be more difficult become minimally invasive [23]. The researchers have stated that AR when combined with dependable force feedback could drastically change surgery, and by extension, medical practice. AR has also been demonstrated to improve the learning experience by delivering a sense of immediacy, presence and immersion to the user [40]. Chien et al. use AR to help medical students learn and understand the structure of an interactive 3D skull [27]. Other researchers have demonstrated that AR could be highly beneficial when used to supplement lesson content in the education of human anatomy [30].

AR in Nursing Education

There exists a myriad of AR research conducted with the intention of assisting in the education of nursing students. In 2019 Wuller et. al. presented an overview of the existing research with regards to using AR to assist in nursing education [41]. Foronda et. al. have demonstrated 3 types of augmented reality applications used to enhance nursing education [9]. One of these approaches involves using a Microsoft Hololens device to view the anatomy of muscles and bones of a human body augmented on to real-world space. There also exists research using tablet computers to visualize organs overlaid on human bodies. One such study was conducted by Rahn et. al., who used iPads to overlay 3D images of lungs and other organs on students in real time [42]. These images were placed according to markers present on a white T-shirt which were distributed to the students prior to the experiment. iPads were also used by Abersold et. al. in their study to educate students in the correct placement of nasogastric tube(NGT) in an augmented reality environment [43]. Augmented reality has demonstrated real promise when implemented in a training environment. In their study, Ferguson et. al. have summarised the potential of AR and game-based AR applications as a supplementary addition to the process of nursing education [44]. This is also supported by Garrett et. al. who in their study have demonstrated the enhanced acquisition of nursing and clinical skills while participating in AR experiences [45]. Our study differs from the aforementioned existing research of efficient AR systems to supplement nursing education by focusing on a specific aspect of nursing education, which is the acquisition of fundamental physical assessment skills using AR headsets. Our primary intention in developing this application was so that it could be used as an adjunct to traditional training methods used by students to obtain this knowledge.

Simulating Surgeries

Scott Delp et al. have identified certain shortcomings in the process of educating medical personnel to provide emergency care [3]. Samset et al. [24] have developed tools based on novel visualization concepts using augmented reality, along with haptics and robotics for minimal invasive therapies (MIT). They present scenarios involving liver tumors, liver surgery, and cardiac surgery. Researchers use augmented reality to overlay real world 3D imagery obtained from CT scans onto manikins using markers for accurate placement. Researchers have also been able to couple this with remotely controlled robotic manipulators that offer haptic feedback so that the user feels accurate responses on their hands as though they were actually performing surgery. The researchers demonstrated that their research could be used to bring about improvements in healthcare related to increased quality, utilization, and reduced cost with respect to minimally invasive therapies and surgeries. Kawamata et al have developed an AR application to assist in the surgery of pituitary tumors [29]. Their software was used to overlay 3D images of tumors and nearby anatomic structures on live real-time endoscopic images. The researchers discovered that this type of navigation allowed surgeons to perform safe and accurate endoscopic operations on pituitary tumors.

Simulation of Tissue Deformation using AR During Surgery

Augmented reality has also been used to develop applications that are used for surgery in the operating theater. Haouchine et al [4] proposed using augmented reality in real-time during surgery. The authors presented a method to superimpose digital renditions of the vascular system and certain tumors during liver surgery, wherein they overlayed these images (attained from a previously performed CT scan) onto the laparoscopic view. They used an accurate model of a deformed liver accounting for heterogeneity and anisotropy caused by arteries and veins. The researchers focused on 3D visualizations of structures internal to the human body such as tumors and blood vessels. Their biomedical model was able to accurately capture deformations undergone by the liver at the time of surgery. The actual liver model was represented by wireframe, while the blood vessels were represented with a blue overlay and the tumor with a purple overlay. The authors conducted several experiments with varying conditions of blood vessels, liver and tumor after which they performed *in vivo* assessment of the liver in which they reported promising results. In their study, researchers Joldes et. al. have developed algorithms that are fast, accurate and handle deformations and non-linearities which can be used for real-time computations soft tissue deformities in AR devices that also use haptic feedback for surgeon and operation education [32].There have also been other research based on using AR to enhance soft tissue surgery. Mountey et al. have developed an AR application to assist soft tissue laparoscopic surgery [31].

