Anatomy Learning in a Magic Way: Assessing the Capabilities of a Mixed Reality Technology for the Purpose of Anatomy Education

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Abstract

When teaching anatomy and physiology at a university level, two resources have long been used as the standard method of teaching: Atlas textbooks and cadavers. While there is little doubt that these tools are effective, alternative teaching methods are often underutilized in the classroom. As the classroom paradigm continues to evolve, new technologies are also being developed. By combining these two ideas, the introduction and utilization of novel technology in classrooms can allow for alternative, effective teaching methods that appeal to a wider range of students.

This research project developed and evaluated the capabilities of a novel technology that utilizes augmented and virtual reality for the purpose of anatomy education. This technology, called the Magic Mirror, uses a sensor to overlay human anatomical models onto a user while tracking their movements in a real-time three-dimensional environment. By using this technology, students are able to take an active role in learning human anatomy.

User studies, student surveys, and professor questionnaires were conducted over the course of this thesis to evaluate the capabilities of the Magic Mirror while comparing it to standard methods of teaching human anatomy. The results demonstrated the potential of the Magic Mirror as an effective tool for anatomy education, producing similar results to Atlas textbooks for the short-term learning of anatomical structures in the cardiovascular system. It also showed the students' and professors' interest regarding the use of novel technology in the classroom. The Magic Mirror was able to provide a unique experience that cannot normally be obtained through the use of Atlas textbooks or cadavers. With continued development of the Magic Mirror, we are hopeful that it can one day be integrated as a part of the anatomy classes at the University of Ottawa.

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Abbreviations and Definitions

MM = Magic Mirror

AR = Augmented Reality

VR = Virtual Reality

2D = Two Dimensional

3D = Three Dimensional

CPU = Central Processing Unit

CE = Concrete Experience

AC = Abstract Conceptualization

AE = Active Experimentation

RO = Reflective Observation

RGBD = Red-Green-Blue-Depth

CT = Computerized tomography

MRI = Magnetic resonance imaging

MSK = Musculoskeletal

1 Introduction

1.1 Introduction

Anatomy and physiology knowledge is required for all students who hope to work in the fields of health science and medicine. Currently, the most common and effective methods of teaching these subjects is through the use of cadaver dissections and Atlas textbooks. Cadavers are thought to be the most useful method for students learning human anatomy, as they provide real life examples of different organs and structures within the human body. They may also show students examples of the effects of pathological conditions on the human body [1]. On the other hand, cadavers are a limited resource that is expensive to maintain. There are also some cultures that forbid the use of cadaver dissections [2]. For almost all educational institutes, there are not enough cadavers available for students thus leading to many students sharing a single cadaver. Additionally, cadavers are typically only available to students in medical school. These are not the only issues with cadavers though. Increased expenses related to maintaining the bodies, availability of dissection labs, and training administrative and education personnel to run these labs has led to some institutions looking for alternative options for teaching anatomy [3].

Alternatively, the most widely used method for anatomy education is the use of Atlas textbooks. Textbooks provide fully labelled, two-dimensional (2D) diagrams of human organ systems, but lack realism, especially compared to cadavers [1]. The main reason for their widespread use is that they are much more affordable and widely available compared to cadavers. Textbooks can be used alone or as reference material by students, providing highly descriptive passages regarding physiology and the role of different structures in the human body. Although they are effective learning tools, textbooks are not exciting for students. Students across many disciplines prefer to skim through readings and summarize the main points of the text [4]. University students also seem to believe that assigned readings are less important, maintaining this idea throughout their university careers [4]. Textbooks are thought to be a necessity to learning regardless of discipline, but they should not be the only method available to students. As such, more appealing methods can allow students to learn the same material in a more exciting way.

Though technology has recently been developing at an exponential pace, these two teaching methods remain the standard way of teaching students human anatomy and physiology. New technology is being developed for the purpose of medical education, but there is still a long way to go before they can fully replace the use of cadavers or textbooks. That does not mean that these technologies are not useful though. An application available on phones or computers makes information easy to access and readily available for students. These programs are often independently developed though, meaning there is not a real standard for specific features or information present [5]. Some of these new technologies utilize Augmented Reality (AR) or Virtual Reality (VR). AR technologies will add digital components to the real world while VR technologies will try to provide an immersive experience within a virtual space. Initial studies exploring the effectiveness of some of these technologies as educational tools have yielded positive results [3. 6. 7. 8]. Additional hardware has even been developed solely for the purpose of medical education. These novel technologies would provide students with a variety of different options as they learn human anatomy. AR and VR technologies also provides immersive, engaging experiences that requires students to take a more active role in learning anatomy compared to Atlas textbooks.

1.2 Thesis rationale

Innovation should not be limited due to the effectiveness of current standards. Although cadaver dissections and Atlas textbooks have long been the standards for anatomy education, newer technologies and methods are continually being developed for the purpose of medical education. These newer, novel technologies provide more opportunities for students to learn in different ways.

This stems from Kolb's Learning Style Model and Experiential Learning Cycle. The idea behind experiential learning is that it is *"education that occurs as a direct participation in the events of life"* [9]. This means that educators who assist students with experiential learning would not only be passing on information but showing students how to utilize their own personal experiences and apply them to real world problems [10]. In theory, students that learn in this way would draw on past experiences, utilizing the knowledge they learned in the past to continue learning and allow them to reach new goals they would not have otherwise. Through experiential learning, Kolb believed that students would develop higher meta-cognitive abilities and allow them to be more self-directed learners [11]. Kolb's Learning Style Model states that individual students have a preference for specific learning styles that would complement their individual abilities, helping them reach specific educational goals [12]. He believes that there are four learning modes separated onto two different axes: Concrete Experience (CE) and Abstract Conceptualization (AC) are on opposite ends of one axis while Reflective Observation and Active Experimentation (AE) are on a separate axis. Figure 1-1 displays Kolb's Experiential Learning Model. The axis containing CE and AC is called the Perception Continuum, which looks at how an individual emphasizes feeling and thinking. The other axis contains AE and RO, called the Processing Continuum looks at how an individual emphasizes active and passive learning. Over time, it is thought that students will develop preferences for their own learning style based on how they think according to these two continua. Although university classrooms have highly diverse groups of individuals with a variety of preferences for different learning styles, there has historically been a greater focus on RO, while Kolb believes that learning is a cyclical process that should incorporate all four modes of learning to be most effective [13].

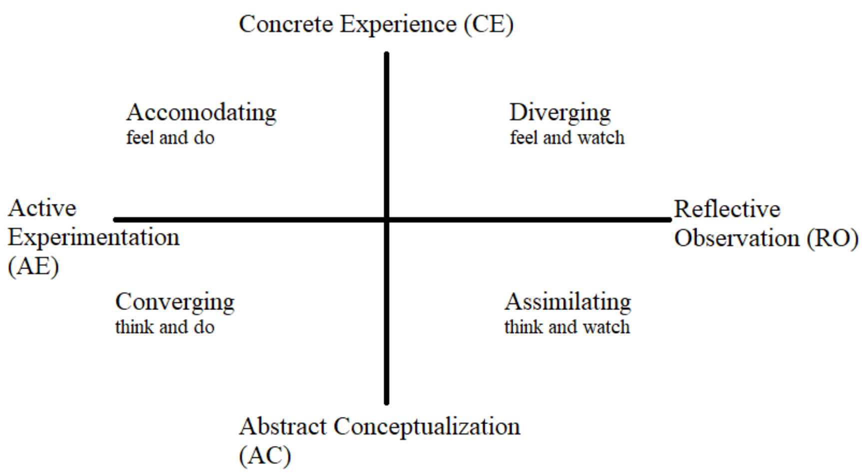


Fig 1-1. Kolb's Model of Experiential Learning

In recent years, new developments to technology have changed classrooms into more dynamic learning spaces. In high schools, the introduction of technologies such as the Smart Board allows the use of multimedia experiences for students. This technology alters the teaching-learning process and encourages students to engage with different sorts of technology in and out of the classroom [14]. In universities though, the incorporation of alternative and newer technologies can prove to be more difficult. Lower level university courses are more likely to have very large class sizes, limiting the option for professors to introduce alternative teaching methods in a classroom setting that may appeal to students who prefer something such as a converging learning style. When trying to incorporate Kolb's Learning Styles into anatomy education, it is more feasible to do so through supplemental tools used outside of lectures. One option could be to incorporate extra workshops for students that mimic a clinical workplace or by incorporating newer technologies such as AR or VR.

For the purposes of medical education, technologies that can utilize AR and VR have also become more common. An example of such technology is the Microsoft HoloLens. During a 2016 conference, an on stage demonstration showed the potential of the technology for the purpose of teaching [15]. The presenter was able to view and interact with highly detailed models of organ systems in the human body. They were also able to see magnetic resonance imaging (MRI) scans of different organs such as the brain. In another study, researchers conducted a survey of 500,000 participants consisting of students, teachers, school administrators and parents, asking them about the prospect of introducing AR and VR technology to classrooms [16]. The researcher found that 33% of middle school students surveyed and 26% of high school students surveyed would like to see AR technology implemented into their education. They also found that 47% of middle school students and 33% of high school students would like some sort of VR technology in classes. There is interest among newer generations of students to translate this newer technology into classrooms, giving them optional methods to learn.

The main idea of this thesis builds off of this paradigm. It looks at the development and tests the effectiveness of utilizing a new, novel technology for the purpose of anatomy learning. This technology has the potential to offer the positive benefits associated with textbook learning and cadaver dissections, while trying to minimize on the shortcoming of each of these teaching methods.

1.3 The Magic Mirror technology

The Magic Mirror (MM) technology is a mixed reality system that utilizes both AR and VR for the purpose of anatomy education. The technology overlays anatomical data onto the user using a Red-Green-Blue-Depth (RGBD) sensor, tracking the movements of the user and moving the models as the user also moves. This is displayed in two parts on a computer screen or display. Half of the display shows the user with anatomical models overlaid onto their body. The other half of the display shows a virtual view of the user. The user can change this virtual view to zoom in and focus on specific areas of the models shown on the virtual display. The anatomical models in the virtual view are also fully labelled, allowing users to learn the names of specific anatomical structures as they interact with the MM. The MM is designed for students at the university level as a learning tool for human anatomy.

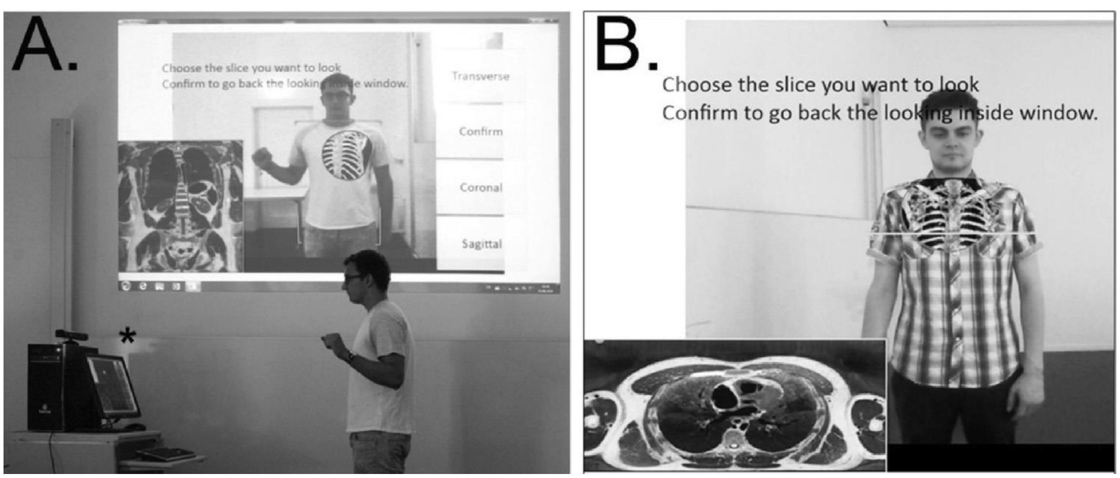


Fig. 1-2. Magic Mirror technology developed in Munich, Germany [17]

The MM was originally developed in Munich, Germany at the Technical University Munich. This initial MM used the Microsoft Kinect as the RGBD sensor that would track the movements of the user standing in front of the device. The MM was shown on a large, static display where the user was displayed with anatomical data overlaid onto them (Fig. 1-2). This version of the MM was capable of displaying radiological slices of human anatomy, including different planes and systems onto the user [17]. An initial study was conducted in Munich using this version of the MM to test general reactions to the technology and to see whether the technology was suitable for use in anatomy and physiology courses at the university level. This user study consisted of 880 first year medical students from the Ludwig-Maximilian- Universität in Munich, Germany. Overall, there were highly positive reactions to the MM, with students stating they had increased motivation to learn after continual use of the MM [17]. This helped motivate the development of a new MM at the University of Ottawa, Ottawa, Canada.

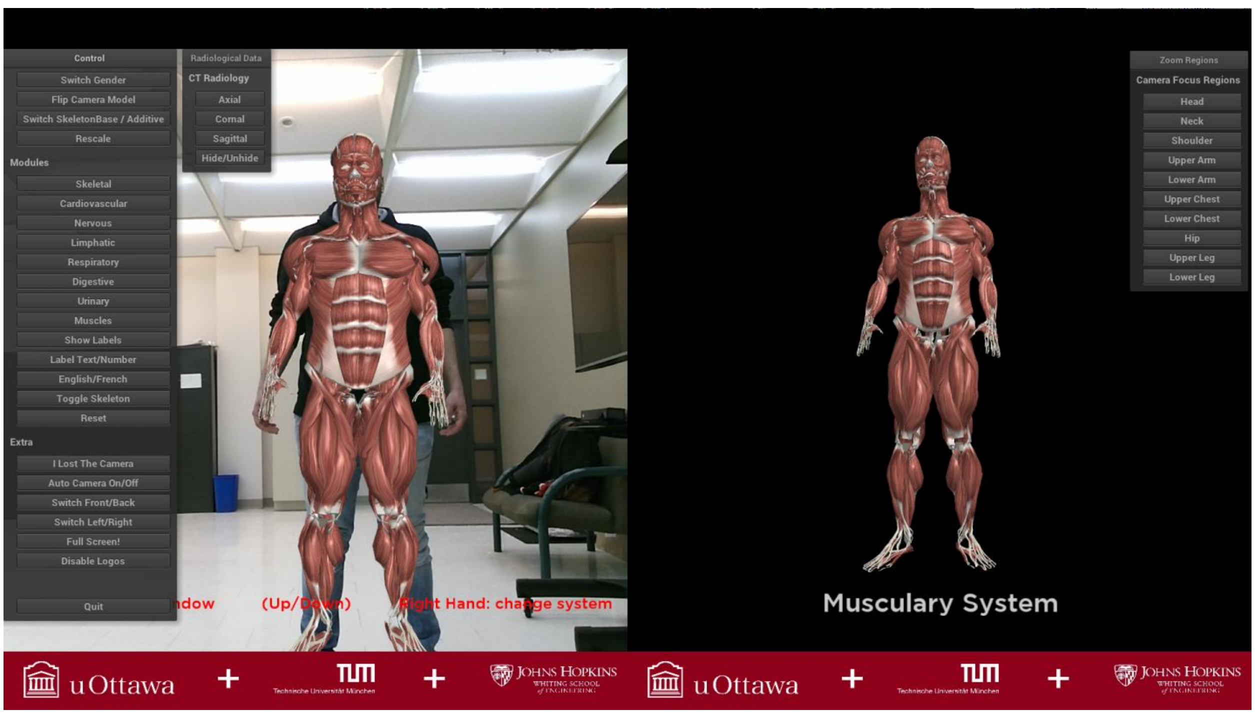


Fig 1-3. Initial Build of the MM, developed in Microsoft Visual Studios 2017

At the University of Ottawa, the MM was developed over the course of the 2017-2018 academic years with the goal of eventually utilizing the technology as a part of the anatomy and physiology curriculum at the University of Ottawa. The hope was that the MM could incorporate advantages that would normally be provided by cadavers or Atlas textbooks to create a unique learning experience that would benefit students learning human anatomy. Table 1-1 illustrates some of the aspects of the MM we hope to take from the current standards of anatomy education. The models used in our build of the MM were obtained along with a prototype build of the MM sent from Technical University Munich. The program was initially coded in C++, a standard programming language and developed using Visual Studios 2017. The RGBD sensor used was the Xbox One Microsoft Kinect. This build of the MM was capable of displaying eight organ systems (respiratory, skeletal, muscular, lymphatic, nervous, digestive, cardiovascular, and reproductive). The camera could initially be controlled with either a keyboard and mouse or with motion controls, though the motion controls were eventually disabled due to issues with sensitivity and for the purpose of a later pilot study. A full 360-degree rotation of the models could be displayed, with the user able to zoom into and focus on any peripheral region of the model they pleased. Unfortunately, as more features were continually added to this build, stability issues began to manifest with the program. The program would occasionally crash when models were refreshed or changed, and the camera controls would occasionally stop working, requiring the MM to be rebooted. Labels for anatomical structures were also unable to be added to this build of the MM. This is due to the method that was used when attempting to add this feature. Blender, a software program was used to attach nodes to the models that were displayed in the MM. These revised models were then implemented into the software, with labels pointing to each of these newly attached nodes. In theory, the MM would display the labels and point to their corresponding structures, but the issue with this method of implementation was that the labels did not track three-dimensional (3D) movements and would remain stationary and anchored to the original placement of the node. To troubleshoot all of these issues with this initial build, the MM was redeveloped in the Unity Engine, which provided stability to the program.

Table 1-1. Advantages of current anatomy education tools and the MM

Cadaver dissections	Textbook learning	Magic Mirror learning
Active, hands on experience with human anatomy	Cheap, easily accessible	Relatively cheap and accessible
Real life “patient” experience	Labelled diagrams of major organs and organ systems	Active learning experience
Provides spatial information on anatomical structures	Detailed description of anatomy and physiology	Provides spatial information on anatomical structures
Potential to see effects of pathological conditions on the body	Can be used alongside multiple teaching tools	Labelled models of major organ systems

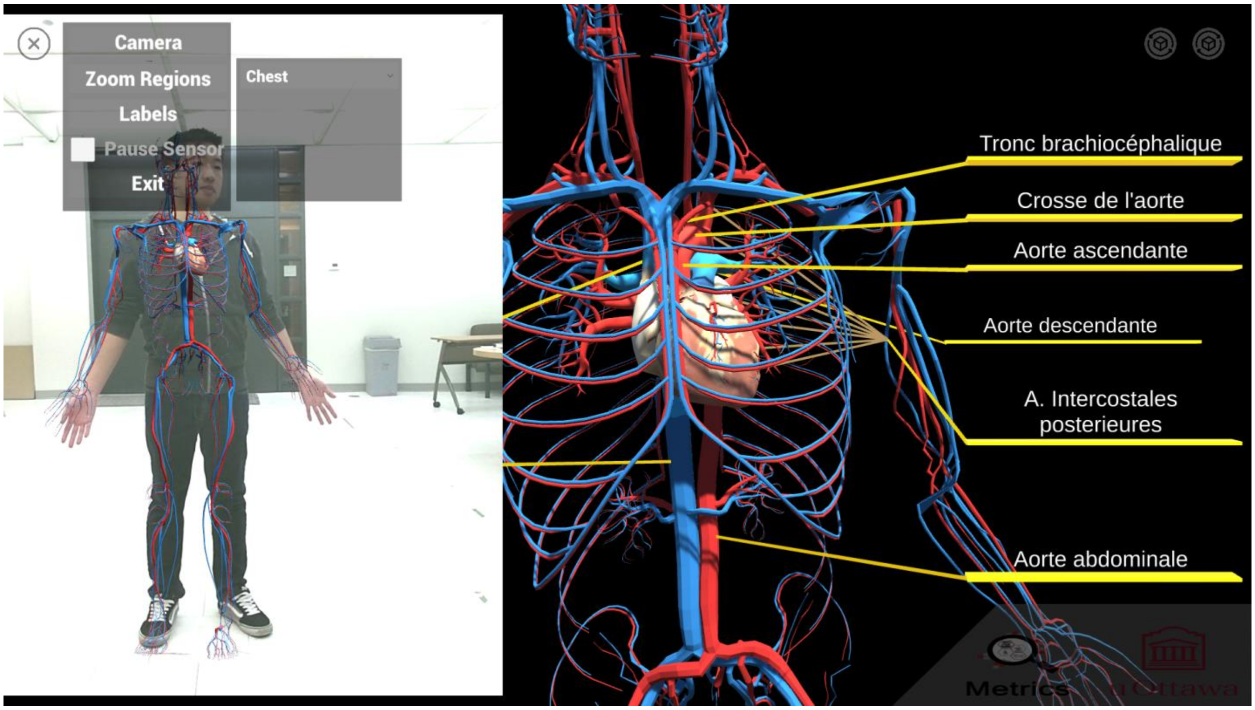


Fig 1-4. Redeveloped version of the MM, developed in the Unity Engine

The redevelopment of the program was needed in order to implement functioning motion tracking labels to the MM. This feature was also required for a user study that would be conducted comparing the MM to Atlas textbooks for the purpose of anatomy education (Chapter 4). A post-doctoral fellow assisted in rewriting the MM program, now using C#, another programming language, due to their increased familiarity with the language. This build of the MM currently only features models for the cardiovascular system, with the major anatomical structures of the system fully labelled in French. The labels on the model also track the movement of the user as they move in front of the sensor. This version of the MM still utilizes the Xbox One Microsoft Kinect as the sensor to track the movements of the users, with this build also allowing multiple users to be tracked on the MM at the same time.

1.4 Thesis objectives & hypothesis

The objective of this thesis was to evaluate a mixed-reality technology known as the Magic Mirror for the purpose of anatomy education. The Magic Mirror was compared to the current standard methods for teaching anatomy (Atlas textbooks and cadaver dissections) and evaluated based on the ability of the user to retain knowledge of the human anatomy. The comparison was performed using a series of mixed-research methodologies (both quantitatively using pre-tests and post-tests as well as qualitatively through the use of questionnaires). The research hypothesis is that the Magic Mirror will be compared effectively to textbooks and cadavers as anatomy teaching tools.

1.5 Thesis contributions

Over the course of this research project, three specific projects were undertaken:

- Section 3.4: An initial pilot study was performed to test the capabilities of the MM technology as a lecturing tool in anatomy classrooms.
- Section 3.5: A large-scale study was performed to determine the potential of the MM on teaching a specific anatomical system (i.e. the cardiovascular system).
- Section 3.5 – Section 3.8: A needs assessment was conducted on the potential integration of the MM into future classrooms, via surveys and questionnaires administered to university students and anatomy professors.

1.6 Thesis outline

This thesis is divided into five chapters and one appendix:

Chapter 2 is a literature review that looks at different teaching methods for anatomy education. It covers the current standard methods for teaching anatomy, supplemental tools that are currently used alongside these standards as well as recently developed novel technologies that have been developed for the purpose of anatomy education. This chapter looks at some of the benefits and limitations of these different methods and studies that have been done comparing these newly developed technologies to textbook and cadaver learning.

Chapter 3 covers the purpose and methodologies for the professor interviews, student questionnaires and user studies. This chapter looks at study design and explains the process of data collection for each of these studies.

Chapter 4 includes the analysis for all data collected in the interviews, questionnaires and user studies. It looks at the trends and patterns that appear in the data while trying to explain what this could mean for the MM. This data will also try to illustrate the current capabilities of the MM system as a tool for anatomy education. It will also look at limitations to the study design and changes made between the user studies.

Chapter 5 is the conclusion to this thesis. It will give a brief overview and final thoughts regarding the Magic Mirror and the future of the technology.

Appendix A contains resources used during the user studies conducted through this research project. This includes some of the questions asked on the pre-test and post-test for the pilot study and large-scale user study, the word bank provided to participants who participated in the large-scale user study and the textbook resources for participants that were a part of the control group in the large-scale user study.

Appendix B presents the interview questions that were asked during the professor interviews as well as the full interview transcripts with professors who teach anatomy and physiology courses at the University of Ottawa. These interviews cover the current state of anatomy classrooms at the university, supplemental teaching methods for anatomy education and improvements that can be made to the Magic Mirror as of the first half of 2019.

2 Literature Review

2.1 Overview

This chapter presents several different solutions used for the purpose of anatomy education. It will go over a variety of different tools, the benefits they provide to students, as well as different limitations or challenges involved with using these teaching methods. This chapter concludes by providing insight into the current landscape for teaching anatomy as well as what the future may hold for this subject.

2.2 Cadavers

Considered by many as the optimal method for teaching anatomy, cadaver dissections are one of the oldest methods for teaching students the basics of anatomy and medicine. Cadavers give students; a hands-on, real-life example of human anatomy, which is essential for helping them transition to medical professionals [18]. During cadaver dissections, students not only learn of the location of anatomical structures within the body in relation to one another, but also have the potential to see the effects of different pathological conditions on the human body and how they can affect different organs within the body [1]. For many students, dissecting a cadaver is their first experience interacting with a “patient” and provides them with a unique opportunity that they would not have with other learning tools [18].

For some students, especially at the beginning of their university studies, cadaver dissections can be a traumatic or uncomfortable experience [18]. Between 25-48% of medical students in the US and UK have reported some level of anxiety during cadaver dissections [19, 20, 21]. Despite this, as more time passes and with each additional interaction with the cadavers, they are able to deal with these experiences through different coping mechanisms. A study looking at perceptions of cadaver dissections by medical students from the Oakland University William Beaumont School of Medicine reported different coping methods by students after interacting with cadavers [18]. This included "*looking at the positives coming from the dissection, seeking emotional support from others, engaging in recreational activities, or turning to religion*" [18]. As the students became more familiar with cadavers, these coping mechanisms were required less often, with students believing the experience was invaluable for the theoretical and practical knowledge they gained about anatomy.

To keep up with the continuous stream of new medical students, universities must also find a way to continually obtain new cadavers that can be dissected. The most common sources for cadavers are through donation programs, unclaimed bodies from those that have passed away, or importing a cadaver from another country [22]. In developed countries such as those in North America, Europe, as well as parts of Asia and South America, body donation programs are regulated by laws that are well known to the general public, leading to a greater amount of donations [22, 23]. On the other hand, some cultures have different beliefs regarding death and how bodies should be treated, thus prohibiting the use of cadavers for dissection and education for those groups [2]. This same ideology also applies to certain religions, as countries that are a majority Muslim faith, such as the Arab Gulf States, have very low body donation rates, while most bodies donated for anatomical purposes in India are those of Hindu faith. A similar trend is seen in countries that are a majority Buddhist such as Sri Lanka, Thailand, and Japan, all of which rely almost exclusively on body donations as a source of cadavers [22]. This all culminates in developed countries having greater access and a greater amount of cadavers available for dissection. Although a lower student/cadaver ratio has been linked to improved student performance in the anatomy classroom, in areas of the world such as western China or developing countries, the number of donated cadavers is too scarce to meet the educational requirements of medical students [23]. In Western China, there may only be a single cadaver available for dissection by an entire class of around thirty students. For a learning tool as important as cadavers, different programs should be set up worldwide to try and get a greater amount of cadavers to help student learning.

Another issue with the use of cadavers is the many expenses linked to obtaining and maintaining cadavers. Some of these expenses includes cadaver labs, which must be built and used to store the bodies, as well as trained administrators and educators to not only prepare the bodies for dissection, but also to watch over and advise students as they perform the dissection [3]. Although it is not directly related to the costs of cadavers, bodies can only be used once, meaning that after medical students are finished with all of their cadaver sections, the bodies need to be disposed of and replaced for the next wave of medical students. On top of this, maintenance costs associated with preserving the cadavers is high [2]. For these reasons, some European medical schools have stopped using cadaver dissections in their curricula and no longer have cadaver labs [24]. This trend is more likely to continue, especially as more teaching alternatives to cadaver dissections become commercially available and well known.

Despite the issues associated with them, cadavers provide students with an experience that cannot currently be replicated. Though some technologies using AR and VR are being developed to try and mimic the dissection experience [25, 26], they are still in their infancy. Although it is possible that using new technology alongside cadavers can improve student learning further, until the curriculum requires students to learn using both methods [27], it is more likely cadavers will continue to be the main focus for medical students as they are educated about human anatomy.

2.3 Atlas textbooks

Compared to cadaver dissections, textbook learning is a more cost-effective and accessible method for teaching anatomy and physiology to students. Anatomy textbooks provide detailed, often labelled, 2D images of organs and organ systems that students can use for learning anatomy. Though students can use textbooks to learn anatomy and physiology individually, they are more often used as reference material in conjunction with didactic lectures and/or cadaver dissections. Unfortunately, students learning from Atlas textbooks also need to interpret and mentally map the 2D images as they might look in a 3D space; to get a better idea of how things would look in a real body. For students with lower spatial reasoning abilities, this can be challenging and has a negative effect on how they learn anatomy [28].

While textbooks have long been used for anatomy education, they are not considered exciting tools to students and do not promote active learning. Despite the fact that students are supposed to be the main benefactors of textbooks, some find the concepts difficult, abstract, and uninteresting [29]. This can be due to the fact that course instructors are usually the ones to decide on what textbook is used for their course, but view the material just as a source of information instead of actively incorporating it into their lectures. Due to the difficulty of the textbooks, some instructors need to reword the content so that it can be more easily interpreted by students. To resolve this issue, instructors could ask students about the kinds of textbooks that would be best for them [29]. Student opinions can provide valuable insight regarding textbook difficulty; clarity; and comprehensibility, helping instructors know if the contents of the textbook match their learning needs.

Nevertheless, compared to other traditional anatomy learning tools, textbooks are easily accessible at any time and provide a wealth of information to students. Some publishing companies have even made their textbooks available online and can be accessed through purchasable keys. This would provide students more access to the resource. However, other similar online anatomy resources such as "*UpToDate*" are updated more frequently, leading to the possibility that the textbook has out of date information, especially if the student purchased an earlier version of the textbook [30]. It is now much easier for students to find information they are looking for online, and with so much information readily available to them, textbooks could soon be nothing more than lesson planners for anatomy professors.

Instructors and researchers are looking at different ways to motivate student learning while still using Atlas textbooks as a major resource in anatomy courses. One study looked at replacing didactic lectures with small group learning sessions. This changed the focus on how students learned. The focus was on self-regulated studying as opposed to attending lectures and content was reviewed by meeting with a small team of students and discussing what they learned individually. This provided a different learning experience that was reinforced by what was studied by the team members, thus leading to increased satisfaction and improved learning outcomes, especially among higher performing students [31]. Another study incorporated Atlas textbooks; as well as mobile AR through cellphones. Students would be able to use an app that detected different markers on diagrams within the textbook. This would then allow students to access the multimedia or superimposed object on their phones [7]. The researchers found that compared to traditional textbooks, mobile AR are more engaging for students and helps to lower cognitive load associated with visualizing anatomical structures. In another study, a scale was developed to try and assess the usage of college textbooks and how they affected course performance in a psychology class. This scale, called the Collegiate Student Assessment of Textbooks scale, looked at student preferences for textbooks and how it affected their usage throughout the course. Students had a preference towards the text if it taught practical content that was applicable to their lives and it was easily accessible. They also found that chapter reviews and study aids within the books increased usage among students. Finally, the researchers stated that it was up to the instructor to keep the contents of textbooks relevant to the course and that they should work towards encouraging students to use their textbooks to keep up with their studies throughout the course [32]. Different ideas can be tried in the classroom to try and make things more interesting for students. Although there are newer technologies being developed, they are not the only option for changes that can be made.

Even though new teaching tools and methods using 3D technology are being introduced to students, results have been mixed regarding their effectiveness compared to traditional 2D teaching methods [33, 34, 35]. In these studies, learning outcomes were either not affected by the teaching method, or showed how new technology helped improve student knowledge and motor function [27]. Atlas textbooks are proven resources that can assist with anatomy learning and will likely remain a staple option for any student taking an anatomy and physiology course.

2.4 Three dimensional models

Used as a supplemental tool to assist students, 3D models allow for the visualization of organ systems and structures within the body. For the purposes of anatomy education, these models are most commonly used alongside Atlas textbooks, with previous studies showing they help to improve student scores on anatomy course examinations [36, 37]. With 3D printers and 3D printed resources becoming commercially available and cheaper, the scope of use for 3D models can be expanded. An example of this is in surgical training and pre-operation briefing. Accurate models of patient organs including pathological conditions can be created by first obtaining computerized tomography (CT) scans in a Digital Imaging and Communications in Medicine (DICOM) format. This data is then converted until fused disposition modelling can be used to create plasticine 3D models based off of the original CT scans [38]. These models can be used to brief patients on surgical procedures, increasing their understanding of basic anatomy and the planned surgical procedure. Another study utilized 3D printed silicone moulds for the purpose of ureteroscopy surgical training [39]. These resources can be a very cheap and precise way of teaching students anatomy.

Similar to other anatomy teaching tools, 3D models excel in certain aspects of anatomy education, but may fall short compared to others when looking at certain aspects of medical education. Some studies have shown that physical 3D models are more effective for learning anatomical structures compared to computer generated images or textbooks [40, 41], but others have shown that static models are less effective for surgical training [42]. While it appears that physical models help students understand anatomical 3D structures [43], learning difficult surgical procedures on top of that appears to be too difficult for the average student. This can be due to the cognitive load theory, which hypothesizes that humans have a limited working memory that is required for learning new tasks or remembering facts [44, 45]. Although learning human anatomy may be more difficult compared to other disciplines, using 3D models can lower the cognitive load compared to other teaching tools [41]. This is due to the need to utilize part of the cognitive load to infer the 3D anatomical structures from 2D images, which does not need to be done when looking at a 3D model. This means that students can utilize that same amount of cognitive load to learn the anatomical structures.

Physical models naturally encourage the dynamic visualization of anatomical structures, meaning the models would help students spatially organize different elements and how they change with time [46]. On the other hand, traditional teaching methods such as textbooks contain static visualizations, meaning students would need to mentally rearrange a 2D image to infer their 3D relationships [28]. 3D models provide a greater sense of depth, and a different perspective, helping students' perceptions of the orientation of different structures. Another component that is said to affect how students learn anatomy is their spatial ability. This includes their ability to rotate between 2D and 3D images mentally as well as the ability to operationalize mental representations [47, 48]. The relationship between dynamic visualization is addressed in two hypotheses. The *compensating hypothesis* states that dynamic visualization makes up for a lower spatial ability, allowing those with low spatial ability to learn at the same level as high spatial ability learners if they utilize dynamic visualization tools [49]. On the other hand, the *enhancer hypothesis* states that students with high spatial abilities are better at handling dynamic visualizations because they require less cognitive load to build mental models and can use the remainder to learn content [50]. These different hypotheses and theories regarding learning support the idea that 3D models benefit students learning human anatomy.

It appears that in current anatomy classrooms, there is still a place for the use of 3D models [51], but as computer programs and new technologies continue to be developed, the effectiveness of physical models should continue to be evaluated as supplemental tools for the purpose of anatomy education. While these technologies can continue to improve to be more effective anatomy learning tools, models and textbooks are a more stagnant form of learning that is not likely to improve in the way they help students [42]. If the time comes where 3D models are inferior to anatomy teaching tools that are not only more effective, but more easily available, their use should begin to diminish from the medical education curricula.

2.5 Videos, animations, and social media

Often used as supplemental methods for introducing information to students, videos, animations, podcasts and other forms of media have become more popular for the purpose of educating students in recent years. Although changes to teaching formats have been historically slower for anatomy education [52], changes to teaching methods and lessons are being seen as well. This trend will likely continue as newer generations of students continue to enter post-secondary learning institutes. Conventional training methods have evolved for educators at these facilities, incorporating multimedia technology that appeals to different learning and teaching styles [53]. Different forms of media may be used to explain certain topics, concepts, or as a way to review content covered during lectures. For modern generations of students, this fits their approach to learning new things.

University students now have a different mindset and mentality when it comes to learning. They incorporate their social lives and technology as a part of learning, utilizing laptops, phones, and social media as a part of their educational experiences [53]. Modern students operate at "*twitch speed*" [54], meaning they expect fast responses when researching and interacting with others. Therefore, when engaging with course materials, their peers, educators, or online resources, they expect to quickly find the answers they are looking for. Different social media sites are used for a variety of different reasons in addition to communicating with others. This includes building a business, selling or buying items, professional networking, and simply blogging. Other reasons to try and integrate social media in higher education include: (i) newer students entering university are believed to be more creative, connected, and collective, (ii) a shifting focus from institutionally provided learning to "*user-driven*" learning, and (iii) students' different perspectives in regards to what they learn, how they learn, and formal education [55]. If instructors choose to try and integrate social media into their courses, it must be done in a practical way that would help achieve specific course goals while also acting as a learning resource that fits the overall theoretical framework [56]. Overall, there is little information on how effective social media is in enhancing student learning as few instructors have integrated it into their courses.

Online videos are also a valuable source of information and effective tools to assist with learning. The cognitive theory of multimedia learning suggests that videos enhance learning by activating auditory and visual pathways, presenting pictures and words simultaneously, thus allowing students to efficiently absorb the information they are being presented [57]. Depending on where these videos are posted, there is a possibility that they are also free. An example of this is Osmosis Videos, which posts educational disease focused videos on YouTube. These videos are widely available, "*reusable learning objects*" [58] that can be easily accessed by different individuals. Learning videos can also help to reduce faculty effort while improving the quality of information that learners can access [59]. Another benefit to creating videos for students is that they can be paused at the viewer's discretion. This allows for easier note taking and prevents cognitive fatigue of the learner. That does not mean that videos will be effective in all contexts though. Educators must still be knowledgeable about the context of when videos will be effective and helpful to students.

Due to the popularity of YouTube and other video streaming services, students will also have specific preferences for video content. If used for the purpose of education, instructors should make sure the videos are not too long, the content is engaging, and to orient students to the topics covered in the video beforehand [60]. For students, limiting the length of the videos not only makes it more likely that they will pay attention throughout its entirety, but it will also lessen the chance of cognitive overload. Implementing questions or activities periodically during the videos will also keep students more engaged with the content, while introducing the topic to students beforehand will give them a basic idea of what will be covered and lower the chances of them not understanding the content [60]. The content covered within videos should also be in line with the learning goals of the course or subjects currently being taught. One way of ensuring this is for educators to produce videos themselves, but they should be aware that a lower quality video will also lower the engagement among students [60]. Although many students will spend time online streaming videos, a specific alternative form of media that has become more popular is audio or video podcasts.

Online podcasts have also become more popular tools for learning. They offer similar benefits compared to videos in the way that many are free to view and can be paused and rewound at the user's discretion. These resources can also be accessed at any time by students, who like the format due to the convenience it provides, allowing them to view different lectures while learning outside of universities [61]. This makes podcasts a preferred method of learning compared to textbooks for some students [62, 63]. Podcasts can be available in either an audio or video format. Audio podcasts do not require listeners to look at anything when listening, allowing them to complete other tasks while putting on the podcast in the background such as driving, household chores, or exercising [64]. For video podcasts, PowerPoint slides can be shown with professor commentary in the background. This allows these online podcasts to mimic a live lecture. Unfortunately, this format is often less engaging for students compared to live lectures with students not being able to directly engage with the professor and ask questions as they arise [65]. Though they would not replace live lectures from professors, they are convenient for students, especially if they miss a lecture or want to review a specific topic.

Animations are commonly used when explaining difficult topics or to help visualize specific structures or phenomena that occur in the body [66, 67]. Similar to other forms of media, animations must be utilized in the right circumstances and are not always effective for teaching. Animations are able to show dynamic changes that occur overtime, making it easier for students to follow. Animations can also be used alongside other new technologies such as VR to train students on certain tasks. For the purpose of surgical training, students would be able to practice basic skills in a virtual space utilizing different models and animations. Visual animations alongside oral explanations from instructors can increase student understanding on difficult topics, including anatomy. At the end of the day, the effective use of different forms of media for the purpose of education will come down to the learning goals and topics the instructors wish to cover. For a field as unique as medicine, deciding on the best way to deliver different concepts will come a long way in helping students learn.

2.6 Mobile phone and computer software

With the advent of portable electronics, different resources and information have become easily accessible for the general public. For the purpose of medical education, several different mobile applications and computer programs have been developed, allowing students to learn anatomy whenever and wherever they please. These forms of software fall under the broad category deemed "*Computer-assisted learning*," which is described as the use of computers for the purpose of educating individuals [68]. These programs are often developed independently by different companies or with advice from medical professionals [5]. Similar to Atlas textbooks, these resources can be used as reference material alongside other anatomy teaching tools or in some cases, are developed to help students learn specific concepts related to medicine.

A large majority of students now own some sort of mobile device (such as a smartphone, tablet or eBook reader) [69], with a variety of different applications available that can help with medical education. A study has shown that smartphones and tablet PCs have become widely adopted for the purpose of mobile learning [70]. Although there are some concerns regarding the frequency that some of these mobile apps may be utilized by students in anatomy and physiology classrooms, it can come down to familiarity with the device and application [71], as well as the how the content of the course relates to the information presented in the mobile app. Some apps are developed for specific purposes, such as RealWorld Orthopedics, which can be used as a reference tools for musculoskeletal conditions [5], while others contain more general information regarding anatomical structures and physiology. The fact that these different programs are mostly developed independently means there is a large range in quality for different mobile apps.

Different companies and apps stand above others when it comes to teaching anatomy. Developers such as 3D4Medical were rated highly by students in a study looking at the implementation of mobile apps into university level anatomy and physiology courses [72]. Apps such as Essential Anatomy 4/5 as well as Visible Body Human Anatomy Atlas (Fig. 2-1) are generally regarded as higher quality mobile anatomy teaching tools. They provide users with interactive, 3D models that can be rotated while also giving written descriptions of anatomical structures. They also help users by pronouncing different anatomical structures and have quizzes that can be used to test the user about their anatomy knowledge [72]. It could be argued that some apps can replace anatomy textbooks as reference materials for students, but instructors would need to thoroughly review the programs before this could be considered.