Using Hololens to Visualize Endovascular Interventions

Endovascular procedures, while improving, still depend on the use of radiologic imaging contrast agents. These procedures come with radiation risks. Kuhlemann et al. [12] have devised a way to visualize the insertion of a catheter on a manikin using the Hololens. They circumvent the need for X-Rays, hence avoiding risk of radiation, by offering a 3D holographic view of the vascular system placed on a manikin or patient. A patient's vascular tree and surface is extracted from a tomography data. A magnetic tracking system is used to register this data to the patient. Landmark-based calibrations are used to place virtual objects on real world surfaces using the Hololens. This model is used for endovascular training. The system was evaluated on a full body phantom. Experienced clinicians used a 4-point questionnaire and found the average score to be 87.5%. This system showed great potential in improving the procedural workflow of endovascular surgeries, simultaneously reducing exposure to radiologic procedures significantly. The system also enhances the training of clinicians and surgeons to gain mastery of the required skills related to endovascular procedures. Garcia-Vazquez et al. have conducted a similar study used to circumvent fluoroscopy and digital subtraction angiography to perform device navigation during endovascular procedure using augmented reality [13]. Other researchers have augmented reality simulations to assist in endovascular neurosurgery and discovered promising results [33] .

Memory Retention While Using AR

Using Steady State Topography (SST) brain imaging to examine the brain activity of people who participated in AR and non-AR tasks, Heather Andrew et. al. [15] found that the visual attention is almost double when performing AR tasks when compared to non-AR tasks. The author also found that what is stored in memory is 70% higher for AR experiences [15]. Other studies show that the long term memory of the learner can be enhanced by using multiple media interactions in the learning process [14]. Adedukon-Shittu et. al. have also demonstrated the effectiveness of AR technology with regards to enhancing memory retention and performance [34]. Other studies have also demonstrated the enhanced knowledge acquisition and retention of adequate memory when using AR as a supplemental tool in the education process [35].

Feasibility of Using AR to Train Resuscitation

In their paper Steve Balian et al. [11] have devised a method of testing the feasibility of using augmented reality to educate healthcare providers about administration of Cardio Pulmonary Resuscitation (CPR). The researchers used Microsoft's Hololens to provide users with audio and visual feedback of the blood flow in the human body in real time superimposed on a manikin. 51 health care providers volunteered for this study, and were asked to perform CPR using only the Hololens for two minutes. The chest compression parameters were then recorded for this test. The participants' response to the system was primarily positive, perceiving this method to be realistic and found that AR is a helpful tool when it comes to training in medical education. 94% of the participants also stated that they would also be willing to use this application for CPR training in the future. Balien et al. demonstrated that augmented reality can be a valuable tool when integrated with existing education approaches in medical training[27]. Based upon the literature reviewed, the researchers were motivated to develop an augmented reality application to help nursing students in their training process. Time and again augmented reality has proven to be advantageous when integrated into education in terms of novelty, memory retention, and knowledge gained [14] [15] [34] [35] .

AR Triage Training for Multi-Casualty Scenarios

Establishing priority of care plays a huge part in triage training. John Hendricks et al. [5] have developed a simulation in virtual reality to help train medical personnel and military field medics in making these decisions in triage training environments. In their model they present a scene in which multiple injury scenarios are presented to users on a virtual patient. Each virtual patient has it's on injuries as well physiological conditions that evolve with time based on their allotted injuries. Animations are added to each of these patients that include, and are not limited to, bleeding, seizures, etc. The user would wear augmented reality headsets, watch these scenarios play out, and make appropriate decisions using command options on their headsets to successfully prevent the virtual patient's condition worsening. Users would be assisted by a supervisor who would monitor the decisions made by the user using a mobile device, such as a tablet or a mobile phone, which would be connected to the AR headset. The supervisor would then grade the user's decisions once the simulation is complete. The user can then utilize virtual medical devices, and apply medications accordingly. Scenarios of injuries presented also include gunshot wounds and injuries resulting from the blasts such as amputations, burns, blunt trauma, chest injuries, etc. Virtual patients could also be overlaid atop a manikin so that correct actions selected by the user can then be performed on the manikin. Users are required to assign triage priorities to the virtual patients and dispense immediate care as needed [5]. Other researchers have also developed triage systems enhanced by augmented reality to emergency medical services [37].