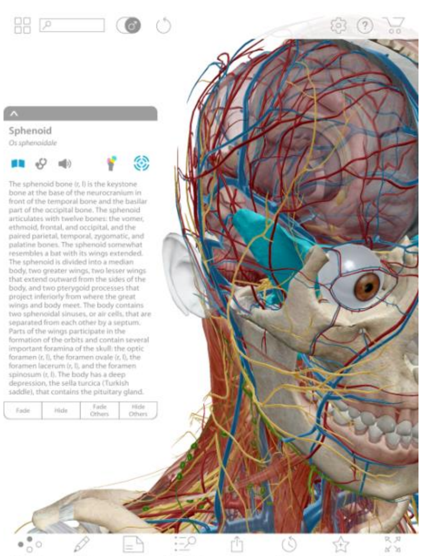


Fig. 2-1 Visible Body Human Anatomy Atlas. An application available for mobile devices and desktop computers [73]

Numerous studies have been performed assessing the effectiveness of learning anatomy using 3D model computer software. The programs used in these studies are executed using desktop or tablet computers, with students utilizing these programs to learn anatomy, physiology, or basic surgical skills. Studies looked at comparing these programs to existing teaching methods such as plastic models, 2D images from textbooks or online, as well as traditional textbook learning. One study also looked at whether these computer programs improved student learning when used in conjunction with didactic lectures and textbook learning. The results are relatively mixed on the effectiveness of these different 3D model programs [1, 7, 8, 41, 42]. For the purposes of short –term learning of anatomical structures, these apps have similar results to other newer anatomy teaching tools [8] and can keep up with or exceed traditional teaching tools in some aspects [1, 7] (especially if these apps incorporate other teaching methods such as AR). On the other hand, computer-based apps and resources have struggled compared to traditional teaching tools for material such as nominal anatomy [41]. However, due to the wide variety of differently developed computer programs, it is hard to identify what aspects of these technologies help with anatomy learning and which are inferior compared to traditional teaching methods. This does not mean that these alternative ways of teaching anatomy are not effective. There is continued development of newer technologies that are building off of these computer programs and apps. They would also allow students to manipulate 3D models, but would be more immersive compared to these programs due to the utilization of AR and/or VR technologies.

It can also be argued that students are unfamiliar with these programs, leading them to be less effective compared to the more intuitive plastic models or the more commonly used Atlas textbooks. Before students can effectively and efficiently utilize these different teaching tools, they must put in time to familiarize themselves with the technology. This will allow for greater comprehension of the content and makes it more likely that they will be familiar with similar applications in the future [8]. By interacting with 3D model computer programs more frequently, it is more likely that students will obtain improved results as they become more familiar with learning using these computer learning tools [72].

2.7 Augmented and virtual reality technology

A form of technology that is gaining popularity are those that utilize AR and VR to provide consumers enhanced or immersive experiences. Specifically, VR is able to provide users a total immersive experience by changing the environment around the user. This is especially pronounced when using a VR headset. On the other hand, AR adds additional elements to the environment, allowing the user to interact and manipulate these objects in different ways [74]. More commonly used for the development of video games, different developers have also created different educational programs that utilize this newer form of technology.

Fig 2-2. The Microsoft HoloLens II, an AR Headset that is beginning to see more use as a tool for medical education [77]

Examples of different VR headsets currently available include the HTC Vive and the Oculus Rift. These headsets have seen use for the development and testing of educational programs, with some universities already developing laboratories and work spaces to allow students and faculty members to experience VR and possibly develop their own programs [75, 76]. Developers are also continuing to improve the technology, releasing new upgrades and peripherals to make the experience better for the user. This includes upgraded headsets as well as haptic gloves, which would give tactile feedback, even in a VR environment (Fig. 2-3) [77, 78]. Microsoft has also partnered with different universities and companies to develop new educational programs and tools using VR headsets [74]. With these new options becoming available, it will be possible to train students in realistic settings that were previously impossible, such as different forms of astronaut training, or practicing surgical procedures.

Fig 2-3. VR haptic gloves. Peripherals that can be used alongside VR headsets to provide users with tactile feedback and a more immersive experience [78]

Recent studies have been done looking at different aspects of AR and VR to see how they can be used in an educational setting. Better suited for individual learning, users' opinions of the headsets were dependent on the weight of the device as well as how intuitive and responsive the controls were. Field of view with the headset as well as the ability to track the movement of the user also influenced the immersion that VR can bring. It was found that while motion controls and gestures were a more natural way of navigating in VR, using a controller or joystick was easier to control [79]. A study was also done comparing sixty-six medical students learning with either a VR model of a brain or with an online textbook. Researchers found that while both groups achieved similar results on pre-intervention, post-intervention and retention quizzes, the group that learned from the VR model found the technology more engaging, useful, and were more motivated to learn as a result [80]. While these are subjective measurements for participants in this particular study, previous works have shown that a lack of motivation and time for using newer technologies limit the adoption and utilization of new, novel technologies [81, 82, 83].

While AR and VR have seen some promise for teaching human anatomy and physiology, it is already in use for a number of medical procedures such as larcoscopic surgery or joint injections [84]. This can continue to expand to surgical training or practicing different healthcare professional-patient interactions. Some AR headsets such as the Microsoft HoloLens (see Fig. 2-2) allows for remote viewing from another device. This would allow a professor to connect and provide students with real time feedback during procedures such as dissections of autopsies [6]. Another study looked at training medical students in standardized patient encounters through first person recordings using the Google Glass headset. Using this technology, students would get more experience in patient interactions on more sensitive subjects [85]. Allowing students to record these interviews in first person also allows for greater self-analysis and evaluation. A final study looked at using both AR and VR in the operating room, providing the surgeons with hands free additional information. The researchers found that additional information allowed for easier transitions between pre-operation planning and intraoperative surgery [86]. By providing surgeons with more information on the fly, they are able to improve their decision making. It is evident that both AR and VR technologies have a lot of clinical potential in the medical field.

This does not mean there are not problems associated with the implementation of AR and VR in medical education. Initial costs for the hardware are high, with highly variable prices between headsets. The Microsoft HoloLens is around $3000 US, while the Google Glass Explorer package is around $1500 US. The HTC Vive Pro is around $1400 US and the Oculus Rift is the cheapest at around $600 US [86]. If VR is to be used by students during classes or as a method of training, there needs to be a sufficient number available to the students. Another potential issue with prolonged use of VR headsets is increased risk of nausea or cybersickness [87]. Finally, as AR and VR are relatively new technology, there are not many software programs relevant to medical education or training. This limitation should disappear with time as developers continue to release new software aimed at helping students learn different aspects in the field of medicine.

2.8 Novel technology

Differing from technology that was discussed in the previous section, some developers have created hardware specific for the purpose of anatomical or medical education. These technologies provide users with a unique experience and in some cases, are created in order to train students in a specific task. This can include learning about specific anatomical structures, surgical training and dissections, use in a clinical setting to help patient understanding, or creating an interactive virtual environment for student learning. Unique training tools and learning methods can help student learning, offering a different experience that would not be possible through traditional methods. Table 2-1 gives a brief description of the technology discussed in this section.

Table 2-1. Novel technologies developed for the purpose of medical education

Name of technology	Description/purpose of technology
VR temporal bone simulation	Surgical practice station for the temporal bone, providing tactile feedback to students. Practice for future surgical procedures, lower chances of mistakes [2]
Virtual interactive presence and augmented reality (VIPAR)	Remote surgery assistance, allowing for remote training of surgical students. [89]
Rapid prototyping	3D printing models for patients, allowing them to understand potential treatment options [90]
AnatOnMe	Projection of medical imagery onto the patient, easing communication between the practitioner and patient [91]
DextroBeam	Virtual classroom allowing students to see projections of anatomical structures during lessons [92]
Bangor Augmented Reality Education Tool for Anatomy (BARETA)	Utilizes rapid prototyping to create model simulations students can interact with [93]
Anatomy Studio	Utilizing AR headsets and stylus that allow students to practice surgical training in small group settings [26]
Anatomage Table	Virtual anatomy dissection training tool, allowing for 3D visualization of human anatomy for purpose of dissection [3]

Due to various problems such as ethical or cultural concerns with cadaver dissections [2, 3, 23] new alternatives for surgical training are being developed and tested. The goal of these new teaching methods is to find a safe, reliable, and affordable way to provide students with effective, practical surgical training. From general surgery practice [88], to working with specific structures such as the temporal bone (Fig. 2-4) [2], new tools ranging from virtual work stations to stylus that provide tactile feedback have been developed to try and give students realistic surgical practice. With the possibility of telesurgery also being more feasible, students can get real-time, remote training from experienced surgeons as well [89]. By using surgical simulations, students are given an effective tool to practice surgical techniques, thus minimizing potential errors in the future while also increasing their ability to perform different skills [2, 88].

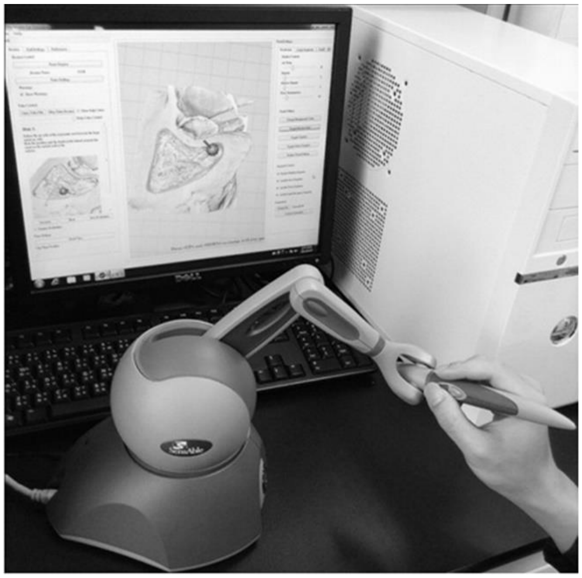


Fig 2-4. VR temporal bone simulation station using a computer, specialized software, and a hand stylus [2]

Different novel technologies are also being developed for use in a clinical setting, allowing for easier patient understanding regarding pathological conditions or surgical proceedings. An example of this is through the use of rapid prototyping, which utilizes a patient's CT and MRI scans to create models of the patient's brain [90]. This can be used to explain to the patient the planned procedures or potential treatment options. Another device, called AnatOnMe, projects medical imagery onto the patient, making it easier for the practitioner to explain the condition to the patient [91]. These newer technologies make doctor-patient communication easier and allow the patient to absorb the information being presented.

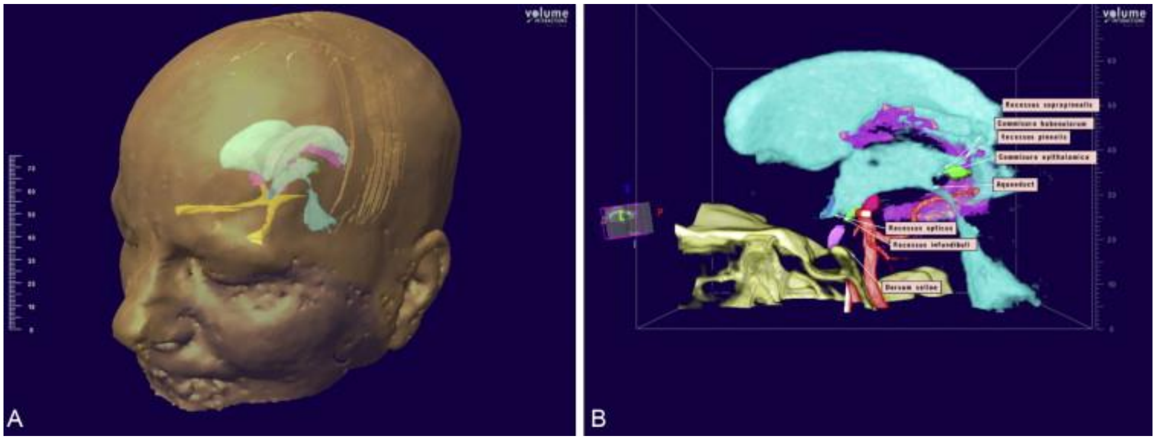


Fig 2-5. Neuroanatomy projection images using the DextroBeam technology [92]

Alternative anatomy classrooms are also being developed, which would allow students to learn in an entirely virtual environment. Compared to traditional didactic lectures, students would be able to engage with professors in a more active learning environment. These virtual classrooms will typically utilize mixed reality (AR + VR) technology, with students being able to see anatomical models through projections using DextroBeam (Fig. 2-5) [92] or wearing headsets while also being able to interact with the models using a stylus through Anatomy Studio [26]. Another system, called the Bangor Augmented Reality Education Tool for Anatomy (BARETA) uses rapid prototyping to create model simulations that students can interact with [93]. Although the BARETA system and Anatomy Studio were both designed for use by small groups or pairs of individuals, user perceptions to the technologies were very different. The studies showed that the BARETA system was not very helpful to students for the purpose of understanding the shape and location of the ventricular system [93], but found that Anatomy Studio (Fig. 2-6) was a feasible method for supporting collaborative dissection training [26]. A final study comparing the DextroBeam system also found that it produced comparable results to PowerPoint lectures when looking at memory retention of anatomical structures in the ventricular system [94]. These tools would not only help with the perception of spatial understanding [26, 94], it also has the potential to motivate student learning, leading to increased understanding and knowledge retention [95, 96]. Though only in its early phases, the use of 3D projections and mixed reality technologies can greatly benefit students learning anatomy in both a lecture and small group setting.

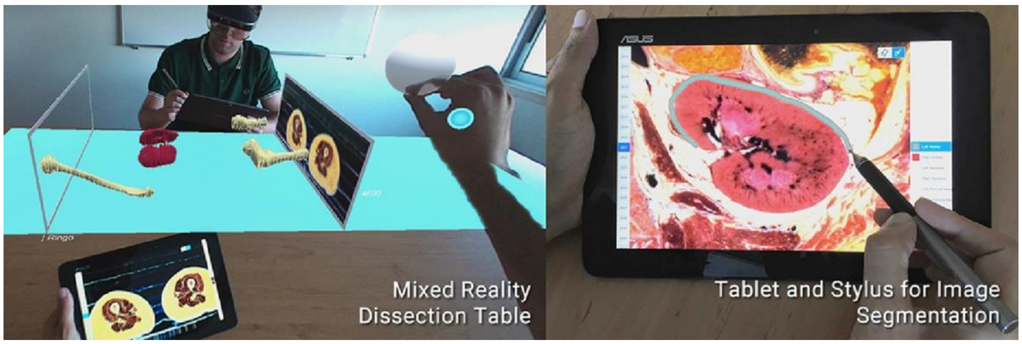


Fig 2-6. Anatomy Studio: a mixed reality technology allowing for virtual dissection simulations using tablets, head mounted displays and a stylus [26]

Recently, newer technologies have also been developed for the purpose of learning human anatomy and physiology. Compared to traditional teaching methods such as textbooks or mobile apps, these newer methods of learning utilize AR and VR technology, promoting active learning and a more engaging experience for students. Numerous studies have been done in recent years looking at the capabilities of a variety of different novel technologies, often comparing them to traditional teaching methods such as textbooks or cadaver dissections. Each study focused on different anatomy such as the musculoskeletal (MSK) system for the Anatomage Table [3], Medulla Spinallis with the MagicBook [7], and a gross anatomy course utilized a Magic Mirror that used radiological slices, as well as the Anatomage Table [97]. All these studies showed benefits in using these novel technologies including a lower cognitive load, increased motivation to learn, and also performing to a similar level to Atlas textbooks and cadaver dissections [3, 7, 97]. While these new technologies are not currently seen as replacements for cadavers or textbooks, continued research is being done to look at the benefits and limitations of novel technology when used for anatomy education.

There have been a wide range of different technologies that have been developed for different aspects of medical education. This ranges from general anatomy learning through the use of AR and VR technology, or highly specialized surgical training using a stylus or surgical workstation. Compared to cadavers, these technologies aim to be highly accessible, while minimizing cleanup and maintenance costs. Unfortunately, they usually have a high installation cost due to the state-of-the-art technology and often require users to grow accustomed to the technology before it can be used optimally [2]. Still in its early phases, these kinds of technology have great potential with the possibility that they can one day replace didactic lectures or cadaver dissections as the default methods for anatomy education, especially if cadaver dissections continue to see less use internationally [3, 98].

2.9 Summary

Based on the literature, these are the main points that can be seen:

- Anatomy education is most commonly taught through a combination of cadaver dissections, didactic lectures, and learning from Atlas textbooks, all of which have been used for centuries.
- Although both traditional teaching methods have certain limitations, such as potential trauma and high costs associated with cadavers, as well as boring and potential out of date information associated with textbook learning, they are proven to greatly benefit student learning.

- Currently used supplemental teaching tools include physical 3D models as well as different forms of media ranging from videos, podcasts, and animation. These mediums are used alongside traditional anatomy teaching tools, they ease student understanding in different ways (lowering chance of cognitive fatigue, increases spatial understanding).
- Mobile applications are similar to anatomy textbooks and are used as reference material that is readily accessible by students.
- New technologies are beginning to see use in anatomy classrooms, such as mobile applications, AR, and VR, but each requires further studies. These technologies have a lot of potential to enhance student learning, but currently lack the software to effectively promote student learning compared to cadavers and textbooks in regard to long-term knowledge retention or as complete anatomy teaching tools.

3 Methodology to Assess the Capabilities of the Magic Mirror

3.1 Overview

This chapter discusses the methodologies for user studies, professor interviews and student surveys that were performed to collect data on the current capabilities of the MM technology. The user studies focused on comparing the MM to textbook learning and cadaver dissections for the purpose of short – term memory retention of anatomical structures in the cardiovascular system. The interviews and survey questions focused on what these participants thought of the MM at the time, how they would compare the MM to current methods used for teaching anatomy, and suggestions they have on how to improve the MM for its potential future integration in anatomy classrooms.

3.2 Preamble: Novel technology in the classroom

Changes and developments to technology have altered many aspects of our daily lives. This is also true at all levels of education and in the classroom. For this generation of students, new tools and methods are present to help them learn inside and outside of the classroom. Different learning philosophies are beginning to be implemented in anatomy classrooms as well. Changes that occur to education affects not only what is already being taught, but also new learning tools that are being developed.

Even the development of new learning tools and technologies such as the MM require iterative changes and improvements to best fit into university classrooms. Additional features and content, while also making the system easy to access and use, are all changes that would fit the current generation of students. At the same time there are features that no longer appeal or are necessary for students. The development of technology must continue to adapt and maintain a quality standard to keep up with the changing classroom environment. To do this, it is sometimes necessary to work with the target demographic to discover their preferences and expectations for your learning tool.

3.3 Planning Magic Mirror user studies

When developing a new product or service, continuous testing is necessary to make sure the idea works as intended. Even if there is a theoretical need for a certain product or it can fill a certain niche, if there are debilitating side effects or the product is impractical, it may not be useful for its intended audience. This was the case for the MM in its infancy of development. It was a newer technology that would be theoretically useful with many potential benefits but struggled with execution. Even though an initial study conducted in Munich, Germany showed there was an interest in this type of technology [17, 97], designing the program for everyday use by students was a difficult task. A completed prototype had been developed and was usable in 2017, but the only users who had used this version of the technology were those that had developed the program and a couple of anatomy professor consultants who tested the practicality of the software.

When planning the user studies at the University of Ottawa, inspiration was taken from previous studies that looked at novel technologies for the purpose of anatomy education [1, 3, 7, 8, 27]. Following a similar format to these previous studies, it was decided that the initial study would look at short – term memory retention of anatomical structures assessed in a quiz format before and after interacting with the MM. The focus of each of these user studies would be organ systems that coincided with the courses our student sample were enrolled in. When completing data analysis, it was decided that changes to average scores by participants from the pre-test to the post-test would be the method for evaluating increases in anatomical knowledge. Statistical analysis was completed through paired T-tests, which evaluated if there was a significant change in the participant's anatomical knowledge after interacting with the MM, cadavers or Atlas textbooks. Independent T-tests were also completed to evaluate if there were significant differences between the MM and cadavers or Atlas textbooks as tools for anatomy education.

There were two iterations of user studies completed over this thesis work. In each of these studies, the MM was compared to either cadaver dissection or textbook learning for the purpose of anatomy education. Each study was done in person and followed the same format, starting with an initial pre-test to evaluate the participants' base anatomy knowledge. This was followed by a lesson where a participant interacted with either the MM, or a traditional tool for teaching anatomy. After completing the lesson, all participants completed a post-test to see if there was an improvement in their anatomical knowledge. Those that interacted with the MM would then complete a short survey where they gave their opinions on the technology compared to textbook learning.

Two professors from the Faculty of Medicine at the University of Ottawa helped plan and carry out the user studies. They helped with booking the cadaver lab for sessions comparing the MM to cadavers, recruitment of students to participate in the studies and designing questions that would be used to assist the participants in their knowledge of anatomy before and after interacting with the MM, textbooks or cadavers.

3.4 November 2017 pilot study

3.4.1 Study design

After developing an initial prototype for the MM over the summer of 2017, testing began during the Fall 2017 semester at the University of Ottawa. This initial pilot study tested the capabilities of the technology as a lecturing tool in anatomy classrooms. The build of the MM used in this study contained models for the following organ systems: skeletal, lymphatic, muscular, respiratory, nervous, digestive, urinary, and cardiovascular. It could be controlled using a keyboard and mouse or through motion controls. The AR view of the model could be adjusted to focus on different areas of the body such as the upper arm and could be fully controlled to look at the front or back of the body. The view on the display could also be mirrored according to the preferences of the user. A major feature – labelling of major anatomical structures – could not be implemented in time for the beginning of the first session and therefore was not present for the duration of the pilot study.

While it would have been ideal to obtain significant data from the pilot study, our main goal when conducting the pilot was to assess the study design. We were looking at knowledge assessment, organization of the sessions, and assessing what would work effectively in a larger-scale study. The pilot study was conducted as an initial test for the upcoming large-scale user study.

3.4.2 Sample

Upon ethics review and acceptance, n=22 nursing students enrolled in a pathophysiology course (PSH 4300/4700) agreed to participate. This study consisted of five sessions in which the

MM was compared to cadaver dissection as anatomy education tools. Each participant had taken an anatomy and physiology course in the past prior to participation in the study.

3.4.3 Procedure

Sample questions used for the pre-test and post-test can be found in Appendix A.

Each session began with all participants completed a six – question pre-test in which they had to identify labelled anatomical structures from the cardiovascular and respiratory system upon arrival. The pre-test was administered in a histology lab located adjacent to the anatomy laboratories. All questions were created with the help of two professors from the faculty of medicine as well as a fourth-year health science student from the University of Ottawa. The participants were each given a sheet of paper which contained the four-option multiple-choice questions that were used for the pre-test. The pictures containing the structures were then shown to the participants one at a time, moving onto the next image after all participants in the session have answered. All questions asked in the pre-test consisted of structures that would be covered in the anatomy lesson that took place during this study. This was used to gather baseline data on the participants' anatomical knowledge. After completing the pre-test, participants were divided into two groups: one went to the cadaver laboratory where they were given an anatomy lesson by medical students using cadavers. The other group remained in the histology lab where they were given an anatomy lesson using the MM by an anatomy professor (Fig. 3-1).

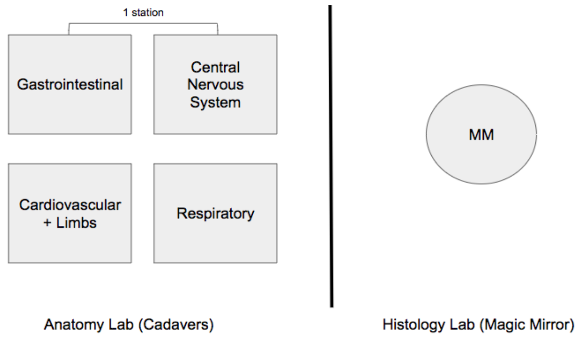


Fig. 3-1. Station layout for Nov. 2017 pilot study

The anatomy lesson given using the MM covered structures in the cardiovascular system and the respiratory system. An anatomy professor gave the lecture while a participant acted as the model, standing in front of the Kinect sensor and having the models displayed onto them. A technician operated the MM, changing the views and systems being displayed (Fig. 3-2). The anatomy lesson given in the cadaver laboratory consisted of structures in the cardiovascular, respiratory, gastrointestinal, and central nervous system. Lessons were given in the same manner, but participants were provided with more details regarding physiology of the different structures compared to the lesson given using the MM. Table 3-1 illustrates the differences between the lessons given with the MM and cadavers.

Table 3-1 Differences between the lessons given with the MM and cadavers

Cadaver	Magic Mirror
Covered structures from numerous organ systems (cardiovascular, nervous, respiratory, digestive, skeletal)	Covered structures in the cardiovascular system and respiratory system
Covered anatomy and physiology	Focused only on anatomical structures
Lesson given by medical students from the University of Ottawa	Lesson given by professor from the faculty of medicine

Fig. 3-2. Demonstrator teaching using the MM

After completing their lessons with either the MM or in the cadaver lab, all participants returned to the histology lab and completed an eight – question post-test in the same format as the pre-test. The six questions from the pre-test were repeated in a different order and two new questions were added. After completing the post-test, the MM and cadaver groups switched so that all participants were able to see both anatomy teaching tools. The pre-test and post-test were both marked at the completion of each session. Participants were not informed of their scores on either the pre-test or the post-test. Table 3-2 shows the rotations of participants in the two groups throughout each session.

Table 3-2. Timetable of MM pilot study

Group 1 n=9	Pre-test (10 minutes)	Interaction with MM & Post-test (30 minutes)	Interaction with cadavers (40 minutes)
Group 2 n=13	Pre-test (10 minutes)	Interaction with cadavers & Post-test (50 minutes)	Interaction with MM (20 minutes)

3.5 Fall 2018/Winter 2019 large-scale study on the cardiovascular system

3.5.1 Study design

Resources used during this study can be found in Appendix A

After the conclusion of the pilot study, the entire study design was evaluated, and changes were made for the following large-scale study. Before deciding on changes that would need to be made, we looked at the positives of the pilot study that would be used again. The belief was that the pre-test and post-test evaluations were a good indicator of short – term learning for participants who interacted with the learning tools. The difficulty of the questions asked on these tests was ideal, but the format was changed from multiple-choice questions to word bank style questions. The word bank used for the pre-test and post-test were identical and contained 40 structures from the cardiovascular system. Nineteen structures were arteries and twenty-one were veins. Participants were shown pictures of anatomical structures and asked to write down what they believed to be the correct answer from the word bank provided. *Appendix A shows the word bank provided to students as well as some sample questions asked.* This change would lower the chances of participants guessing the correct answer while not making the questions too difficult. The last thing that was carried over was the focus on specific organ systems and structures. Creating a lesson based off the content participants are currently learning about in their courses would not only help them in their studies, but also make it more likely that they will recognize some of the anatomy they are being taught. The content covered in the lessons were made to be as close as possible, covering the structures that were present in the word bank used for the pre-test and post-test.

For the large- scale user study, the main research question was: How does the MM technology compare to a standard teaching tool for anatomy education (Atlas textbooks) for the short-term learning of anatomical structures in the cardiovascular system? Hypotheses were also formed prior to statistical analysis. The null hypothesis (H_0) was that there was no significant improvement between the results of the pre-test and the post-test, while the alternative hypothesis (H_A) was that there was a significant improvement between the results of the pre-test and the post-test. When comparing the MM to Atlas textbooks, the H_0 was that there was no significant difference between the two teaching methods as short-term tools for cardiovascular anatomy, while the H_A was that there was a significant difference between the MM and Atlas textbooks for the short-term learning of cardiovascular anatomy. Alterations to the study design stemmed mainly from limitations that were present in the pilot study. By increasing sample size, we also increase the power, while standardizing the lesson and making it more concise, hoping to eliminate some potential confounding variables that could affect the results.

3.5.2 Sample

After these decisions were made, we had to come up with changes that would address the limitations that were present in the pilot study. The highest priority issue that needed to be addressed was recruiting a larger sample size that is more representative of our population of interest. Multiple changes were done to try and address this problem. The first change was to the location the study would be conducted. The Hospital campus for the University of Ottawa is around 6.5 km away from the main campus, so the location of the large – scale study was changed to the Lees Campus, which is only 2 km from the main campus. We hoped that making it easier to reach the study location would mean more students sign up to participate. The next change was the student population type participants were recruited from. Our main target sample for this study was university students enrolled in Anatomy and Physiology I (ANP 1105/1505) at the University of Ottawa during the Fall 2018 and/or Winter 2019 semesters, which has around 1500+ students throughout the two semesters. Finally, the two anatomy professors assisting us with the previous pilot study provided an incentive to their students to boost our sample size. They agreed to give students who participated in our study a 1% bonus mark in the Anatomy and Physiology course. Due to the fact that an incentive was offered to students who participated in the study, there was no hard cap on the size of the sample. This allowed anyone in the enrolled courses to participate.

The change in location also meant that the cadaver lab was not an option for this study. As a result, the MM was compared to Atlas textbooks instead of cadavers. Without the restrictions in scheduling for the cadaver lab, a larger number of sessions were created to accommodate the schedule of participants. Content covered in the study was standardized for both the MM and textbooks. All participants now interacted with one of the learning tools for 15 minutes and covered the same material regardless of which group they were a part of.

The final, significant change made to the study design was to the MM software. The program was redeveloped in the Unity engine. This change allowed for the implementation of labels to major structures that moved along with the user in a real time 3D space. Two technicians were trained to operate the MM and assisted the participants throughout the study. These technicians would change the focus region of the MM and help the users if they had questions while they interacted with the MM. For participants that were assigned textbook learning, a researcher would be present to answer any questions they had. Since the sample population for this study was made up entirely of students enrolled in Anatomy and Physiology I, the lesson consisted of structures in the cardiovascular system only.

3.5.3 Procedure

After all these changes, the study design and sample size were finalized. This large-scale study consisted of 213 undergraduate students enrolled in Anatomy and Physiology I (French language delivery). Each session lasted around thirty to forty minutes and consisted of four to six participants at once. Upon arrival at the study location, all participants completed an eight – question pre-test used to evaluate their base knowledge of structures in the cardiovascular system. Afterwards, participants were randomly assigned to the experimental group or the control group (Fig. 3-3).

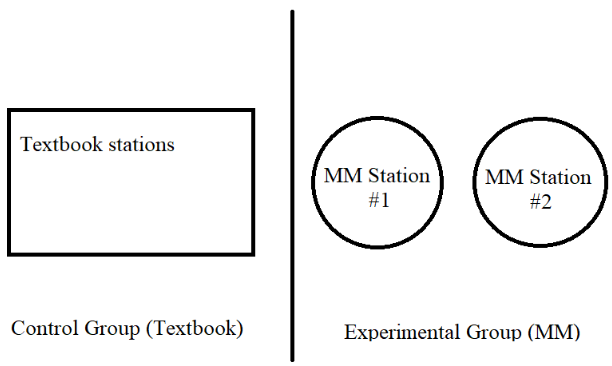


Fig 3-3. Station layout for Fall 2018/Winter 2019 large-scale study

Those in the experimental group (n=106) completed a fifteen – minute lesson on the anatomy of the cardiovascular system with the help of the MM. A technician operated the MM, altering the view of the system and assisting participants in identifying the location of specific structures. While the technicians were aware of the questions that would be asked on the post-test, they were instructed on how to specifically carry out the fifteen minute lesson and would only provide further details on specific structures if the participants first asked about them. They did not give any hints about potential content that would be on the post-test. Those in the control group (n=107) were moved to a separate room, where they were instructed to try and learn those same anatomical structures individually using an Atlas textbook for fifteen minutes. A researcher was present in the same room in case participants had questions. Once again, they researcher would not give any hints about the post-test, but would answer questions about anatomical structures if the participants asked about them. Following the fifteen – minute learning period, all participants completed an eight-question post-test that followed the same format as the pre-test. Two of the questions on the post-test were repeated along with six new questions. Just like the pilot study, participants were not told how they scored on the pre-test or post-test. Table 3-3 shows the general timetable for each session.

Table 3-3. Timetable of Fall 2018/Winter 2019 large-scale study

Experimental group N = 106	Pre-test (10 minutes)	Interaction with MM (15 minutes)	Post-test (10 minutes)
Control group N = 107	Pre-test (10 minutes)	Interaction with textbook (15 minutes)	Post-test (10 minutes)

3.6 Student surveys

3.6.1 Study design and recruitment

The student surveys were completed as a part of the Fall 2018/Winter 2019 MM large-scale study. Among them, n=106 participants interacted with the MM, with all but one of them also completing the survey. The remaining n=107 participants did not interact with the MM and therefore, did not complete the survey.

The Magic Mirror is...	←strongly disagree				strongly agree→
(1) increases motivation to learn anatomy	○	○	○	○	○
(2) stimulates active learning	○	○	○	○	○
(3) helps with 3-D learning	○	○	○	○	○
(4) offers benefits compared to textbooks	○	○	○	○	○
(5) is a more engaging introduction to anatomy	○	○	○	○	○
What do you like about the Magic Mirror System/what would you like improved?					
Final grade I give the Magic Mirror	A	B	C	D	E
(6) I think the exercise compliments textbooks when learning anatomy	○	○	○	○	○

Fig. 3-4. Survey provided to participants who interacted with the MM

The survey was completed anonymously by participants at the conclusion of the large-scale study. At the time of these student interviews, the MM had been imported to the Unity engine, but only had the models and structures for the cardiovascular system fully labelled in French. The student survey consisted of six statements answered by participants on a five-point Likert scale. The following numbers corresponded with the following statements: 1/strongly disagree, 2/disagree, 3/no opinion, 4/agree, and 5/strongly agree. While the results of these surveys were not used for statistical analysis, they provided us with the first instance of user feedback for this build of the MM. They also gave a general idea on what university level health science and nursing students thought of the MM in comparison to how they currently learn anatomy and physiology (textbooks). There was also an empty space available where participants were able to provide feedback on the MM or suggestions on how they believe the MM can be improved. Participants were also able to give their “Final grade” of the MM in its current state (Fig. 3-4). However, there was an oversight in the format of the survey: the order of the final grading goes in the opposite direction compared to the rest of the survey. This could have resulted in some participants answering statement six according to the letter grading scale. It also led to many participants not providing a final letter grade to the MM. When analyzing these surveys, we looked at general trends regarding the students' opinions of the MM in comparison to textbook learning.

3.7 Needs assessments on medical education

When looking for the best method to qualitatively assess the MM, it was decided that the information should come from the population that the MM is targeted for. At the time, information from the student surveys gave a general view of their opinions regarding the current state of the MM. These opinions coincided with the oral opinions obtained from participants in the MM pilot study. While the students thought highly of the MM, little information had been obtained from the professors who teach these students. Unlike the students, the professors would be able to offer information regarding the logistics of planning classroom lectures and the current state of their individual curriculum. They would also be able to offer their own opinions regarding their expectations for the MM. It is likely that their differing priorities compared to students will also lead to different ideas for the MM.

Thus, a needs assessment was completed to evaluate the current developmental pathway of the MM after the conclusion of the Fall 2018/Winter 2019 large-scale study. When deciding on the methodology that would be used to assess this, previous needs assessments on medical education were consulted. These previous studies provided information on the format that should be used to gather feedback on the MM, the types of questions that should be asked to those providing feedback, as well as the development decisions that could be answered from gathering this feedback.

Articles were gathered using the University of Ottawa's Search+ engine. All articles were written in English. The selected articles looked at needs assessments in medical education, with the focus on new technology or new approaches and teaching methods for students in the field of medicine.

Previous needs assessment on medical education focused on specific topics and issues that the author believes needs to be addressed. This could include health policy, student learning styles, standardizing content taught in medical schools, or changing priorities and perspectives of medical students in different generations [53, 100, 101, 102, 103]. Each of these studies tailored questions specifically for their sample. This is especially important if the sample is highly diverse. In those cases, those from different backgrounds or those with different levels of experience can offer different perspectives and should therefore be asked different questions to allow them to give these opinions [100]. For the case of the MM, while the student survey looked more at the hands-on experiences of the participants, interviews conducted with professors would focus on their classrooms: what they teach, how they teach and how they help students. While professors teach different aspects of anatomy, similarities in faculty and subject means the same interview guide can be used for all participants.

When deciding on the content that would be covered in the interviews, inspiration was taken from three previous needs assessments. These studies looked at medical students' perceptions on improvements that could be made to curriculum and anatomy learning, the learning styles of students, and standardizing the implementation of imaging education technology [101, 102, 103]. When looking at the perceptions and learning styles of students, these studies focused on trying to understand the preferences of the population of interest and why these methods benefit the sample [101, 102]. In the same way, professor interviews could look at not only the content the professors cover, but their perceived effectiveness, alternatives and difficulties. The needs assessment that looked at how best to integrate imaging education into medical schools also had a couple of interesting similarities to the MM. This study looked at the skillset that should be taught, and potential content that should be standardized for imaging education [103]. In a similar way, the MM has a niche that differentiates it from cadaver dissection and Atlas textbooks. Being able to extrapolate from this and focus on these strengths when developing the MM can greatly benefit it in the future.

The format chosen for data collection can also influence the responses of participants. Focus group interviews, individual interviews and questionnaires all have different benefits as methods for qualitative data collection. For our needs assessment, the decision was between individual interviews or a focus group among anatomy professors. Focus groups offer greater possibility for in depth data collection through group interactions [104] but require meaningful discussion and moderation to get the most out of the group. The moderator must also create an environment that encourages the participant to voice their opinions [104]. On the other hand, individual interviews are a more time – consuming process and require a skilled interviewer to get the most out of the participants. This could come from asking follow up questions or having the interviewer go more in depth about the topic. In the end, the professor interviews were conducted individually. Since the sample size was only n=6 professors, the scheduling and interview process was not too time consuming and allowed all the participants to answer at their own pace and detail. These articles helped to shape the interview questions that would be used for interviews with anatomy professors regarding anatomy education and the MM.

3.8 Interviews with anatomy professors

3.8.1 Study design and recruitment

To assist in the developmental pathway, n=6 professors who teach anatomy and physiology courses at the University of Ottawa were interviewed about the current state of their classrooms, other options students have to help them learn anatomy, and the current state of the MM. Two of the professors interviewed had assisted with previous studies involving the MM. At the time these interviews occurred, the MM had been imported to the Unity engine, but still only had the models for the cardiovascular system labelled in French. All participants interviewed were aware of what the MM was and had previously interacted with a version of the MM.

In person interviews were conducted in a semi-structured format by a fourth year Health Science student from the University of Ottawa. The interviewer was assisting with MM user studies at the time the interviews were conducted. All interviews were done in French and subsequently translated to English by the interviewer at a later date.

The interview questions can be found in Appendix B

The questions were designed so that we may learn more information about current methods used to teach anatomy and physiology, while also learning about other supplemental tools students can access that could assist them. This would give a better idea of how these supplemental tools differentiate from the standards of textbooks and cadavers while also giving information about what these professors think about the current state of the MM. It would also extend the development pathway of the MM in regard to what else could be added to enhance the technology.

4 Results and Discussion of Magic Mirror Studies

4.1 Overview

This chapter looks at the results of data collection from the user studies, student surveys, and professor interviews. It shows how the MM compared to cadavers and textbook learning for short-term retention of anatomical structures in the cardiovascular system. It also discusses common trends and answers from students and professors regarding improvements that can be made to the MM, as well as perspectives for its potential translation into future classrooms.

4.2 November 2017 pilot study

4.2.1 Results

Appendix A contains sample questions and diagrams used for the pre-test and post-test

Table 4-1 shows the structures that were included for the pre-test and post-test. The photos containing the structures were either obtained from an Atlas textbook or were photos taken from cadavers. There were two versions of the pre-test given. One featured questions QA-QF while the other featured QA-QD, QG, and QH. When designing the questions for the pre-test and the post-test, there were some concerns that participants would have difficulties identifying more precise blood vessels and anatomical structures. An example of this would be the external iliac artery, which branches off from a larger blood vessel at a specific point. We believed that since many of these participants would be years removed from their last anatomy and physiology course, they would struggle with these kinds of anatomical structures, even after obtaining a lesson from the MM or cadavers. The opposite was also true. If a question was too easy, it becomes less likely that we will see any kind of meaningful change in the data from the pre-test to the post-test. Therefore, the different versions of the pre-test were done to gauge the difficulty of the questions and would allow us to collect data regarding whether these anatomical tools would be useful to students learning human anatomy. All questions were used for the post-test.

Table 4-1. Structures asked about during Nov. 2017 pilot study.

Legend	Structure	Diagram Type
QA	Right Subclavian Artery	Textbook
QB	Right Subclavian Artery	Cadaver
QC	Radial Artery	Cadaver
QD	Cephalic Vein	Textbook
QE	Left Pulmonary Artery	Cadaver
QF	Larynx	Cadaver
QG	External Iliac Artery	Cadaver
QH	Left Common Carotid Artery	Cadaver

Figure 4-1 shows the percentage of correct responses on the pre-test and post-test for students that first interacted with the MM. While all participants who interacted with the MM completed QA-QD on the pre-test (n=9), n=4 participants completed the pre-test containing QE and QF while n=5 participants completed the pre-test that featured QG and QH. All participants who interacted with the MM (n=9) completed every question on the post-test. Similarly, Figure 4-2 shows these results for students that first got their lesson using cadavers. Once again, all participants who interacted with the cadavers completed questions QA-QD (n=13), while n=4 participants completed QE and QF. On the other hand, n=9 participants completed QG and QH. Finally, Figure 4-3 shows the average mean scores on the pre-test and post-test for both groups. The cadaver group (n=13) had an average score of 46.2 percent on the pre-test (s = 18.35%) and 51.9 percent on the post-test (s.d. = 24.92%). The MM group (n=9) had an average score of 40.7 percent on the pre-test (s.d. = 14.79%) and 47.2 percent on the post-test (s = 10.42%). Any column that is not shown indicates that there were no correct responses to that question.