Various other triage training simulations have also been developed. One such study has been conducted by Andrei Sherstyuk et al. [6]. In their paper they have proposed a system using a head-mounted display as well as external sensors connected to gloves in order to train medical personnel in a triage situation using body poses and hand gestures as user input in a virtual environment. They claim to use this form of input in order to alleviate the inherent shortcomings of virtual reality headsets, such as claustrophobia, and tunnel vision. Researchers provide the user with the ability to travel to multiple virtual casualties/patients using body poses and select tools using gestures in order to perform the required medical operations on the virtual patient. Primarily the researchers focus on the efficacy of navigation and travel to a virtual patient using body pose commands as input and also object manipulation using gestures. Stuart et. al. have developed an AR application that facilitates the user's development of correct stress management skills by using virtual patients that appear overlaid on real-world environments [38]. In our research the application is implemented using augmented reality headsets, which significantly diminishes the aforementioned shortcomings of virtual reality headsets. We use hand gestures to navigate our application when using the Hololens, and use the handheld controller while using the Magic Leap One device. In their review study, Munzer et. al. demonstrated that AR has feasibility and utility not only in patient-care and operating room settings, but also in training and educating emergency response personnel [36].

System Design

The goal of this project was to design an augmented reality simulation to augment existing nursing education in physical assessment skills to improve both psychomotor skill and clinical competence. The project team sought to develop visual aids in 3D that mimic real-life anatomy and functionality of bodily organs providing additional information to the learner that is usually not visible by allowing the learner to view internal organs and structures. The learning experience was enhanced by providing a deeper understanding of both the psychomotor process of assessment and interpretation of findings. Project development was an iterative process guided by the technological capabilities and the collaborators from the nursing department. Initially, the designer/developers approached the Department of Nursing at Wright State University and met with the domain-specialists to discuss our project and its initial requirements. Throughout our undertaking of this project, this type of inter-professional collaboration allowed the team to share resources and ideas. The domain specialists helped the developers to attain a more refined and streamlined objective by focusing on developing this application specifically for nursing education of fundamental physical assessment and auscultation. An initial version of the project was developed containing static models of ribs, kidneys, liver, heart and lungs, which was presented in the initial iteration of our AR application to the nursing subject matter experts. We were also able to demonstrate the software to the Dean of Nursing, students, and other nursing faculty. We were met with a lot of excitement during our initial demonstration and were encouraged to keep pushing forward having received the full support and backing of the nursing department. Upon close review, our collaborators found that this idea was very novel. However, the nursing representatives suggested that additional information could be conveyed using the augmented reality device. Working collaboratively with the subject matter experts enabled the developers to implement accurate animated models of the lungs and heart, as well as accurate labelling of the auscultation sites and landmarks with respect to the ribs model. Since the simulation was now focused on auscultation, there was no longer a use for the kidney and liver models, so these were removed. The team followed an iterative process of meeting with our collaborators regularly to exchange notes on improving the functionality of our application. Once we implemented the required functionality to our project, we approached the nursing professionals again with our application for review, and even had the opportunity again to allow a small group of nursing students to test out the latest version of the application with the help of a manikin. This proved to be a success. The nursing faculty then pointed us to accurate heart and lung sounds needed for our application which helped give our project more depth and versatility.