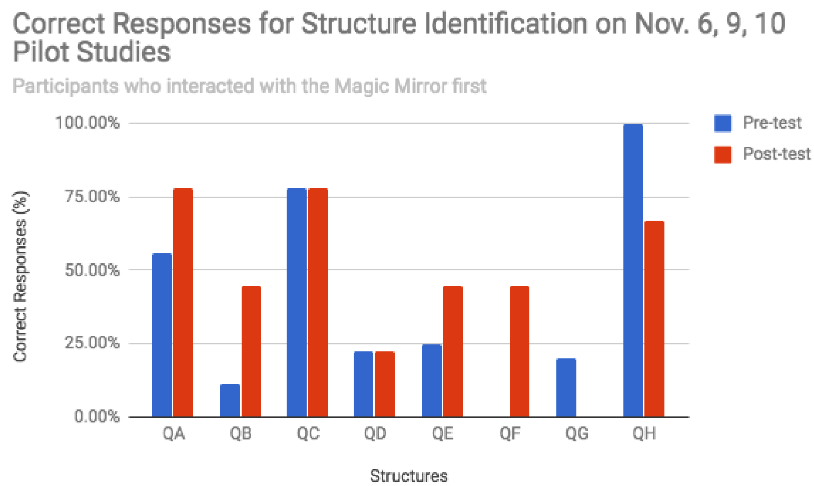


Fig. 4-1. Percentage of correct responses by participants who first interacted with the MM

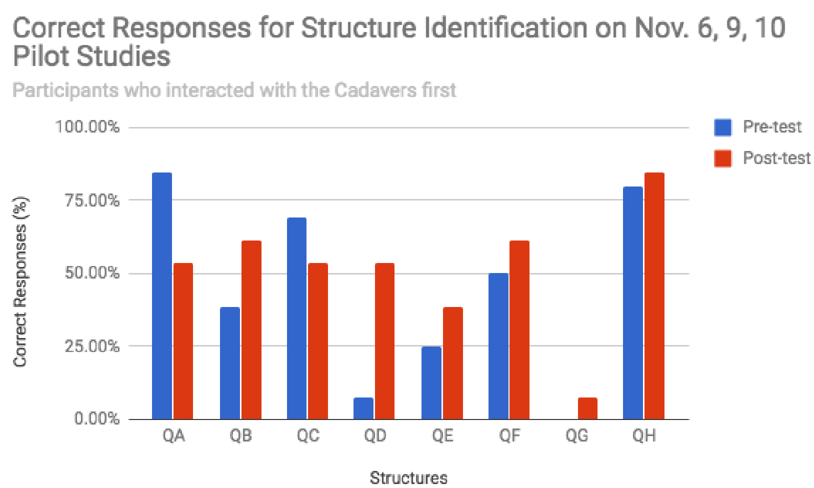


Fig. 4-2. Percentage of correct responses by participants who first interacted with cadavers

Paired T-tests were completed to compare the results of the pre-test to the post-test for both types of interventions. This was done to see if there was a significant increase in knowledge for participants after they received a lesson using either the MM or cadavers. An independent T-test was done comparing the difference between the pre-test and post-test for both the MM and cadavers. This was done to see if there was a significant difference between the knowledge obtained from the two teaching methods. T-tests were decided as the method for statistical analysis because of the small sample size of the pilot study. Due to the fact that both groups had an n<30, it cannot be assumed that the data would be normally distributed around the mean, therefore t-tests would be the best statistical test for calculating significance between variables. The paired t-test looked at two different variables from the same sample (pre-test vs post-test scores), while the independent t-test compared two samples with uneven sample sizes (MM group vs cadaver group). From the results of the paired T-test, it was concluded that there is no significant increase from the results of the pre-test to the post-test for both teaching methods (Cadaver group, $p = 0.401$, MM group, $p = 0.114$). The same conclusion was reached after completing the independent T-test comparing the two teaching methods. It showed that there was no significant difference between the two teaching methods for the purpose of anatomy education (pre-test, $p = 0.466$, post-test, $p = 0.601$). Thus, if we follow the data obtained, our overall conclusion would be that there is no significant difference between the MM and cadavers as tools for medical education. All statistical analysis was completed using IBM SPSS Statistics software.

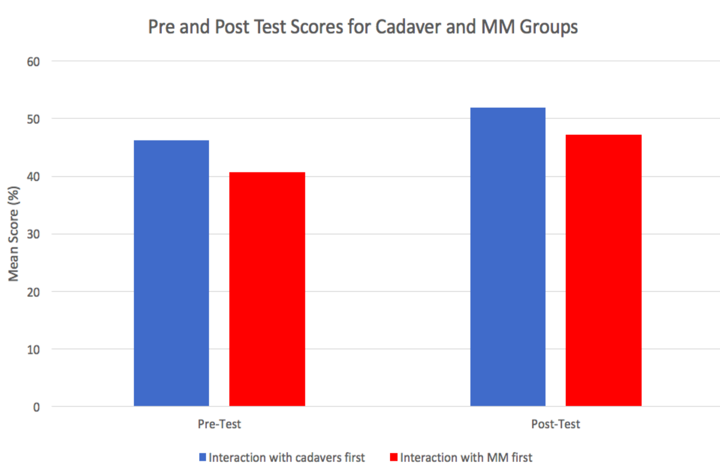


Fig. 4-3. Average scores on the pre-test and post-test for groups that interacted with the MM (n=9) and cadavers (n=13)

4.2.2 Discussion

While the data obtained suggested that there was no significant difference between the MM and cadavers, it is also not reasonable to believe that the MM is equal to cadavers as an anatomy teaching tool. The data collected in this pilot study seems to indicate that both the MM and cadavers are not effective for the purpose of short-term learning of anatomy structures. It was assumed this is not true due to the idea that cadavers are the most effective tools for teaching anatomy. With a larger sample size, it is assumed that cadavers would have outperformed the MM in its current state. This is due to the amount of details that can be provided through cadavers as well as technical problems associated with the MM (software crashes, issues with camera tracking fine motor movements, no labels or tools to help with learning in the program).

Even though significant results were not obtained from this pilot study, it gave important information regarding study design and influenced future changes to the following large-scale study involving the MM. In terms of study design, the focus would remain on how the participant's anatomy knowledge would be assessed, the amount of time and content that should be covered during each session, and time management during sessions to efficiently transition between group sessions. In terms of knowledge assessment, we decided to continue focusing on short-term knowledge retention of anatomical structures. While there have been fewer studies assessing long-term learning, we feared that attrition rates would be high in a long-term study spanning one or two academic semesters. We wanted to focus on a larger sample size and improving awareness of the MM technology among health science and nursing students at the University of Ottawa. We also wanted to streamline each session so that the amount of time spent with the quizzes and the content taught during the lessons were equal to one another. By doing this, we were hoping to minimize confounding variables that could influence the results of the pre-test and post-test.

4.2.3 Limitations

There were multiple issues regarding the study design in this pilot study that likely affected the results and data collected. The first problem occurred due to difficulties scheduling the cadaver lab sessions for these tests. Since the cadaver lab is normally used by the medical school throughout the day, it could only be booked in the evening and only on specific days. This limited the number of participants that could be recruited as well, since sessions would need to line up with their schedules. Finally, the cadaver lab is located within the University of Ottawa's medical school, which is at The Ottawa General Hospital campus as opposed to the University of Ottawa's main campus. These difficulties likely led to fewer students signing up and participating in the study

The next limitation for this study was that the MM evaluation was added on as a last minute idea, thus the main reason for students to participate in this study was being able to see cadavers, while the MM was just a novel technology that they were able to interact with. The anatomy models in the MM also did not have the same level of detail compared to cadavers. The differences between the quality and quantity of information the teaching methods were able to provide led to cadaver sessions being much longer and providing much more information compared to the lessons taught using the MM. This potentially led to cognitive fatigue for the group who interacted with cadavers first and affected their results on the post-test. The last limitation for this pilot study was the sample size. Only n=22 participants completed this study, many of them being years removed from taking a pure anatomy and physiology course. A larger sample would have also given us more information on scheduling within the sessions to balance the amount of time participants interacted with each of the teaching methods. The recruitment of participants was a priority when deciding on the methodology for following studies. Hence, this pilot study provided valuable information that would be taken into consideration for the following large-scale study.

4.3 Fall 2018/Winter 2019 large-scale study on the cardiovascular system

4.3.1 Results

Table 4-2 shows the structures that were included in the pre-test and post-test for the large-scale user study. Two questions were repeated on the pre-test and the post-test alongside six new questions on each test. The repeated questions were also reordered. These steps were taken to prevent participants from trying to memorize the questions on the pre-test. All diagrams shown to the participants were taken from Atlas textbooks

Table 4-2. Structures asked about during the large-scale user study

Pre-test	**Both**	**Post-test**
Axillary artery	Common carotid artery	Femoral vein
External jugular vein	Deep palmar arch	Brachiocephalic trunk
Grand saphenous vein		Basilica vein
Superior vena cava		Anterior tibial artery
Aortic arch		Femoral artery
Subclavian artery		Cephalic vein

Statistical analysis was once again done through t-tests. We believe that our sample meets the assumptions required to perform the t-test. The sample is relatively large and should be representative to the total population (university level health science and nursing students), the data is normally distributed around the mean, and there is homogeneity of variance between the variables being compared. This form of statistical analysis was chosen over z-tests since we were not comparing the variables to the total population. It was also chosen over ANOVA due to each comparison consisting of only two variables. The average scores of the pre-test were compared to the average scores of the post-test using paired T-tests. This was done for both the experimental group (n=106) that interacted with the MM, as well as the control group (n=107) that interacted with the Atlas textbooks. These tests were done in order to see if a significant change in the participants' anatomical knowledge occurred after interacting with either the MM or textbooks. Two different t-test hypotheses were formed regarding the comparison from the results of the pre-test to the results of the post-test: $H_{0,}$ there was no significant improvement in the results of the post-test compared to the pre-test and H_A, there was a significant improvement in the results of the post-test compared to the pre-test. Due to the fact that only two structures were repeated on the pre-test and post-test, individual questions/ structures were not directly compared between the pre-test and the post-test. In theory, these questions would likely follow the same general trend seen with the average scores on the pre-test and post-test. An independent T-test was also done comparing the average change in scores from the pre-test to the post-test for the experimental group and the control group. Two hypotheses were once again formed for the independent t-test: H_0, there is no significant difference between the MM and Atlas textbooks as short-term learning tools for cardiovascular anatomy and H_A, there is a significant difference between the MM and Atlas textbooks as short-term learning tools for cardiovascular anatomy.

This test was done to compare the effectiveness of the two teaching methods. It would also show if the two teaching methods were comparable as tools for anatomy education or if there is a significant difference between them. All statistical analysis was completed using IBM SPSS Statistics software.

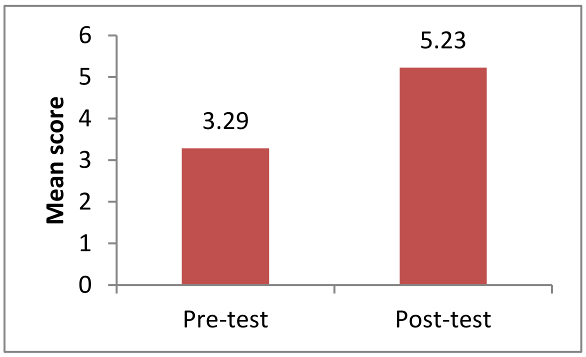


Fig. 4-4. Mean scores (out of 8) of experimental group that interacted with the MM (n=106)

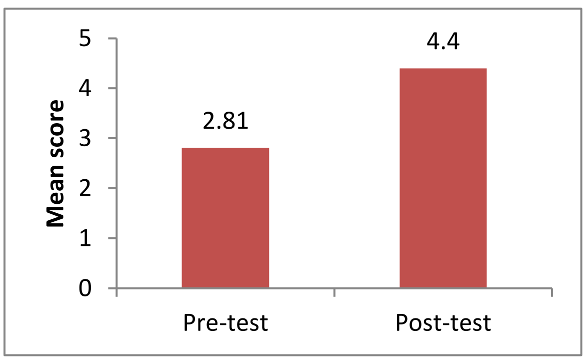


Fig. 4-5. Mean scores (out of 8) of the control group that interacted with Atlas textbooks (n=107)

Figure 4-4 shows the mean scores of the experimental group on the pre-test and the post-test, while Figure 4-5 shows the mean scores of the control group on the pre-test and post-test. The experimental group showed a mean score increase from 3.29 (s.d. = 1.95) to 5.23 (s.d. = 2.17) (+1.94). A paired T-test was done, giving a p value less than 0.001. This indicated that there was a significant improvement to the participants' anatomical knowledge. We believe this supports the idea that the MM can be an effective tool for the short-term learning of anatomical structures of the cardiovascular system. The control group also saw a mean score increase from 2.81 (s.d. = 1.86) on the pre-test to 4.40 (s.d. = 2.10) on the post-test (+1.59). After completing a paired T-test comparing these scores, a p value less than 0.001was once again obtained, indicating that there was also a significant improvement of the mean scores of the control group. Therefore, it can be concluded that Atlas textbooks are effective tools for anatomy education, as expected, considering textbooks are one of the most common tools used for anatomy education. The final statistical analysis was a comparison between the change in the mean scores from the pre-test to the post-test for the experimental group and the control group. An independent T-test was completed to compare the scores and see if there was a significant difference between the two teaching methods. From the analysis, a p value of 0.229 was obtained. Therefore, it can be concluded that there is no significant difference in the changes to the mean scores and there is no significant difference in the effectiveness of the two teaching methods for the short – term learning of anatomical structures in the cardiovascular system. It can also be interpreted that the MM and Atlas textbooks have comparable effectiveness as learning tools for the short-term memorization of anatomical structures.

4.3.2 Discussion

This large-scale study shows the potential of the MM as an anatomy teaching tool. When it comes to short – term learning, it appears that the MM has comparable effectiveness to Atlas textbooks. The MM displaying fully labelled structures to students in a 3D environment gives them a better idea of where different anatomical structures are in relation to one another compared to a 2D image. Learning with the MM also seems to be more appealing to students compared to textbooks. By having students take a more active role in the learning process, they will have more motivation to learn, resulting in a more engaging, prolonged learning experience. This large-scale study only looked at short-term learning of anatomical structures in the cardiovascular system. It would be interesting to see if similar results would be obtained if the MM was compared to textbooks over the course of an entire semester or if the user study focused on a variety of organ systems simultaneously. Unfortunately, the focus of the MM is solely on anatomy, while university students will usually need to learn both anatomy and physiology simultaneously. Therefore, just like learning through cadaver dissections, separate reference materials are required to learn physiology alongside the MM. A potential follow – up user study looking at long-term learning using the MM in conjunction with Atlas textbooks compared to just Atlas textbooks would be interesting to test if the MM provides any additional benefits to students learning anatomy.

The change to the Unity engine allowed us to implement motion tracking labels to the MM, which greatly enhanced the functionality of the MM as an anatomy teaching tool. The previous prototype of the MM had issues tracking movement of the labels in a 3D environment, resulting in inaccurate labelling of structures. The next step in the process is to add these labels for the remaining organ system models. After that, development can focus on more quality of life features such as greater control of the camera, including zooming into different areas and making the system usable by a single user.

In its current state, the MM is more suited as a supplemental tool for anatomy learning. Two users are currently required: one to stand in front of the sensor and display the models and another to operate the views on the display including the structures that are currently displayed. In past iterations of the MM, additional features were available that were taken out such as motion controls. When continuing to develop the MM, it would be prudent to revisit these features in the future to assess if they have become necessary inclusions for the MM. For motion controls specifically, they would provide a method for the MM to be used independently by a single user.

4.3.3 Limitations

While there were numerous improvements made to the MM between the pilot study and the large-scale user study, there were some problems that arose during the large-scale study. The first had to do with the delivery of the lesson. While the experimental group had a technician to run them through the different structures in the cardiovascular system and point out their location, the control group had to learn entirely on their own. Although both groups of participants were aware they could ask questions, very few members of the control (textbook) group asked for clarification about cardiovascular anatomy. Even though the MM was developed in a way to make it as intuitive as possible, students interacting with the technology for the first time would likely have some issues trying to operate it without the help of a technician. To try and alleviate this problem, a small tutorial could be implemented that would appear when the program starts.

It is also possible, though unlikely that the technicians operating the MM were unintentionally giving hints regarding the contents of the post-test. Both technicians that assisted with the study helped to design the pre-test and post-test questions that would be asked during the sessions. When training them on how to operate the MM, what to say during the lessons, and what to show the participants, they were told not to answer questions regarding the contents of the post-test. Regardless, it is possible that they have said something or focused on specific structures during the lesson that was covered on the post-test. In future studies, having a separate group design the assessment tools would eliminate this potential confounding variable.

Another issue has to do with current capabilities of the MM. Although the technology was revamped to include real-time tracking anatomical labels, not all features of the previous version have been imported from the previous iteration of the MM. Most notably, many models for organ systems that were present before are excluded. Before planning future studies, the remaining organ systems should be added into the program and fully labelled. While there are more quality of life features that can be added such as enhanced camera controls, adding the remaining organ systems are a high priority.

The hardware used by the MM can also be improved. While the Kinect sensor is relatively cheap, it is not the most powerful sensor and it is also no longer in development. Even though ideally the MM should be an affordable resource, it can be more effective as a learning tool if the user is also able to track fine movements of their hands or legs. While some tests with the MM have been done with the Microsoft HoloLens, Microsoft, the creators of the Kinect has also announced a revamped, more powerful Kinect sensor [105] that can potentially replace the existing sensor.

The last limitation would be the amount of times data was collected on a single participant. While the MM has shown to be effective for short-term learning, before this technology can be considered for use in classrooms at the University of Ottawa, it will have to show that it is also effective as a long-term tool for anatomy learning. This could be done in a future study that works with a smaller sample over the course of an entire semester. This study would assess the long-term benefits of learning with the MM while providing a better idea of the capabilities of the MM.

4.4 Student surveys

4.4.1 Results

The results of the survey are shown based on the frequency of each response for the corresponding statement. The only data that will be omitted is the "*Final grade I gave the Magic Mirror*" due to the low response rate by participants (less than twenty percent of participants answered). Table 4-2 shows the frequency of responses for each of the statements asked on the survey.

Table 4-3. Frequency of response to survey questions by participants who interacted with the MM (n=105)

The Magic Mirror…	Frequency of response				
	I strongly disagree/1	I disagree/2	No opinion/3	I agree/4	I strongly agree/5
(1) Increases motivation to learn anatomy	0	2	11	39	53
(2) Stimulates active learning	0	2	1	36	66
(3) Helps with 3D learning	0	0	6	26	73
(4) Offers benefits compared to textbooks	0	1	11	29	64
(5) Is a more interesting introduction to anatomy	0	2	6	27	70
(6) I think the exercise complements textbooks	9	2	1	20	73

A majority of the participants agreed with each of the survey statements with at least n=92 participants (87.6% of responses) agreeing or strongly agreeing with each of the statements. We postulate that most participants believe in the potential of the MM as another tool that can be used to help learn human anatomy. The only statement that had participants who strongly disagreed was statement six: *I think the exercise complements textbooks*. While it is plausible that some of them believed the MM would not work well alongside textbook learning, it is also possible that the placement of this statement and the Final grade statement directly above it confused participants. The sixth statement has the same order for the Likert scale as the whole survey (Strong disagreement to strong agreement goes from left to right), but the Final grade statement goes in the opposite order (the leftmost response meaning participants would grade the MM highly). Therefore, while some participants may believe that the MM does not complement learning with a textbook, we believe there is a higher frequency of participants who strongly disagree with that statement because they believed that the statement followed the same order as the grade lettering directly above it. If similar data is to be collected as a part of future user studies, the survey will need to be redesigned to make it as clear as possible and avoid this possible confusion.

As a part of the survey, participants were also able to leave feedback and suggestions they may have about the MM. Sixty-seven out of the n=105 participants (63.8%) who completed the survey left some sort of comment about the MM. A common comment left by participants is that they found the MM visually appealing and liked that it allowed them to take a more active role in learning. They also believe that it helped with visualizing the different arteries and veins, showing where these structures are in relation to one another. The final comment that was seen more frequently was that the MM was a more motivating tool compared to textbooks with the participants believing that more frequent or longer interactions with the MM will be highly beneficial for learning human anatomy.

Regarding suggestions left by participants, a common one was for the user to have greater camera control over the view of the MM. Allowing users to zoom in and rotate around different areas of the body would allow them to see structures more clearly, see areas where different structures intersect, and see if there are different structures that would not normally be visible from a single view. Another suggestion was to give the users more fluid control over the camera movements. This would tie into the previous suggestion but would also limit a common side effect that some people experience with AR/VR experiences: motion sickness. The next suggestion was to add models for the remaining organ systems that are currently not available in the MM. At the time of the user study, the only organ system that was fully labelled and implemented into the MM was the cardiovascular system. One of the goals for the MM's development is to add all major organ systems to the software fully labelled in both English and French. While the development of the software was rushed to have a demo completed in time for the large-scale study, remaining organ systems are currently being added.

The final suggestion made by participants was to better optimize the technology. This would include more accurate movement tracking as well as minimizing input delay on the display screen. Unfortunately, these specific changes would only be able to occur if there were changes in the hardware used to run the MM. Movement tracking of the user comes from the sensor. Currently, the MM uses a Kinect sensor, which is not able to track fine movements that occur in the extremities. An upgraded sensor may be able to more accurately track movement, but it would likely be more expensive. On the other hand, to have the MM running more fluidly, an upgrade to the computer is required, more specifically to the CPU and graphics card. Figure

4-6 displays some of the common phrases, suggestions, and feedback made by the students who interacted with the MM in the user study. Overall, the MM seems to be well received by these students and it appears they believe it can be one day used as an effective learning tool.

Fig. 4-6. Word cloud of common terms and feedback left by users who interacted with the MM as a part of the Fall 2018/Winter 2019 large-scale study

4.4.2 Discussion

Participants who interacted with the MM as a part of this study seem to think very highly of the technology. They believe it differentiates itself from textbooks while also appealing to students who prefer to take more active roles in learning. The technology will also be continually developed to try and fit suggestions made by participants. The remaining organ systems are among the higher priority, especially if future studies involving the MM will look at other organ systems or structures. The general positivity and feedback received by participants reinforces the idea that with continued development, the MM can one day be used alongside Atlas textbooks and cadavers as tools for anatomy education at the University of Ottawa.

4.5 Interviews with anatomy professors

4.5.1 Results

Appendix B contains full interview transcripts for participants interviewed.

The anatomy professors that were interviewed all focus on teaching in a similar style. They deliver the content in a lecture format, while getting most of the information they teach from an anatomy textbook, which they use as reference material. In addition, they include additional resources as a part of their lectures to keep students engaged. This includes videos, 3D animations, online quizzes, and lessons involving previously dissected cadavers. One of the professors that teach both Anglophone and Francophone classes includes additional podcasts and YouTube videos for their French speaking students.

Outside of the classroom, most of the professors will also offer additional resources to students to try and help them learn. This includes other videos, podcasts and quizzes. A program that is mentioned by half of the professors is the Visible Body program, which is VR software that allows students to interact with models on a computer. This program is licensed by the University of Ottawa for the purpose of student use. While the professors believe that students utilize these resources, one professor believes that "*Previous data suggests students lean heavily on professor-made course-specific tools (PPT slides, online quizzes, podcasts) especially near exams, and don't rely extensively on commercial resources with generalized content*." Another professor shares similar views in regard to the Visible Body application, stating "*No survey has been done on this subject. I think that, for course ANP 1506 (Anatomy and Physiology II, French – MSK and Nervous systems), the majority of students will consult it at least once because it is strongly suggested at the beginning of the session, but I doubt it will be very popular* *afterwards*." It seems that while students have numerous resources available to help them study, their preference remains with PowerPoint slides or notes that were taken during lectures. Outside of this program, no other resources were specifically named.