In order to develop our augmented reality application, we used Unity 2019 along with scripting in the C# programming language. We created and manipulated the 3D models for the application in .obj, .fbx, and .stl formats using Blender. We've developed our application for augmented reality headsets: the Hololens and the Magic Leap One devices. We chose to use these devices because they provide a larger field of view and larger computa-

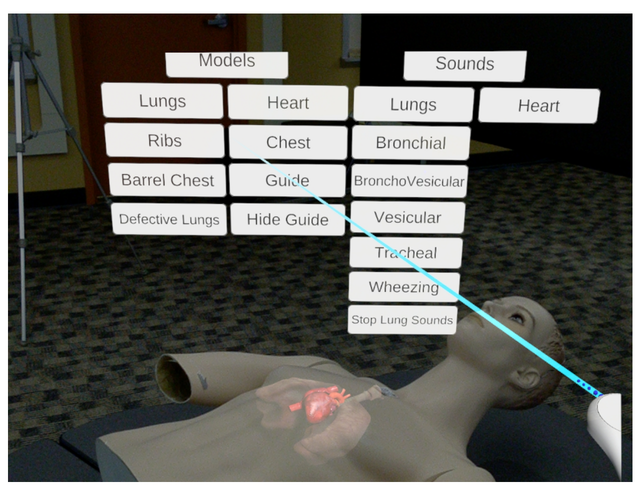

Figure 1. *Application Design.*

tional capabilities when compared to other AR headsets such as the Epson Moverio BT-35E. Magic Leap One devices are made up of three parts,namely the lightwear (head-mounted display), the lightpack (processing unit connected by wire to the lightwear), and the control (a wireless controller). The lightpack can easily fit in one's pocket, be attached to one's garments, or worn with a shoulder strap. The Hololens uses hand gestures for user interface (UI) interactions. We have also implemented voice commands in order to interact with the Hololens. The Magic Leap devices come with a hand held controller that pairs with the headsets and can be used for interactions along with hand gestures. We deactivated voice commands and replaced them with UI buttons in the Magic Leap application due to the ease of use offered by the handheld controller. For our application, we preferred to use the Magic Leap One as opposed to the Hololens for the former's superior performance capabilities compared to the latter.

We used Magic Leap's MLSDK, version - v0.23.0 in order to develop our application in Unity 2019. Magic Leap One devices have the following specifications: The CPU is an NVIDIA® Parker SOC with 2 Denver 2.0 64-bit cores + 4 ARM Cortex A57 64-bit cores (2 A57's and 1 Denver accessible to applications). Its GPU uses an NVIDIA Pascal™, 256 CUDA cores chip along with the following Graphic APIs: OpenGL 4.5, Vulkan and OpenGL ES 3.1+AEP. It has an 8 GB RAM, and 128 GB storage capacity. Audio inputs include voice (speech to text) + real world audio (ambient), and audio outputs include onboard speakers and 3.5mm jack with audio spatialization processing. The device also comes with bluetooth 4.2, WiFi 802.11ac/b/g/n, and USB-C connectivities. The lightpack compute unit has a built-in rechargeable lithium-ion battery that could last up to 3 hours with continuous use and could be charged using a 45-watt USB-C fast charger. In contrast, the Microsoft's Hololens has 2 GBs of RAM, a 64 GB flash memory for storage, and an Intel 32-bit (1GHz) processor with TPM 2.0 support with a custom-built Microsoft Holographic Processing Unit (HPU 1.0).