Table 4-4. Participant responses regarding awareness of alternative teaching tools not offered at the University of Ottawa

Professor	**Faculty**	**Response**
1	Medicine	Some schools use the Anatomage Table resource where clinical imaging is integrated with VR anatomy in 3D. Further, some medical schools formally incorporate POCUS (ultrasound) and 3D printed resources in their curricula where we are in the initial stages of bringing these technologies to our labs
2	Health Sciences	There is a lot of material on the web that students can consult
3	Health Sciences	Other Videos such as Khan Academics and Osmosis Videos
4	Medicine	Yes, http://neuroanatomy.ca/ is a very good resource for BC University
5	Medicine	No
6	Health Sciences	Yes, there are other applications similar to Visible Body. The choice of this application for the University was made because it is bilingual (anatomy) and contains sections on physiology

When speaking about other resources that the University of Ottawa did not offer students, the professors differentiated more based on the content they taught. The full answers by participants for this question are displayed in Table 4-3. A professor who focuses more on neuroanatomy spoke about http://neuroanatomy.ca/, a resource website that is available to students who attend the University of British Columbia. This professor who is a part of the Faculty of Medicine and involved with the University of Ottawa's medical school program also spoke about POCUS (ultrasound) and 3D printed models, which are used for training medical students. This person also mentioned the Anatomage Table, which utilizes VR software to allow users to mimic dissections in a virtual space. General online resources Khan Academy and Osmosis.org were also mentioned as tools that are not readily available to students at the University of Ottawa. The remaining three participants did not name specific resources, only mentioning "*material on the web…*" or "*other applications similar to Visible Body…"* One participant was not aware of any resources that students from the University did not have access to.

In terms of difficult content, almost all the professors interviewed spoke about different areas of anatomy. There was mention of neuroanatomy, embryology, MSK, and pelvic anatomy. This is likely due to the professors specializing in teaching specific aspects of anatomy, while having little crossover between content covered. A common theme that was mentioned by a few of the participants was physiology and the increased workload that comes with learning about different functions in the human body. Courses taught by these professors not only cover the names and locations of different structures in the human anatomy, but also their role in the body and complications that can occur if something goes wrong with them. With a greater amount of content to learn in a short amount of time, anatomy and physiology courses can be difficult for students. Despite this, one participant believes that "*Most students do well in anatomy and, in terms of assessment, perform well, as well or better than most of the other practical disciplines.*"

All of the participants were aware of what the MM was, but had not utilized AR or VR extensively in their lectures. Some of the participants were aware of previous user studies that were completed that compared the MM to cadavers or textbooks as anatomy teaching tools. Those same professors believe that there is potential for the MM as a teaching tool. While most of the professors seem open to one day include the MM as a part of their courses, most require specific features or capabilities from the technology. They believe that the MM in its current state is lacking, with time constraints also preventing it from being used in the classroom. Some of the professors believe it would be better suited for specific systems such as MSK or for independent studying outside of the classroom (individually or in a group).

4.5.2 Discussion

An idea that is reinforced through the interviews is that standard methods of teaching are continually used and applied by professors because they have proven to be effective for student learning.

While the professors were not able to name many teaching methods that utilized AR or VR technology specifically, they seemed interested about looking more in depth at the MM in the future. Only one professor was able to specifically identify a new software or technology outside of the Visible Body App that could be used for medical education. Unfortunately, it appears that the professors interviewed are unaware of the use of newer technologies (such as AR or VR) that have been introduced to try and help students learn human anatomy. Based off how they have responded to the MM, we believe that professors would be interested in hearing about new innovations to technology. Since some of these professors have also helped recruit participants for some studies regarding the MM, we believe they have an open mindset to trying new, alternative teaching tools in the classroom. The professors were able to offer numerous suggestions on improvements or features they would like to see implemented into the MM in the future. Figure 4-7 shows the most common terms and recommendations made by the interviewees. This feedback is encouraging, and we hope that educators will continue to be open to trying innovative teaching tools in classroom settings.

Fig. 4-7. Word cloud of common suggestions made by anatomy professors for Question 9

The most common suggestions for improvements to the MM were in regard to the camera controls and the view displayed on the monitor. The ability to zoom in more on regions of interest and the quality of the models displayed were suggestions made to make it easier for students to understand. Another suggestion was to make labels for the organ systems bilingual, allowing both Anglophones and Francophones to use the MM. Adding the remaining major organ systems that are covered as a part of Anatomy and Physiology courses was another suggestion for the MM. The final suggestions were to allow users to operate the MM independently and to implement a quiz function to allow students to test what they learned. Most of these ideas are mostly straightforward and will likely be added to the MM with time.

Adding other major organ systems and creating labels for major structures in both English and French are basic features that are needed for anatomy learning tools at the University of Ottawa. The same could be said for camera controls. These features could continue to be tweaked and altered to fit the needs of users which will enable users to operate the MM as they see fit. The more difficult suggestions come in the form of independent learning and a quiz function. Adjusting the MM to allow for a single user likely means the reimplementation of motion controls from a previous initial build of the MM. The reason this feature was removed was due to difficulties controlling and maintaining the system in a static state. Users not knowing how to properly use the MM as well as sensitive controls, made the system difficult to use, especially if multiple people stood in front of the sensor simultaneously. Quizzes alone are not incredibly difficult to add, but adjusting the difficulty of questions for personalised questions would likely require the use of AI. It would require multiple sets of questions that would alter based on the responses made by the user. While there is currently no set timeframe for the development of specific features, priorities may change if specific organ systems or features are required for future user studies involving the MM.

We hypothesize this also shows the general learning pattern for university students, who seem to prefer or default towards mostly learning through classroom lectures and slides even if there are other options available. We believe the reasoning behind this comes down to accessibility and convenience. These resources are readily available and they can go through content at their own pace. These things must be taken into consideration when developing the MM. Even if it is a state – of – the – art technology, if it is not easy to use and readily accessible, students are not likely to utilize it as a learning tool. The professors interviewed offered a different perspective on medical education and their expectations of our novel medical education tool.

5 Conclusion

5.1 Conclusion

This thesis looked at the development and early testing of a mixed reality technology called the Magic Mirror. The technology is intended for use as a supplemental tool for anatomy education alongside current standard teaching methods such as cadaver dissections, didactic lectures and textbook learning. Initially inspired by similar technologies with the same name developed at the Technical University of Munich [17, 97], the first build of the MM was developed in Microsoft Virtual Studios 2017 before being remade using the Unity Engine. The program uses a RGBD sensor (currently the Microsoft Kinect) to overlay anatomical models onto the user while also tracking their movements in a real-time, 3D environment. This is displayed on half of a computer display, with the other half shows a fully labelled, virtual view of different organ systems. The virtual view can be controlled using a keyboard and mouse, allowing the user to focus on different areas of the body or specific anatomical structures. Development of the MM is still ongoing, with the MM possibly seeing use alongside head mounted displays such as the Microsoft HoloLens.

To better understand the needs of anatomy professors and students who are registered in anatomy and physiology courses at the University of Ottawa, interviews and surveys were conducted with each group respectively. Six anatomy professors were interviewed about the current state of the MM as well as their knowledge about different supplemental tools that are currently offered to students to help them learn human anatomy. Information obtained from these interviews includes: different resources offered to students enrolled in anatomy and physiology courses at the University of Ottawa (such as the mentoring centre as well as the Visible Body application), knowledge about alternative anatomy teaching tools, and different improvements the professors would like to see for the MM. A common suggestion from the anatomy professors for the MM would be a free roaming camera that allows the user to look at the model from an angle of their choice. Another emphasis was the ability to operate the system individually, allowing for either individual or group learning. One hundred and five students completed surveys about what they thought of the MM in comparison to textbooks and their preferences in learning. This not only gave an idea about what each group thought of the technology, but also their expectations for this kind of novel technology for future use. From a development standpoint, it gives an idea of what should be focused on or what aspects users might focus on. An example would be greater ability to alter the field of view while still allowing the user to manually manipulate the anatomy models shown in the MM. By incorporating surveys into future user studies, we will continue to gauge the thoughts of the potential user base on the MM as a tool for learning anatomy. We will likely continue to work with anatomy professors and other professionals to improve the MM, providing us with valuable information about what direction to take the development of the MM.

A key idea that should be taken into consideration in the development of similar novel technology is looking at how the technology impacts both professors and students. By having students and professors influence how these technologies are developed, it can be better adjusted for the changing landscape of classrooms while appealing to these new students. By providing students more learning options, they can choose a learning tool that fits their preferred learning style, putting these students in a better position to succeed. On the other hand, professors can provide insight on their own classrooms and how new teaching tools can impact how they teach their courses. New teaching methods and technology have the potential to reshape how future students learn human anatomy.

In a 213 participant user study carried out at the University of Ottawa, students enrolled in the course: Anatomy and Physiology I (French section), interacted with either the MM, going through different structures in the cardiovascular system, or learned the anatomical structures of the cardiovascular system individually using a textbook. After interacting with one of these teaching tools for a fifteen – minute session, both groups performed at a similar level, identifying blood vessels among the structures they had just covered. As a learning tool for the short-term memory retention of anatomical structures in the cardiovascular system, the MM has shown comparable results to textbook learning. With continued development, it is possible the MM may one day see use as a supplemental anatomy teaching tool used alongside cadavers and Atlas textbooks.

While current standards for teaching anatomy are still effective, novel technologies can enhance student learning experiences. The MM offers users with an engaging learning experience that takes some of the positives offered by both cadavers and textbooks. It will continue to be developed, considering feedback received from both anatomy professors and university students, so that it may one day see use as a part of the curriculum of anatomy and physiology courses at the University of Ottawa.

5.2 Future works

The research presented in this thesis shows the initial evaluations of the MM technology as a tool for anatomy education. Upon completion, the MM has the potential to provide students with a unique experience they would not have through traditional teaching tools. By taking some of the benefits offered by both cadaver dissections and textbook learning, students would be able to actively learn human anatomy while still having the same level of detail that would be provided in an anatomy textbook. The MM is a cost-effective, easy to learn resource that can be currently used for learning in small groups, but eventually, with the addition of motion controls, may see use by individual users.

With the results of initial studies comparing the MM to Atlas textbooks for short-term memory retention of anatomical structures, new research opportunities are present to test the capabilities of the MM under other circumstances. Previous studies have shown that technology like the MM improves learning performance in similar ways to other established teaching tools such as anatomy textbooks or novel teaching tools such as the Anatomage Table [97]. At the same time, the MM has shown to improve students' motivation to learn [17], which has been correlated with increased understanding and knowledge retention [95, 96]. Follow-up studies involving the MM can look at some of the following scenarios:

- In depth comparisons between the MM and cadaver dissections for short-term/long-term learning of human anatomy
- Effects on student learning of human anatomy if students are routinely exposed to the MM over the course of a university semester or longer
- Looking to see how the MM compares to cadavers or textbooks for teaching specific concepts or organ systems
- Looking at the effectiveness of the MM for learning in different group sizes (individually, small groups, class size etc.)
- Potential benefits of introducing the technology to younger students (such as high school students) and looking to see if it benefits them later

The ability to carry out some of these potential study designs depends on the continued development of the MM to include the remaining organ systems such as the skeletal and muscular system as well as the ability to operate the MM independently. After the MM is ready for commercial use, studies can continue, looking at how the MM compares to similar novel technologies such as the Anatomage Table.

Initial stages of development and testing have been promising regarding the use of the MM as a supplemental tool for learning human anatomy. Similar to other novel technologies that have been developed for similar purposes, familiarizing the potential user base of the MM is going to be just as important as creating a polished teaching tool. By accomplishing these things, the MM could see use at the University of Ottawa as another tool for anatomy learning.

References

[1] Codd, A. M., & Choudhury, B. (2011). Virtual Reality Anatomy: Is It Comparable with Traditional Methods in the Teaching of Human Forearm Musculoskeletal Anatomy? *Anatomical Sciences Education*, *4*(3), 119–125. https://doi.org/10.1002/ase.214

[2] Fang, T.-Y., Wang, P.-C., Liu, C.-H., Su, M.-C., & Yeh, S.-C. (2014). Evaluation of a haptics-based virtual reality temporal bone simulator for anatomy and surgery training. *Computer Methods and Programs in Biomedicine*, *113*(2), 674–681. https://doi.org/10.1016/j.cmpb.2013.11.005

[3] Baratz, G., Wilson-Delfosse, A., Singelyn, B., Allan, K., Rieth, G., Ratnaparkhi, R., Wish-Baratz, S. (2019). Evaluating the Anatomage Table Compared to Cadaveric Dissection as a Learning Modality for Gross Anatomy. *Medical Science Educator*, *29*(2), 499–506. https://doi.org/10.1007/s40670-019-00719-z

[4] Vafeas, M. (2013). Attitudes Toward, and Use of, Textbooks Among Marketing Undergraduates: An Exploratory Study. *Journal of Marketing Education*, *35*(3), 245–258. https://doi.org/10.1177/0273475313482927

[5] Dipaola, M., & Franko, O. (2013). Apps that integrate touch-screens provide interactive learning for anatomy, radiology. *Orthopedics Today*, *33*(3), 22.

[6] Hanna, M. G., Ahmed, I., Nine, J., Prajapati, S., & Pantanowitz, L. (2018). Augmented Reality Technology Using Microsoft HoloLens in Anatomic Pathology. *Archives of Pathology & Laboratory Medicine*, *142*(5), 638–644. https://doi.org/10.5858/arpa.2017-0189-OA

[7] Küçük, S., Kapakin, S., & Göktas, Y. (2016). Learning Anatomy via Mobile Augmented Reality: Effects on Achievement and Cognitive Load. *Anatomical Sciences Education*, *9*(5), 411–421. https://doi.org/10.1002/ase.1603

[8] Moro, C., Štromberga, Z., Raikos, A., & Stirling, A. (2017). The effectiveness of virtual and augmented reality in health sciences and medical anatomy. *Anatomical Sciences Education*, *10*(6), 549–559. https://doi.org/10.1002/ase.1696

[9] Houle, C. O. (1980). *Continuing learning in the professions*. San Francisco: Jossey-Bass.

[10] Manolis, C., Burns, D. J., Assudani, R., & Chinta, R. (2013). Assessing experiential learning styles: A methodological reconstruction and validation of the Kolb Learning Style Inventory. *Learning and Individual Differences*, *23*(C), 44–52. https://doi.org/10.1016/j.lindif.2012.10.009

[11] Kolb, A. Y., & Kolb, D. A. (2006). Learning styles and learning spaces: A review of the multidisciplinary application of experiential learning theory in higher education. *Learning Styles and Learning: A Key to Meeting the Accountability Demands in Education*, 45–91.

[12] Kolb, D. A. (1984). Experiential learning: Experience as the source of learning and development. Englewood Cliffs, NJ: Prentice-Hall

[13] Kolb, A., & Kolb, D. (2018). Eight important things to know about the experiential learning cycle. *Australian Educational Leader*, *40*(3), 8–14.

[14] Mohammad-Hassan Behzadi, & Maryam Manuchehri. (2013). Examining Creativity of Students through Smart Board in Learning Mathematics. *Mathematics Education Trends and Research*, *2013*, 1–7. https://doi.org/10.5899/2013/metr-00008

[15] Case Western Reserve University. CWRU takes the stage at Microsoft's Build conference to show how HoloLens can transform learning. In: *Research News*. http://case.edu/hololens/. Accessed May 14, 2019.

[16] Nagel, D. (2017). Gauging enthusiasm for augmented & virtual reality in education.(EDTECHInsider). *T H E Journal (Technological Horizons In Education)*, *44*(3), 34.

[17] Kugelmann, D., Stratmann, L., Nühlen, N., Bork, F., Hoffmann, S., Samarbarksh, G., … Waschke, J. (2018). An Augmented Reality magic mirror as additive teaching device for gross anatomy. *Annals of Anatomy*, *215*, 71–77. https://doi.org/10.1016/j.aanat.2017.09.011

[18] Hussein, I., Dany, M., Forbes, W., Barremkala, M., Thompson, B., & Jurjus, A. (2015). Perceptions of human cadaver dissection by medical students: a highly valued experience. *Italian Journal of Anatomy and Embryology*, *120*(3), 162–171. https://doi.org/10.13128/IJAE-17811

[19] Dempster, M., Black, A., Mccorry, N., & Wilson, D. (2006). Appraisal and Consequences of Cadaver Dissection. *Medical Education Online*, *11*(1), 4592. https://doi.org/10.3402/meo.v11i.4592

[20] Hancock, D., Williams, M., Taylor, A., & Dawson, B. (2004). Impact of Cadaver Dissection on Medical Students. *New Zealand Journal of Psychology*, *33*(1), 17–25.

[21] Houwink, A. P., Kurup, A. N., Kollars, J. P., Kral Kollars, C. A., Carmichael, S. W., & Pawlina, W. (2004). Help of third-year medical students decreases first-year medical students' negative psychological reactions on the first day of gross anatomy dissection. *Clinical Anatomy*, *17*(4), 328–333. https://doi.org/10.1002/ca.10218

[22] Habicht, L., Kiessling, L., & Winkelmann, L. (2018). Bodies for Anatomy Education in Medical Schools: An Overview of the Sources of Cadavers Worldwide. *Academic Medicine*, *93*(9), 1293–1300. https://doi.org/10.1097/ACM.0000000000002227

[23] Chen, D., Zhang, Q., Deng, J., Cai, Y., Huang, J., Li, F., & Xiong, K. (2018). A shortage of cadavers: The predicament of regional anatomy education in mainland China. *Anatomical Sciences Education*, *11*(4), 397–402. https://doi.org/10.1002/ase.1788

[24] Yammine, K., & Violato, C. (2015). A meta-analysis of the educational effectiveness of three-dimensional visualization technologies in teaching anatomy. *Anatomical Sciences Education*, *8*(6), 525–538. https://doi.org/10.1002/ase.1510

[25] Murgitroyd, E., Madurska, M., Gonzalez, J., & Watson, A. (2015). 3D digital anatomy modelling - Practical or pretty? *The Surgeon : Journal of the Royal Colleges of Surgeons of Edinburgh and Ireland*, *13*(3), 177–180. https://doi.org/10.1016/j.surge.2014.10.007

[26] Zorzal, E. R., Sousa, M., Mendes, D., Dos Anjos, R. K., Medeiros, D., Paulo, S. F., Rodrigues, P., Mendes, J. J., Delmas, V., Uhl, J.-F., Mogorrón, J., Jorge, J. A., & Lopes, D. S. (2019). Anatomy Studio: A tool for virtual dissection through augmented 3D reconstruction. *Computers & Graphics*, *85*, 74–84. https://doi.org/10.1016/j.cag.2019.09.006

[27] Peterson, D. C., & Mlynarczyk, G. S. A. (2016). Analysis of traditional versus three-dimensional augmented curriculum on anatomical learning outcome measures. *Anatomical Sciences Education*, *9*(6), 529–536. https://doi.org/10.1002/ase.1612

[28] Pederson, K. (2012). Supporting students with varied spatial reasoning abilities in the anatomy classroom. *Teaching Innovation Projects*, *2*(1).

[29] Knecht, P., & Najvarova, V. (2010). *How do students rate textbooks? A review of research and ongoing challenges for textbook research and textbook production.(Report)*. *2*(1), 1–16. https://doi.org/10.3167/jemms.2010.020101

[30] Gaitsgory, O., Burgess, A., & Mellis, C. (2013). Opinion piece: “Medical students – learning from textbooks or electronic media?” *Journal of Paediatrics and Child Health*, *49*(9), E370–E372. https://doi.org/10.1111/jpc.12180

[31] Vasan, N. S., Defouw, D. O., & Compton, S. (2009). A survey of student perceptions of team-based learning in anatomy curriculum: Favorable views unrelated to grades. *Anatomical Sciences Education*, *2*(4), 150–155. https://doi.org/10.1002/ase.91

[32] Landrum, R. E., Gurung, R. A. R., & Spann, N. (2012). Assessments of Textbook Usage and the Relationship to Student Course Performance. *College Teaching*, *60*(1), 17–24. https://doi.org/10.1080/87567555.2011.609573

[33] Cho, J. S., Hahn, K. Y., Kwak, J. M., Kim, J., Baek, S. J., Shin, J. W., & Kim, S. H. (2013). Virtual reality training improves da Vinci performance: a prospective trial. *Journal of Laparoendoscopic & Advanced Surgical Techniques. Part A*, *23*(12), 992–998. https://doi.org/10.1089/lap.2012.0396

[34] Hopkins, R., Regehr, G., & Wilson, T. D. (2011). Exploring the Changing Learning Environment of the Gross Anatomy Lab. *Academic Medicine*, *86*(7), 883–888. https://doi.org/10.1097/ACM.0b013e31821de30f

[35] Khalil, M. K., Johnson, T. E., & Lamar, C. H. (2005). Comparison of computer-based and paper-based imagery strategies in learning anatomy. *Clinical Anatomy*, *18*(6), 457–464. https://doi.org/10.1002/ca.20158

[36] Mcnulty, J. A., Sonntag, B., & Sinacore, J. M. (2009). Evaluation of computer-aided instruction in a gross anatomy course: A six-year study. *Anatomical Sciences Education*, *2*(1), 2–8. https://doi.org/10.1002/ase.66

[37] Sugand, K., Abrahams, P., & Khurana, A. (2010). The anatomy of anatomy: a review for its modernization. *Anatomical Sciences Education*, *3*(2), 83–93. https://doi.org/10.1002/ase.139

[38] Favorito, L. A. (2017). Kidney anatomy: three dimensional (3D) printed pelvicalyceal system models of the collector system improve the diagnosis and treatment of stone disease.