We developed our application using Unity 2019 and C# scripting. Game objects used in our application were added as prefabs to our Unity application hierarchy. Prefabs like spatial mapping and input managers were added beforehand so that we could adapt them based on our requirements, whereas the 3D models were dynamically added to the hierarchy as prefabs using our scripting code. We designed these prefabs to dynamically be turned active or inactive based on the user's commands via the aforementioned UI buttons or voice commands for the Microsoft Hololens. We also made use of a few other prefabs that have been designed to handle dependencies and proper functionality of the application. For the Magic Leap One we also added a controller prefab which is compatible with the Magic Leap controller. We used raycasting to shoot a straight invisible "ray" out in the forward direction from our controller for selection purposes. We make this ray visible by creating a blue line which extends from the controller to the object when the ray hits a given collider object within the environment. Selections can be made when this ray strikes a collider object or a button. We have added functionality to make visible a blue line shooting out of the controller prefab when raycasting detects an object that can be selected. We used supplementary software development kits (SDK), namely Magic leap SDK (MLSDK-version v0.23.0), Windows Mixed Reality Toolkit (MRTK) and Vuforia while coding our application to achieve our desired outcome using supporting libraries that come with these SDKs. We used Blender to develop our 3D models which we then transferred to Unity as prefabs. Our heart and lung models have animations attached to them that make the models move in an anatomically accurate manner. We also added sounds to our heart and lung models that can be turned on and off using voice commands in the Hololens or buttons in the Magic Leap. These sounds allow the user to observe normal and abnormal activities of the heart and lungs both visually and through audio. Heart sounds consist of the regular S1 and S2 sounds, which are caused due to the closing of valves [39]. We have implemented several variations of lung sounds for different learning scenarios. These variations include bronchial, bronchovesicular, tracheal, vesicular and wheezing (sonorous rhonchus) sounds. To switch between these variations the user uses voice commands in the Hololens and UI buttons in the Magic Leap One.

Somosky et al. have demonstrated the advantages of using AR to provide students an internal view of anatomy of a chest cavity [25]. Using visual imagery as an added benefit to standard teaching methods, augmented reality offers enhanced learning opportunities for nursing students [9]. Our application may be used to educate nursing students by having them experience auscultations of the chest area (specifically of normal and abnormal heart and lung activities) by simulating these behaviours as animations on 3D models of the appropriate organs and also providing audio cues to these organs for various conditions. Students can visualize the functioning of human hearts and lungs animated in an anatomically accurate fashion. We have also included lung animations that mimic the behavior of a collapsed lung (pneumothorax) in which only one side of the lung is functioning normally. Students can activate the simulation of this form of lung behavior by using the respective UI button. They can view the aforementioned 3D models of the organs in the real world, placed accurately on manikins or live volunteer candidates (which is optional), and view the 3D organs as if they can see through the chest cavity to see the organs. The placement of the 3D models can either be done manually by adjusting the placement via finger gestures (Hololens), the handheld controller (Magic Leap One), or using a custom made QR code with dimensions of 1cm X 1cm. This QR code can be removed once the application has finished detecting it and placing the 3D models. For the sake of accuracy, we place the QR code on the sternum, right below the jugular notch, on the manikin or the volunteer. This QR code is not mandatory as we can place the 3D models anywhere manually. However, it is being implemented here for accuracy and ease of use. We use Vuforia SDK's image target detection to detect the QR code for correct hologram placement [10]. The QR code itself is added to Unity's hierarchy as a prefab titled ImageTarget. All 3D models of the organs and auscultation sites are made to be the child components of the ImageTarget prefab so as to maintain consistency with respect to the location of the QR code in case the location is changed. We utilized the devices' dynamic spatial mapping feature to first map out the environment through wire meshes in order to understand our surroundings for the sake of implementing placement as well as occlusion of our 3D models. We rendered these wire meshes invisible so that the user is not distracted by them. A device-based demerit with regards to both the Magic Leap and Hololens devices is that they tend to displace the 3D models my a small measure in the screenshots taken during application operation.

Results

Augmented reality can be used to teach students psychomotor and cognitive skills that are crucial in clinical practice. In our implementation, we also use AR to help the user associate with things that are not visible such as the location of the heart, lung sounds, and accurate auscultation landmarks. Augmented reality is the technology that places computer-generated 3D objects (holograms) onto real world surfaces using projectors, headsets or mobile devices [9]. In this way we overlay models onto real world objects, hence augmenting visual and audio information that otherwise would not be available in the physical world. Our model incorporates models of the ribcage, landmarks of auscultation sites, and animated models of the lungs and heart, therefore displaying to the user the inside of a manikin or a real person which would otherwise be hidden. This could be used to gain insight into the specifics of procedures being done a certain way.