International Braz J Urol : Official Journal of the Brazilian Society of Urology, *43*(3), 381–382. https://doi.org/10.1590/s1677-5538.ibju.2017.03.01

[39] Marroig, B., Favorito, L., Fortes, M., & Sampaio, F. (2015). Lower pole anatomy and mid-renal-zone classification applied to flexible ureteroscopy: experimental study using human three-dimensional endocasts. *Surgical and Radiologic Anatomy*, *37*(10), 1243–1249. https://doi.org/10.1007/s00276-015-1503-y

[40] Preece, D., Williams, S. B., Lam, R., & Weller, R. (2013). "Let's get physical": advantages of a physical model over 3D computer models and textbooks in learning imaging anatomy. *Anatomical Sciences Education*, *6*(4), 216–224. https://doi.org/10.1002/ase.1345

[41] Khot, Z., Quinlan, K., Norman, G. R., & Wainman, B. (2014). The Relative Effectiveness of Computer-Based and Traditional Resources for Education in Anatomy. *Anatomical Sciences Education*, *6*(4), 211–215. https://doi.org/10.1002/ase.1355

[42] Das, S., & Mitchell, P. (2013). Comparison of three aids for teaching lumbar surgical anatomy. *British Journal of Neurosurgery*, *27*(4), 475–478. https://doi.org/10.3109/02688697.2013.771723

[43] Pawlina, W., & Drake, R. L. (2013). Anatomical models: don't banish them from the anatomy laboratory yet. *Anatomical Sciences Education*, *6*(4), 209–210. https://doi.org/10.1002/ase.1380

[44] Deleeuw, K. E., & Mayer, R. E. (2008). A Comparison of Three Measures of Cognitive Load: Evidence for Separable Measures of Intrinsic, Extraneous, and Germane Load. *Journal of Educational Psychology*, *100*(1), 223–234. https://doi.org/10.1037/0022-0663.100.1.223

[45] Van Merriënboer, J. J. G., & Sweller, J. (2010). Cognitive load theory in health professional education: design principles and strategies. *Medical Education*, *44*(1), 85–93. https://doi.org/10.1111/j.1365-2923.2009.03498.x

[46] Lowe, R. K. (2003). Animation and learning: selective processing of information in dynamic graphics. *Learning and Instruction*, *13*(2), 157–176. https://doi.org/10.1016/S0959-4752(02)00018-X

[47] Hegarty, M., & Kozhevnikov, M. (1999). Types of Visual–Spatial Representations and Mathematical Problem Solving. *Journal of Educational Psychology*, *91*(4), 684–689. https://doi.org/10.1037/0022-0663.91.4.684

[48] Carroll, J. B. (1993). *Human cognitive abilities: a survey of factor-analytic studies*. Cambridge University Press.

[49] Mayer, R. E., & Sims, V. K. (1994). For Whom Is a Picture Worth a Thousand Words? Extensions of a Dual-Coding Theory of Multimedia Learning. *Journal of Educational Psychology*, *86*(3), 389–401. https://doi.org/10.1037/0022-0663.86.3.389

[50] Hegarty, M., & Sims, V. (1994). Individual differences in mental animation during mechanical reasoning. *Memory & Cognition*, *22*(4), 411–430. https://doi.org/10.3758/BF03200867

[51] Azer, S. A., & Azer, S. (2016). 3D Anatomy Models and Impact on Learning: A Review of the Quality of the Literature. *Health Professions Education*, *2*(2), 80–98. https://doi.org/10.1016/j.hpe.2016.05.002

[52] Johnson, E. O., Charchanti, A. V., & Troupis, T. G. (2012). Modernization of an anatomy class: From conceptualization to implementation. A case for integrated multimodal–

multidisciplinary teaching. *Anatomical Sciences Education*, *5*(6), 354–366. https://doi.org/10.1002/ase.1296

[53] Barry, D. S., Marzouk, F., Chulak - Oglu, K., Bennett, D., Tierney, P., & O'Keeffe, G. W. (2016). Anatomy Education for the YouTube Generation. *Anatomical Sciences Education*, *9*(1), 90–96. https://doi.org/10.1002/ase.1550

[54] Prensky M. (2004). *Digital Game-Based* Learning. 2nd Ed. New York. McGraw-Hill. 464 p.

[55] Selwyn, N. (2010). Looking beyond learning: notes towards the critical study of educational technology. *Journal of Computer Assisted Learning*, *26*(1), 65–73. https://doi.org/10.1111/j.1365-2729.2009.00338.x

[56] Tess, P. A. (2013). The role of social media in higher education classes (real and virtual) – A literature review. *Computers in Human Behavior*, *29*(5), A60–A68. https://doi.org/10.1016/j.chb.2012.12.032

[57] Brame, C. J. (2016). Effective Educational Videos: Principles and Guidelines for Maximizing Student Learning from Video Content. *CBE - Life Sciences Education*, *15*(4), 6. https://doi.org/10.1187/cbe.16-03-0125

[58] Tackett, S., Slinn, K., Marshall, T., Gaglani, S., Waldman, V., & Desai, R. (2018). Medical Education Videos for the World: An Analysis of Viewing Patterns for a YouTube Channel. *Academic Medicine*, *93*(8), 1150–1156. https://doi.org/10.1097/ACM.0000000000002118

[59] Ruiz, J. G., Mintzer, M. J., & Issenberg, S. B. (2006). Learning objects in medical education. *Medical Teacher*, *28*(7), 599–605.

[60] Dong, C., & Goh, P. S. (2015). Twelve tips for the effective use of videos in medical education. *Medical Teacher*, *37*(2), 140–145. https://doi.org/10.3109/0142159X.2014.943709

[61] Harris, H., & Park, S. (2008). Educational usages of podcasting. *British Journal of Educational Technology*, *39*(3), 548–551. https://doi.org/10.1111/j.1467-8535.2007.00788.x

[62] Mallin, M., Schlein, S., Doctor, S., Stroud, S., Dawson, M., & Fix, M. (2014). A Survey of the Current Utilization of Asynchronous Education Among Emergency Medicine Residents in the United States. *Academic Medicine*, *89*(4), 598–601. https://doi.org/10.1097/ACM.0000000000000170

[63] Narula, N., Ahmed, L., & Rudkowski, J. (2012). An evaluation of the "5 Minute Medicine" video podcast series compared to conventional medical resources for the internal medicine clerkship. *Medical Teacher*, *34*(11), e751–e755. https://doi.org/10.3109/0142159X.2012.689446

[64] Chin, A., Helman, A., & Chan, T. M. (2017). Podcast Use in Undergraduate Medical Education. *Cureus*, *9*(12), e1930–e1930. https://doi.org/10.7759/cureus.1930

[65] Fukuta Junaid, Schreiber Benjamin E, & Gordon Fabiana. (2010). Live lecture versus video podcast in undergraduate medical education: A randomised controlled trial. *BMC Medical Education*, *10*(1), 68. https://doi.org/10.1186/1472-6920-10-68

[66] Cingi, C. C. (2013). Computer Animation in Teaching Surgical Procedures. *Procedia - Social and Behavioral Sciences*, *103*(C), 230–237. https://doi.org/10.1016/j.sbspro.2013.10.330

[67] Ruiz, J. G., Cook, D. A., & Levinson, A. J. (2009). Computer animations in medical education: a critical literature review. *Medical Education*, *43*(9), 838–846. https://doi.org/10.1111/j.1365-2923.2009.03429.x

[68] Schifferdecker, K. E., Berman, N. B., Fall, L. H., & Fischer, M. R. (2012). Adoption of computer-assisted learning in medical education: the educators' perspective. *Medical Education*, *46*(11), 1063–1073. https://doi.org/10.1111/j.1365-2923.2012.04350.x

[69] Chen, B., & Denoyelles, A. (2013). Exploring students' mobile learing practices in higher education. *Educause Review*, *7*.

[70] Hwang, G.-J., & Wu, P.-H. (2014). Applications, impacts, and trends of mobile technology-enhanced learning: a review of 2008-2012 publications in slected SSCI journals. *International Journal of Mobile Learning and Organisation (UMLO)*, *8*(2), 83–95.

[71] Streepey, J. W., Eugenia Fernandez, & Timothy T. Diemer. (2013). Student Perceptions of Classroom Engagement and Learning using iPads. *Journal of Teaching and Learning with Technology*, *1*(2), 13–25.

[72] Chakraborty, T. R., & Cooperstein, D. F. (2018). Exploring anatomy and physiology using iPad applications. *Anatomical Sciences Education*, *11*(4), 336–345. https://doi.org/10.1002/ase.1747

[73] Visible Body Help Center (2020). Compare human anatomy atlas and muscle premium, https://support.visiblebody.com/hc/en-us/articles/115001011087-Compare-Human-Anatomy-Atlas-and-Muscle-Premium

[74] Roll, N. (2017, July 12). *VR and AR: More Than Just Cool?* Inside Higher ED. https://www.insidehighered.com/digital-learning/article/2017/07/12/vr-and-ar-more-just-cool

[75] Paez, S. (2020, January 5). *Penn State's new Center for Immersive Experiences makes dreams a virtual reality*. Pittsburgh Post-Gazette. https://www.post-gazette.com/news/education/2020/01/05/Penn-State-s-new-Center-for-Immersive-Experiences-makes-dreams-a-virtual-reality/stories/202001050137

[76] Pazzanese, C. (2019, February 15). *A studio to re-create reality*. The Harvard Gazette. https://news.harvard.edu/gazette/story/2019/02/at-studio-harvard-college-senior-celebrates-potential-of-ar-vr-technology/

[77] Bohn, D. (2019, February 24). *MICROSOFT'S HOLOLENS 2: A $3,500 MIXED REALITY HEADSET FOR THE FACTORY, NOT THE LIVING ROOM*. The Verge. https://www.theverge.com/2019/2/24/18235460/microsoft-hololens-2-price-specs-mixed-reality-ar-vr-business-work-features-mwc-2019

[78] Lomas, N. (2015). Manus Machina Is Building Gaming Gloves For VR. *TechCrunch*. http://social.techcrunch.com/2015/06/23/manus-machina-is-building-gaming-gloves-for-vr/

[79] Buń, P., Górski, F., Wichniarek, R., Kuczko, W., Hamrol, A., & Zawadzki, P. (2015). Application of Professional and Low-cost Head Mounted Devices in Immersive Educational Application. *Procedia Computer Science*, *75*(C), 173–181. https://doi.org/10.1016/j.procs.2015.12.235

[80] Stepan, K., Zeiger, J., Hanchuk, S., Del Signore, A., Shrivastave, R., Govindaraj, S., & Iloreta, A. (2017). Immersive virtual reality as a teaching tool for neuroanatomy. *International Forum of Allergy & Rhinology*, *7*(10), 1006(8). https://doi.org/10.1002/alr.21986

[81] Kim, K.-J., & Frick, T. W. (2011). Changes in Student Motivation During Online Learning. *Journal of Educational Computing Research*, *44*(1), 1–23. https://doi.org/10.2190/EC.44.1.a

[82] Chyung, S. Y. (2001). Systematic and systemic approaches to reducing attrition rates in online higher education. *American Journal of Distance Education*, *15*(3), 36–49. https://doi.org/10.1080/08923640109527092

[83] Abdel Meguid, E. M., & Khalil, M. K. (2017). Measuring medical students' motivation to learning anatomy by cadaveric dissection.(Report). *Anatomical Sciences Education*, *10*(4), 363–371. https://doi.org/10.1002/ase.1669

[84] Herron, J. (2016). Augmented Reality in Medical Education and Training. *Journal of Electronic Resources in Medical Libraries*, *13*(2), 51–55. https://doi.org/10.1080/15424065.2016.1175987

[85] Tully, J., Dameff, C., Kaib, S., & Moffitt, M. (2015). Recording Medical Students' Encounters With Standardized Patients Using Google Glass: Providing End-of-Life Clinical Education. *Academic Medicine*, *90*(3), 314–316. https://doi.org/10.1097/ACM.0000000000000620

[86] Tepper, M., Rudy, L., Lefkowitz, A., Weimer, M., Marks, S., Stern, S., & Garfein, S. (2017). Mixed Reality with HoloLens: Where Virtual Reality Meets Augmented Reality in the Operating Room. *Plastic and Reconstructive Surgery*, *140*(5), 1066–1070. https://doi.org/10.1097/PRS.0000000000003802

[87] Mazloumi Gavgani, A., Walker, F. R., Hodgson, D. M., & Nalivaiko, E. (2018). A comparative study of cybersickness during exposure to virtual reality and "classic" motion sickness: are they different? *Journal of Applied Physiology (Bethesda, Md. : 1985)*, *125*(6), 1670–1680. https://doi.org/10.1152/japplphysiol.00338.2018

[88] Seixas - Mikelus, S. A., Adal, A., Kesavadas, T., Baheti, A., Srimathveeravalli, G., Hussain, A., Chandrasekhar, R., Wilding, G. E., & Guru, K. A. (2010). Can image-based virtual reality help teach anatomy? *Journal of Endourology*, *24*(4), 629–634. https://doi.org/10.1089/end.2009.0556

[89] Shenai, M. B., Dillavou, M., Shum, C., Ross, D., Tubbs, R. S., Shih, A., & Guthrie, B. L. (2011). Virtual interactive presence and augmented reality (VIPAR) for remote surgical assistance. *Neurosurgery*, *68*(1 Suppl Operative), 200–7; discussion 207. https://doi.org/10.1227/NEU.0b013e3182077efd

[90] Gargiulo, P., Árnadóttir, I., Gíslason, M., Edmunds, K., & Ólafsson, I. (2017). New Directions in 3D Medical Modeling: 3D-Printing Anatomy and Functions in Neurosurgical Planning. *Journal of Healthcare Engineering*, *2017*, 1439643. https://doi.org/10.1155/2017/1439643

[91] Ni, T., Karlson, A., & Wigdor, D. (2011). *AnatOnMe: facilitating doctor-patient communication using a projection-based handheld device*. 3333–3342. https://doi.org/10.1145/1978942.1979437

[92] Serra, L., Kockro, R. A., Goh, C. G., Ng, H., & Lee, E. C. K. (2002). The DextroBeam: a stereoscopic presentation system for volumetric medical data. *Studies in Health Technology and Informatics*, *85*, 478–484. https://doi.org/10.3233/978-1-60750-929-5-478

[93] Thomas, R. G., William John, N., & Delieu, J. M. (2010). Augmented Reality for Anatomical Education. *Journal of Visual Communication in Medicine*, *33*(1), 6–15. https://doi.org/10.3109/17453050903557359

[94] Kockro, R. A., Amaxopoulou, C., Killeen, T., Wagner, W., Reisch, R., Schwandt, E., Gutenberg, A., Giese, A., Stofft, E., & Stadie, A. T. (2015). Stereoscopic neuroanatomy lectures using a three-dimensional virtual reality environment. *Annals of Anatomy*, *201*, 91–98. https://doi.org/10.1016/j.aanat.2015.05.006

[95] Battulga, B., Konishi, T., Tamura, Y., & Moriguchi, H. (2012). The effectiveness of an interactive 3-dimensional computer graphics model for medical education. *Interactive Journal of Medical Research*, *1*(2), e2. https://doi.org/10.2196/ijmr.2172

[96] Huang, H.-M., Rauch, U., & Liaw, S.-S. (2010). Investigating learners' attitudes toward virtual reality learning environments: based on a constructivist approach. *Computers & Education*, *55*(3), 1171–1182. https://doi.org/10.1016/j.compedu.2010.05.014

[97] Bork, F., Stratmann, L., Enssle, S., Eck, U., Navab, N., Waschke, J., & Kugelmann, D. (2019). The Benefits of an Augmented Reality Magic Mirror System for Integrated Radiology Teaching in Gross Anatomy. *Anatomical Sciences Education*, *12*(6), 585–598. https://doi.org/10.1002/ase.1864

[98] Korf, H.-W., Wicht, H., Snipes, R. L., Timmermans, J.-P., Paulsen, F., Rune, G., & Baumgart-Vogt, E. (2008). The dissection course – necessary and indispensable for teaching anatomy to medical students. *Annals of Anatomy*, *190*(1), 16–22. https://doi.org/10.1016/j.aanat.2007.10.001

[99] Bayer, C. R., Smith, L. L., Volny Darko, R., Mckool, M., Yan, F., & Heiman, H. (2017). Understanding health policy leaders' training needs. *PLoS ONE*, *12*(3), e0174054. https://doi.org/10.1371/journal.pone.0174054

[100] Johnston, A. N. B., Hamill, J., Barton, M. J., Baldwin, S., Percival, J., Williams-Pritchard, G., Todorovic, M. (2015). Student learning styles in anatomy and physiology courses: Meeting the needs of nursing students. *Nurse Education in Practice*, *15*(6), 415–420. https://doi.org/10.1016/j.nepr.2015.05.001

[101] Triepels, C. P. R., Koppes, D. M., Van Kuijk, S. M. J., Popeijus, H. E., Lamers, W. H., van Gorp, T., Notten, K. J. B. (2018). Medical students' perspective on training in anatomy. *Annals of Anatomy*, *217*, 60–65. https://doi.org/10.1016/j.aanat.2018.01.006

[102] Webb, E. M., Naeger, D. M., Mcnulty, N. J., & Straus, C. M. (2015). Needs Assessment for Standardized Medical Student Imaging Education: Review of the Literature and a Survey of Deans and Chairs: Review of the Literature and a Survey of Deans and Chairs. *Academic Radiology*, *22*(10), 1214–1220. https://doi.org/10.1016/j.acra.2015.03.020

[103] Mclafferty, I. (2004). Focus group interviews as a data collecting strategy. *Journal of Advanced Nursing*, *48*(2), 187–194. https://doi.org/10.1111/j.1365-2648.2004.03186.x

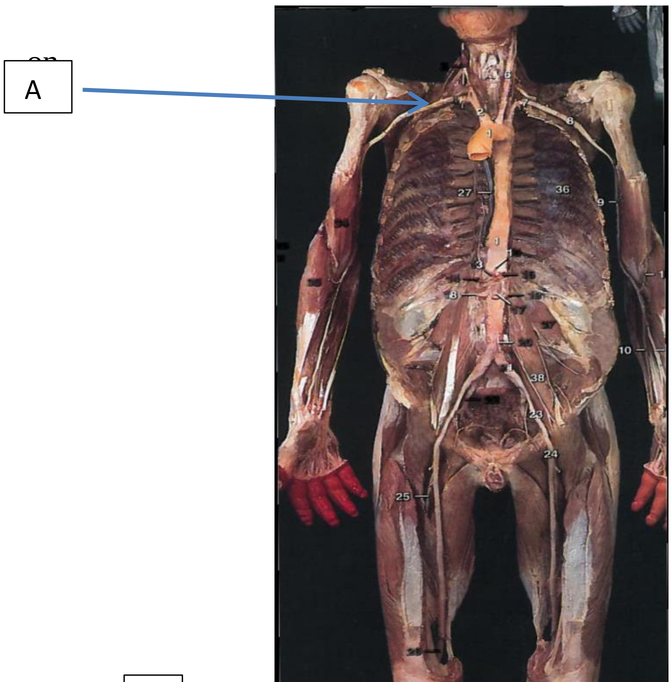
[104] Warren, T. (2019, February 25). A closer look at Microsoft's new Kinect sensor. Retrieved November 10, 2019, from The Verge website: https://www.theverge.com/2019/2/25/18239860/microsoft-kinect-azure-dk-hands-on-mwc-2019

Appendix A

This section contains resources that were used during the user studies conducted through this project. This includes questions asked on the pre-test and post-test during the pilot study as well as the large-scale user study, the word bank provided to participants during the large-scale user study, and the pictures provided to students who learned using Atlas textbooks during the large-scale user study. While the diagrams will be presented alongside the questions in some questions, during the actual study, the diagrams were shown on a projector while participants had the questions in front of them.