When the user puts on the AR headset and starts the application they are presented with a UI button hologram that they can "click" in order to select the 3D organ they wish to visualize. Once the organ is selected, the user may choose to look at the QR code with their headsets still mounted. The camera on the headset detects the QR code and places the 3D model on top of the QR code image target based on its position. If the user does not wish to use the QR code, the models are placed in front of them, which they can then manipulate themselves. We have included the option for extended tracking of the QR code so that if the user wishes to do so, they can use the QR code for correct placement of the 3D models at any time. The user can choose to display multiple organs, while having the option to disable any organ through voice commands or UI buttons. We have also included audio responses of these organs, along with labelled auscultation sites as UI holograms for easy reference. These can also be enabled or disabled by the same means. By displaying landmarks this way we use augmented reality to help nursing students recognize the significance of proper techniques related to physical assessment, namely the correct placement of the stethoscope for heart and lung auscultation sounds.

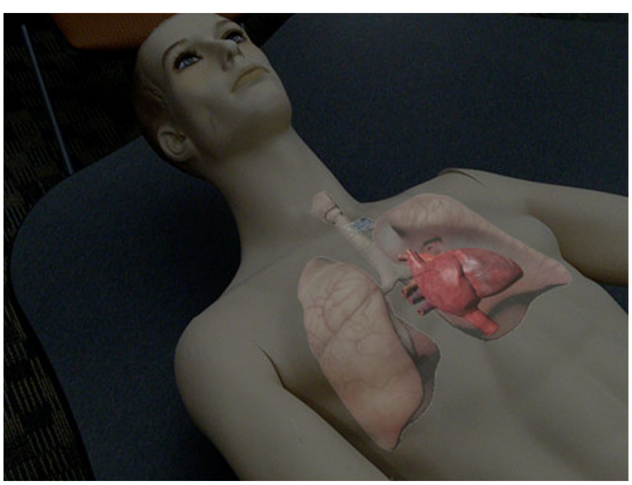

Figure 2. *Heart and Lung Models Placed With The Help of QR Marker.*

We built separate applications for the Hololens and the Magic leap One, since they do not support common formats and are not compatible with one another. Once we successfully built our application we deployed it to the respective devices. The application itself was packaged with the 3D models and audio clips necessary for the project. We also added a FileOpenPicker class which opens a file picker following a button selection that makes it possible to add additional models from the device library if required.

Discussion

The interprofessional team implementing this project includes two doctoral prepared registered nurses who are certified nurse educators and one is certified as a health simulation educator. The team has worked closely through several iterations to improve the usability and optimize learning outcomes. Our application allows users to experience the training aspects of physical patient assessment in a new way. AR is a novel approach coupled with the existing training methods which the nurse co-investigators believe will be an extremely helpful tool to familiarize nursing students with anatomy and anatomical landmarks.

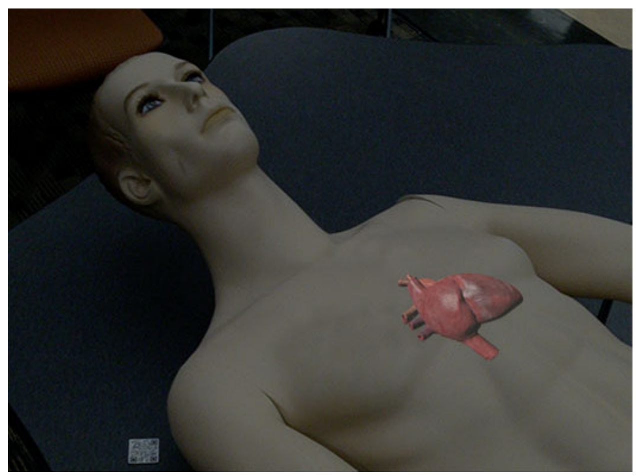

Figure 3. *Heart Model Remains in Position when Marker is Removed. Lungs Disabled With Controller Button.*

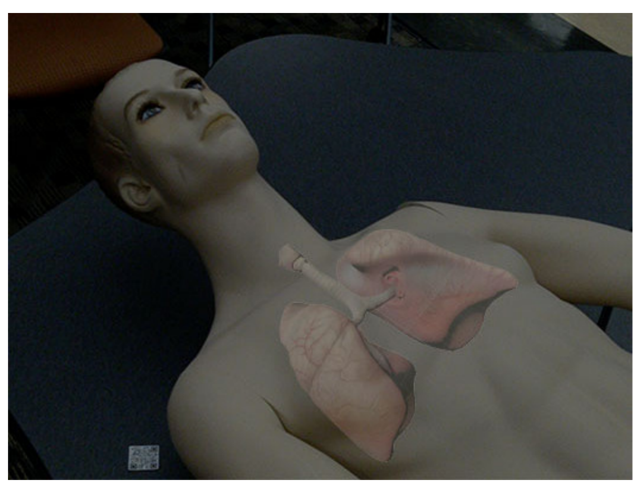

Figure 4. *Lungs Model Remains in Position when Marker is Removed. Heart Disabled With Controller Button.*

Nursing students who had the opportunity to review the AR in one of the earlier iterations were excited about the experience and expressed strong positive comments about the usefulness in learning assessment skills. This application is very helpful for visual learners by providing the capability to see and hear functioning 3D organs and the nursing students greatly appreciated the ability to see anatomical structures that are otherwise invisible to the naked eye. Through faculty and student comments, it was also deemed helpful to be able to visualize what the user was listening to whether normal or abnormal heart and breath sounds. Those who have participated in the AR have found the application easy to use and navigate given it's transparent and user friendly interface. Our application provides a gentle learning curve, this makes it easy to pick up even for users who are new to augmented reality. They were also very supportive of the fact that this application made it possible to alleviate the need for a live volunteer or a manikin in the training process. The capability provided by our application to see anatomically accurate representation of organs in action is something that cannot be otherwise achieved in training scenarios with the help of manikins or cadavers. Our application could also be used using standardized patient actors or with manikins. The mixed simulation modality enhances the effectiveness of the manikin and the standardized patient. The team had developed the functioning of bodily organs in our project so they can be useful in a wide variety of training scenarios for the nursing students for example specific cases, such as damaged lungs, irregular heartbeat patterns (arrhythmia), etc. The inclusion of a guide for correct auscultation landmarks is intended to make it easier for students to understand exactly where to place the stethoscope on a human torso to perform the necessary auscultation. Our project enables students to visualize key landmarks located inside the body that focus on accurate placement for physical assessment techniques. The use of AR to enhance concepts in an introductory physical assessment course is intended to enable the student to contextualize physical assessment findings with the underlying physiology. In this way students will develop a deeper understanding of both the assessment findings and application to health status. It is believed the AR technology will improve both assessment technique and understanding of assessment findings, leading to improved patient safety.

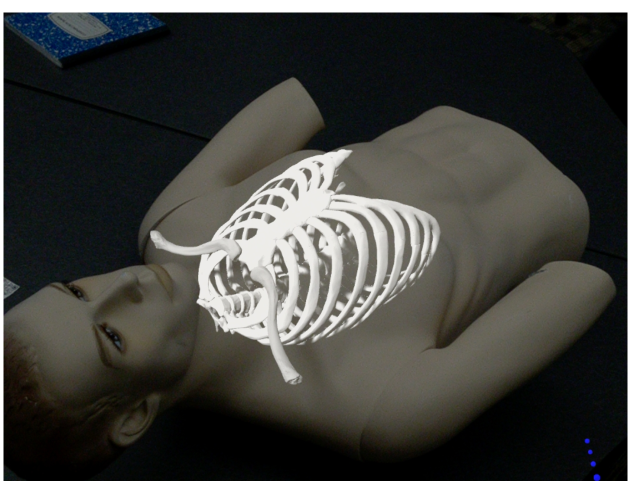

Figure 5. *Ribs Model.*

Conclusion and Future Work

Through our pilot project we were able to develop a novel method of training nursing students in the fundamentals of nursing and physical assessment. The product allows users to visualize anatomical structures within the body. The AR simulation enables the participant to easily locate anatomical landmarks for assessment while being able to hear and see seemingly functioning bodily organs as though they can see through manikins or human subjects. It is hypothesized that this will strengthen understanding and application of assessment findings to improve outcomes. Our project currently has various applications to differing clinical scenarios. In the future, more sounds and organs can be added to our application to enable other training areas. For example, we have the capability to add veins and arteries to show blood flow in the human body.