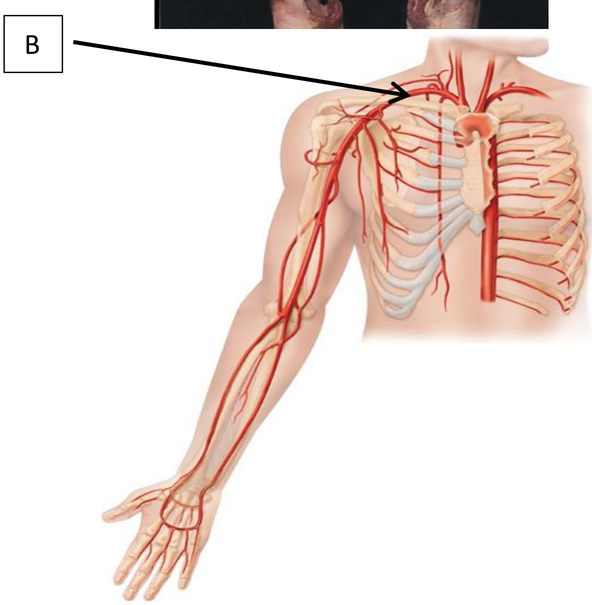
Pilot study

Identify the labeled structures on the images shown



Structure A

a) Axillary artery
b) Brachiocephalic trunk
c) Brachial artery
d) Right subclavian artery

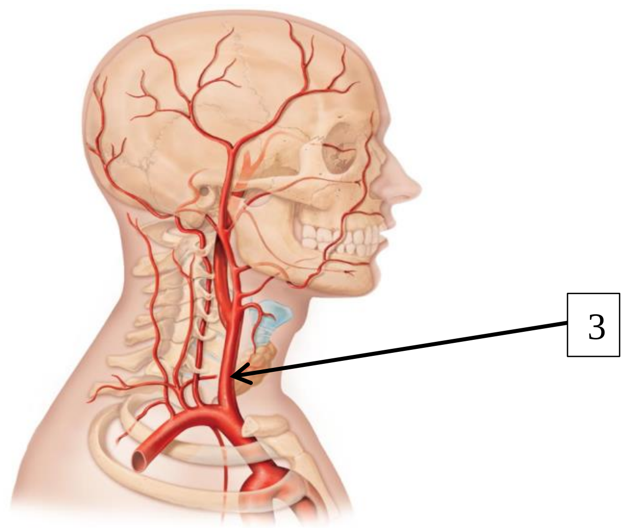


Structure B

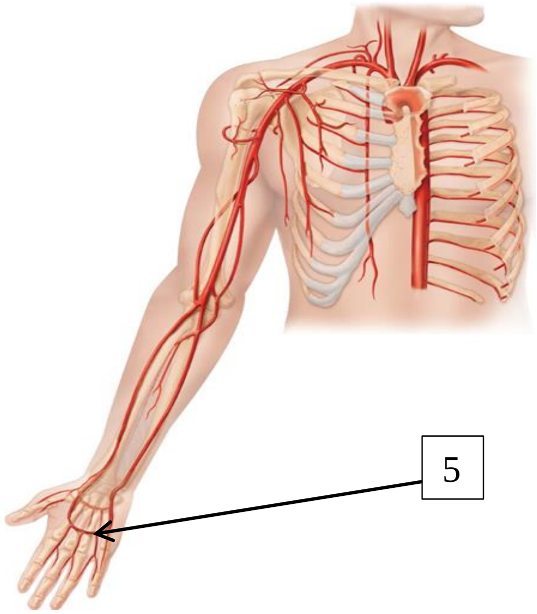
a) Brachiocephalic trunk
b) External carotid artery
c) Right subclavian artery
d) Left subclavian artery

Large-scale user study

Sample questions



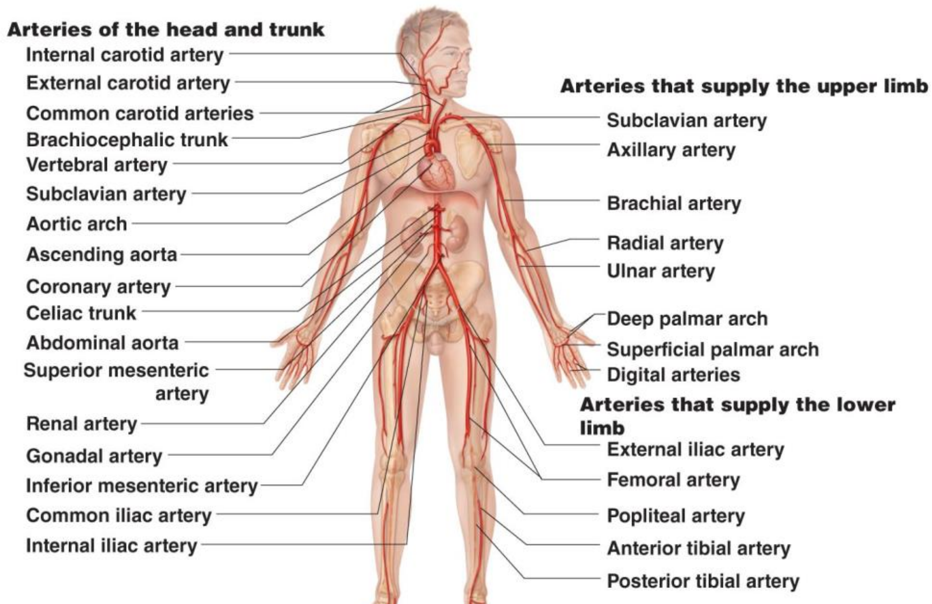
(b)



Word bank

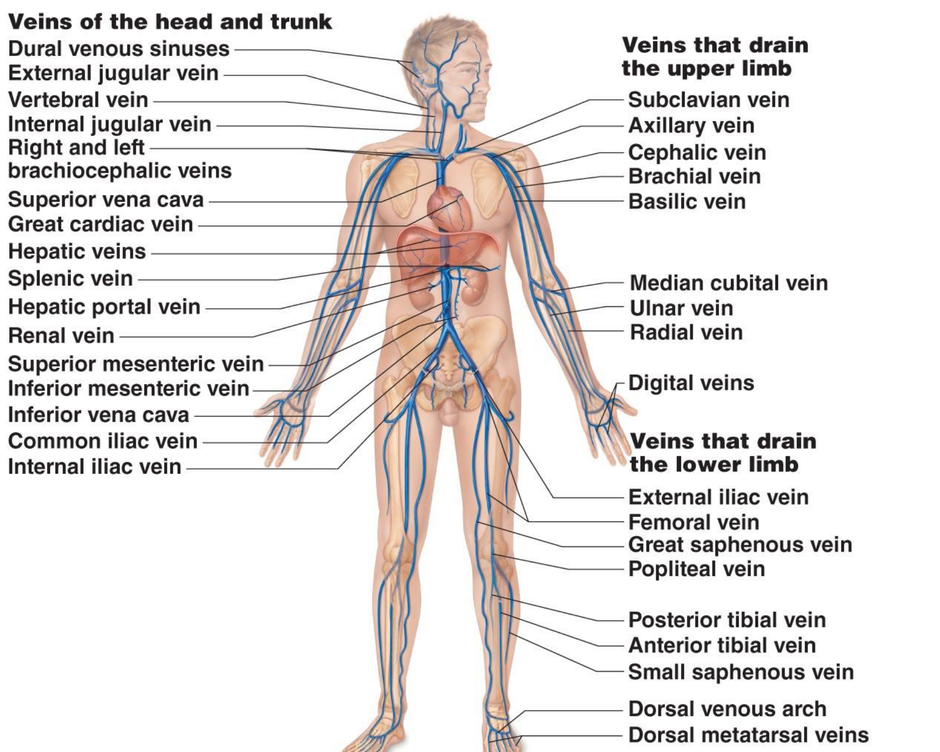
1. A. fémorale (femoral artery)
2. A. tibiale postérieure (posterior tibial artery)
3. A. poplitée (popliteal artery)
4. A. subclavière (subclavian artery)
5. A. brachiale (brachial artery)
6. A. radiale (radial artery)
7. A. ulnaire (ulnar artery)
8. A. tibiale antérieure (anterior tibial artery)
9. A. temporale superficielle (superficial temporal artery)
10. A. axillaire (axillary artery)
11. A. carotide commune (common carotid artery)
12. Tronc brachiocéphalique (brachiocephalic trunk)
13. A. vertébrale (vertebral artery)
14. Arc de l'aorte (aortic arch)
15. A. thoracique interne (internal thoracic artery)
16. A. intercostale postérieure (posterior intercostal artery)
17. Arcade palmaire superficielle (superficial palmar arch)
18. Arcade palmaire profonde (deep palmar arch)
19. Aorte descendante (descending aorta)
20. V. jugulaire interne (internal jugular vein)
21. V. jugulaire externe (external jugular vein)
22. V. Subclavière (subclavian vein)
23. V. tibiale postérieur (posterior tibial vein)
24. V. tibiale antérieur (anterior tibial vein)
25. V. fémorale (femoral vein)
26. V. iliaque commune (common iliac vein)
27. V. basilique (basilica vein)
28. V. céphalique (cephalic vein)
29. V. axillaire (axillary vein)
30. V. médiane du coude (median cubital vein)
31. V. cave supérieur (superior vena cava)
32. V. radiale (radial vein)
33. V. poplitée (popliteal vein)
34. Sinus de la dure-mère (dural veinous sinus)
35. V. ulnaire (ulnar vein)
36. V. rénale (renal vein)
37. V. mésentérique supérieure (superior mesenteric vein)
38. V. mésentérique inférieure (inferior mesenteric vein)
39. La grande veine saphène (great saphenous vein)
40. La petite veine saphène (small saphenous vein)

Diagrams from Atlas textbooks



(b) Illustration, anterior view

Arteries



(b) Illustration, anterior view. The vessels of the pulmonary circulation are not shown.

Veins

Appendix B

This section presents the interview questions as well as the transcripts for the interviews conducted with the six anatomy professors from the University of Ottawa. Interviews were originally conducted and recorded in French by a fourth year Health Science student from the University of Ottawa. The same student subsequently transcribed and translated the interviews into English.

Interview questions

1. In the courses you teach, what learning tools are included to teach anatomy in your lectures?
2. Not included in the previously mentioned learning tools, what resources do students currently have to help with anatomy learning outside of the classroom during the semester? Do you believe students utilize these resources?
3. Are you aware of other resources, courses, material, etc. that are offered at other universities, but are not offered at the University of Ottawa?
4. Are there any areas in particular that you have noticed students struggling in your anatomy courses (content or structure)?
5. Have you or any of your colleagues at the University of Ottawa used virtual or augmented reality technologies to complement anatomy learning?
6. Have you used the Magic Mirror before? If not, please see a sample video of it here (https://www.youtube.com/watch?v=NQ_Jn87E4xE)
7. If you used the Magic Mirror before, would you consider permanently integrating it into the anatomy courses you teach?

8. Yes/No: In your course syllabus, would you be willing to dedicate 1-2% bonus marks to your students to motivate them to participate in future studies aimed at assessing the impact of novel technologies for anatomy learning?
9. Having seen the Magic Mirror technology, what additional features (if any) would you include before you consider it an appropriate learning tool that can be added to anatomy classes?

Professor #1

1. **In the courses you teach what learning tools are included to teach anatomy in your lectures?**

    Anglophone: PowerPoint presentations, online text and image-based formative quizzes, online cadaveric image banks, and structure checklists. Almost all the anatomy curriculum hours are dedicated to hands-on, student-centered learning using previously dissected cadaveric resources in the lab, and these resources help support student preparation and review.

    Francophone: all previously mentioned tools plus Podcasts and Youtube videos.

2. **Not included in the previously mentioned learning tools, what resources do students currently have to help with anatomy learning outside of the classroom during the semester? Do you believe students use these resources?**

The uOttawa Health Science library has several licenses for various digital anatomy resources (Visible Body, for example). Previous data suggests that students lean heavily on professor-made course-specific tools (PPT slides, online quizzes, and podcasts) especially near exams and don't rely extensively on commercial resources with generalized content.

3. **Are you aware of other resources, courses, material, etc. included in other Universities, but that are not done at uOttawa?**

    Some schools use the Anatomage Table resource where clinical imaging is integrated with VR anatomy in 3D. Further, some medical schools formally incorporate POCUS (ultrasound) and 3D printed resources in their curricula where we are in the initial stages of bringing those technologies to our labs.

4. **Are there any areas in particular you see your students struggling in your anatomy courses (content or structure)?**

    Embryology (development) and reproductive anatomy are mentioned at times as difficult subjects, largely owing to the amount of difficult content covered in relatively limited time. Most students do well in anatomy and, in terms of assessment, perform well, as well or better than most of the other practical disciplines.

5. **Have you or any of your colleagues at uOttawa used virtual and augmented reality technologies to complement anatomy learning?**

    Not extensively or consistently.

6. **Have you used the Magic Mirror before? If not, please see a sample video of MM here (https://www.youtube.com/watch?v=NQ_Jn87E4xE)**

Yes

7. **If you used the Magic Mirror before, would you consider permanently using it in the anatomy courses you teach?**

    No, not at this time

8. **Yes/No: In your course syllabus, would you be willing to dedicate 1-2% bonus marks to your students to motivate them to participate in future aimed at assessing the impact of novel technologies for anatomy learning?**

    I don't think that is possible in our course (part of medical school)

9. **Having seen the Magic Mirror technology, what additional features (if any) would you include for it to become a learning tool in your anatomy classes:**

    Real time formative quizzes: posing questions to students, and depending on what they answer correct or incorrect, adjusting to ask similar questions to reinforce concepts of difficulty

Professor #2

1. **In the courses you teach, what learning tools are included in the teaching of your anatomy courses? (books, visualization of corpses...)**

    Marieb Elaine N & Hoehn Katja, Human Anatomy and Physiology (5th edition), Éditions du Renouveau Pédagogique Inc. in St-Laurent, 2005, 1194 p. ISBN 2-7613-1525-1 (Atlas textbook used for class material)

2. **Not included in the learning tools mentioned above, what resources do students currently have to facilitate anatomy learning outside the classroom during the semester? Do you think students use these resources?**

   Videos are selected on the web to visualize the anatomy of the systems I teach. Yes, students take the time to view the videos provided.

3. **Are you aware of other resources (courses, materials and etc.) that are included in other universities, but not used at the University of Ottawa?**

   There is a lot of material on the web that students can consult.

4. **Are there any particular areas in which your students have difficulty in your anatomy courses (content or structure)?**

   The material taught so far requires mainly physiological knowledge of structures and role of organs. Students do not have time to go into too much anatomical detail about the structures they are taught. These details are given in other complementary courses related to their discipline.

5. **Have you (or any of your colleagues at the University of Ottawa) used virtual and augmented reality technologies to complete anatomy learning?**

   Last Fall, Anatomy and Physiology I (ANP1505) students had access to a pilot project on the MM software. It seems that the students who participated enjoyed their experience. It is too early to know if this experience has consolidated their knowledge of anatomy.

6. **Have you ever used the magic mirror? Otherwise, please watch a sample MM video here (https://www.youtube.com/watch?v=NQ_Jn87E4xE).**

   It is interesting that the student can see his own anatomy.

7. **If you used the magic mirror before, would you consider using it permanently in your anatomy classes?**

   Maybe, but for now I prefer to use web videos that are directly related to the subject I teach such as: https://www.youtube.com/watch?v=yxIGpIWWWWwnY for the cardiovascular system.

8. **Yes / No: In your curriculum, would you be willing to give 1 to 2% bonus points to your students to motivate them to participate in future studies to assess the impact of new technologies on anatomy learning?**

   No more than 1%, especially since not all students who registered were able to participate during last Fall's experience.

9. **After seeing Magic Mirror technology, what additional features (if any) would you include to make it a learning tool in your anatomy classes?**

   Perceived blood vessels or organs must be clearly identified (accurate labelling) in real time.

Professor #3

1. **In the courses you teach, what learning tools are included in the teaching of your anatomy courses? (books, visualization of corpses...)**

   Both with videos and the Visible Body application from the library

2. **Not included in the learning tools mentioned above, what resources do students currently have to facilitate anatomy learning outside the classroom during the semester? Do you think students use these resources?**

   Mastering ANP of the book Marieb (Anatomy textbook used by Anglophone students)

3. **Are you aware of other resources (courses, materials and etc.) that are included in other universities, but not used at the University of Ottawa?**

   Other videos such as Khan Academic and Osmosis Videos

4. **Are there any particular areas in which your students have difficulty in your anatomy courses (content or structure)?**

   Some structures are poorly visualized in the textbooks

5. **Have you (or any of your colleagues at the University of Ottawa) used virtual and augmented reality technologies to complete anatomy learning?**

   Yes! The MM, but only as a part of the study

6. **Have you ever used the magic mirror? Otherwise, please watch a sample MM video here (https://www.youtube.com/watch?v=NQ_Jn87E4xE).**

   Yes!

7. **If you used the magic mirror before, would you consider using it permanently in your anatomy classes?**

   Yes! If the student could use it independently

8. **Yes / No: In your curriculum, would you be willing to give 1 to 2% bonus points to your students to motivate them to participate in future studies to assess the impact of new technologies on anatomy learning?**

   Yes!

9. **After seeing Magic Mirror technology, what additional features (if any) would you include to make it a learning tool in your anatomy classes?**

   It must be made more malleable (more functionality) and with the ability to zoom into certain regions and include more organ systems (respiratory, digestive, reproductive systems...)

Professor #4

1. **In the courses, you teach what learning tools are included to teach anatomy in your lectures.**

   I used 3D animation videos

2. **Not included in the previously mentioned learning tools, what resources do students currently have to help with anatomy learning outside of the classroom during the semester? Do you believe students use these resources?**

   The students use many 3D anatomy apps

3. **Are you aware of other resources, courses, material, etc. included in other Universities, but that are not done at uOttawa?**

Yes, http://neuroanatomy.ca/ is a very good resource from BC University

4. **Are there any areas in particular you see your students struggling in your anatomy courses (content or structure)?**

    The students find neuroanatomy very hard, so I try to simplify the material and use 3 D animation. I do the same for embryology course

5. **Have you or any of your colleagues at uOttawa used virtual and augmented reality technologies to complement anatomy learning?**

    I do not know

6. **Have you used the Magic Mirror before? If not, please see a sample video of MM here (https://www.youtube.com/watch?v=NQ_Jn87E4xE)**

    Yes

7. **If you used the Magic Mirror before, would you consider permanently using it in the anatomy courses you teach?**

    Yes

8. **Yes/No: In your course syllabus, would you be willing to dedicate 1-2% bonus marks to your students to motivate them to participate in future aimed at assessing the impact of novel technologies for anatomy learning?**

    I would love to do that, but I do not have the authority to do so.

9. **Having seen the Magic Mirror technology, what additional features (if any) would you include for it to become a learning tool in your anatomy classes:**

    Labelling the different structures, preferably in both English and French

Professor #5

1. **In the courses you teach what learning tools are included to teach anatomy in your lectures?**

   PowerPoint presentations and Cadavers

2. **Not included in the previously mentioned learning tools, what resources do students currently have to help with anatomy learning outside of the classroom during the semester? Do you believe students use these resources?**

   Podcasts, YouTube videos, Online Anatomy Images, and the Visible Body App. Yes I think students use them

3. **Are you aware of other resources, courses, material, etc. included in other Universities, but that are not done at uOttawa?**

   No

4. **Are there any areas in particular you see your students struggling in your anatomy courses (content or structure)?**

   Neuroanatomy, Pelvis Anatomy

5. **Have you or any of your colleagues at uOttawa used virtual and augmented reality technologies to complement anatomy learning?**

   Yes: Visible Body

6. **Have you used the Magic Mirror before? If not, please see a sample video of MM here (https://www.youtube.com/watch?v=NQ_Jn87E4xE)**

   Yes

7. **If you used the Magic Mirror before, would you consider permanently using it in the anatomy courses you teach?**

   Yes, For some regions such as the musculoskeletal system

8. **Yes/No: In your course syllabus, would you be willing to dedicate 1-2% bonus marks to your students to motivate them to participate in future aimed at assessing the impact of novel technologies for anatomy learning?**

   I cannot, as Medical School Office allocates the points

9. **Having seen the Magic Mirror technology, what additional features (if any) would you include for it to become a learning tool in your anatomy classes:**

   Greater ability to zoom in and out

Professor #6

1. **In the courses you teach, what learning tools are included in the teaching of your anatomy courses? (books, visualization of corpses...)**

   Learning tool: Essentially the anatomy book (Marieb) and PowerPoint presentations.

2. **Not included in the learning tools mentioned above, what resources do students currently have to facilitate anatomy learning outside the classroom during the semester? Do you think students use these resources?**

   For anatomy, the main additional source is the "Visible Body" application available on the University Library website.

Use of Visible Body by students: No survey has been done on this subject. I think that, for the course ANP 1506 (Anatomy and Physiology II, French – MSK and Nervous systems), the majority of students will consult it at least once because it is strongly suggested at the beginning of the session, but I doubt it will be very popular afterwards.

3. **Are you aware of other resources (courses, materials and etc.) that are included in other universities, but not used at the University of Ottawa?**

Yes, there are other applications similar to Visible Body. The choice of this application for the University was made because it is bilingual (anatomy) and contains sections on physiology.

4. **Are there any particular areas in which your students have difficulty in your anatomy courses (content or structure)?**

Most difficult anatomical section: muscle system. But the reason is mainly because students also need to know the function of muscles, not just their identification.

5. **Have you (or any of your colleagues at the University of Ottawa) used virtual and augmented reality technologies to complete anatomy learning?**

"Visible Body"

6. **Have you ever used the Magic Mirror? If not, please see a sample video of MM here (https://www.youtube.com/watch?v=NQ_Jn87E4xE)**

Yes, I know what it is.

7. **If you used the magic mirror before, would you consider using it permanently in your anatomy classes?**

Certainly not in class, due to lack of time.

I think that the use of the Magic Mirror will only become relevant if the application becomes available for personal studies, i.e. linked at a reasonable cost that would allow students to use it at home.

8. **Yes / No: In your curriculum, would you be willing to give 1 to 2% bonus points to your students to motivate them to participate in future studies to assess the impact of new technologies on anatomy learning?**

Yes for a 1% bonus. But be careful, however, the study must be offered to all students in the class. The problem is that many students who have not participated due to lack of space may consider themselves disadvantaged in their quest for a maximum score. Perhaps what we could do: offer different educational research activities, say with a 2% bonus, and ask students to participate in one of them. It's just an idea like that.

9. **After seeing Magic Mirror technology, what additional features (if any) would you include to make it a learning tool in your anatomy classes?**

This is imperative: identification of all structures in French, with the possibility of zooming in. The tool must be able to be operated completely independently. The quality of the images must be equivalent to that of their reference manual (Marieb for PDA courses).