Our application could also be adapted to accommodate additional 3D models of organs including respiratory and nervous systems, airways, throat, arteries, veins,eyes, etc. As of now, our implementation allows each user to perform tasks on their own

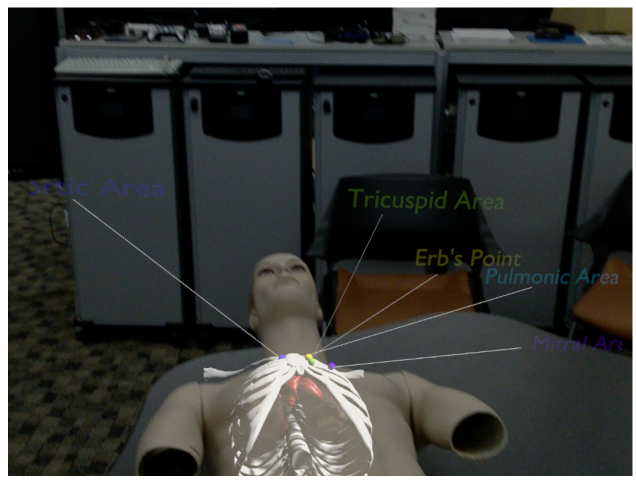

Figure 6. *Auscultation Locations Indicated on Ribs Model with Heart and Lungs Models Present Inside Ribs.*

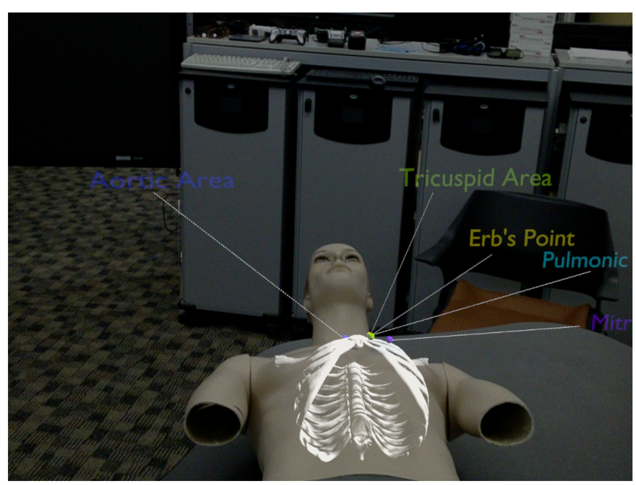

Figure 7. *Auscultation Locations Indicated on Ribcage Model Without Heart and Lung Models.*

and witness the results for themselves. Future iterations could include the capability of all AR devices syncing up to a "master" device which is controlled by the instructor, so that all student participants can witness in-application actions performed by the instructor on their devices. Our project could also be slightly modified to be used by surgeons in the operating room (OR). In this scenario we would first receive a CT scan of a patient from which we would extract 3D models of required organs (such as ribs, etc) and implement it into our application. When the patient then visits the operating room, one of the surgeons would have the AR device mounted on their heads and be able to see the patients organs outside the body, placed anatomically accurate to where they would be in real life. One sample scenario would be if a patient has cracked ribs. We would get a CT scan from the patient's preliminary hospital visit from which we would extract their ribs as a 3D object and use it in our application. A doctor/surgeon would then be able to see the patient's ribs using the AR device as though they can see through the patient's body. This would enable the surgeons to require less incision to get to the cracks in the ribs and be more accurate in detecting locations of damage.

While we obtained some informal feedback from nursing students and faculty, a more formal evaluation of the application will have to be performed. We had scheduled the use of our software in the classroom for the Spring semester of 2020. However, due to the COVID-19 restrictions, we were not able to do that.

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