Medical decision-making largely depends on the caregiver’s fundamental knowledge of anatomy. To this end, the authors discuss a cost-effective augmented reality system for simulated medical research and education. First, we define augmented reality. Second, we will review the history of augmented reality in medical training. Third, we will discuss some of the human factors principles associated with augmented reality training systems. Fourth, we will describe our insight and methods for building a Simulated Medical Augmented Reality Training (SMART) system, which can be used as an alternative training tool for medical and anatomy students. Finally, we will outline five steps that can be taken to build a SMART system.

INTRODUCTION

At the heart of medicine is the ability to diagnose and treat patients. Being skilled at patient diagnosis and management relies on a deep understanding of anatomical and pathological knowledge. Unarguably, this is a fundamental knowledge-base with 98% of anatomists stating that anatomy is important for clinical medicine (Patel & Moxham, 2006). However, medical students and junior clinicians have an alarmingly poor understanding of anatomy (Prince, Scherpier, van Mameren, Drukker, & van der Vleuten, 2005; Xu, 2008). In fact, newly qualified physicians perceived their anatomy training to be insufficient (Fitzgerald, White, Tang, Maxwell-Armstrong, & James, 2008), and only 29% of residency program directors stated residents were adequately prepared with regards to gross anatomy (Cottam, 1999). Senior physicians have even suggested that anatomy education is "below the minimum necessary for safe medical practice" (Waterson & Stewart, 2005, p. 380). Unfortunately, these problems extend beyond mere perceptions. That is, during one assessment, students responded to questions with fictitious body parts (Creswell, 2010), and even within actual medical practice, malpractice claims associated with deficits in anatomical knowledge have been on the rise (Raftery, 2007). Similarly, such poor knowledge is also contributing to anatomical complications within the operating room (Ellis, 2002). These outcomes suggest that anatomy training is on the decline and in desperate need of repair.

Current anatomy training relies on the use of cadavers as one of the primary teaching modalities. Even though cadavers have previously been a staple of medical education due to some of the advantages (e.g., hands-on experience and anatomical variation), there has been a host of complaints associated with their use. Most noteworthy are the ethical issues surrounding the use of cadavers (Hariri et al., 2004; McKeown, Heylings, Stevenson, McKlevey, Nixon, & McCluskey, 2003). Because of the problematic outcomes associated with ill-prepared clinicians, the issues surrounding cadavers and instructors, as well as less time dedicated to teaching anatomy; there is a need to identify additional training methodologies to improve the current state.

One potential strategy that can facilitate anatomy training, while circumventing the drawbacks associated with cadavers is the use of augmented reality (AR) (Figure 1). Augmented reality systems overlay computer-generated imagery (CGI) onto actual physical surfaces. This creates a composite or mixture of real and computer generated information that can be used to enhance educational outcomes. Because augmented reality involves CGI, it has several advantages in comparison to other anatomical education tools. The most obvious benefits are that AR systems create no ethical issues (compared to cadavers); AR does not require extensive space or building requirements, and AR systems have a substantially lower cost. Another notable advantage is that all anatomical structures are simply digital files, so there is the capability to introduce learners to a vast data-base of imagery, allowing the study of biological variation, which is at the crux of anatomy education.

With this foundation in mind, we will first provide a deeper understanding of AR and its functions. Then, we will discuss how AR has been used in medical training. Following, we will review some Human Factors principles, which support AR systems for learning. Specifically, we will describe how AR can improve anatomical learning via based on Cognitive Load Theory. Next, we will describe the development of the Simulated Medical Augmented Reality Training (SMART) system and provide a detailed explanation of the system, giving others an opportunity to create a similar SMART system if interested. Finally, we will end with implications for future research and practice as well as concluding remarks. We hope that this detailed discussion of AR training will assist future medical trainers, educators, and researchers on how to effectively leverage AR in a time- and cost-effective manner to train anatomy at their respective institutions to better supplement anatomy education in order to better prepare students and ultimately clinicians.
AUGMENTED REALITY

The term augmented reality emerged from research on mixed reality in the early 1990’s and has been defined as a real environment being augmented by virtual objects (Azuma, 1997; Milgram and Kishino, 1994). Within the context of anatomy education, the use of AR will mainly consist of overlaying images of organs and anatomical structures onto a manipulate-able physical surface. Through the use of a fiducial marker (i.e., a graphical stamp that dictates where in physical space the images are placed), organs can be superimposed onto surfaces that individuals can manipulate in actual space. See Figure 1 for an example of a 3ds image of a heart overlaid onto a square piece of poster board with a fiducial marker at its center. This form of augmented reality system simply requires a computer, a fiducial marker surface, 3ds images, software (which can be downloaded for free), and a webcam. Unlike other systems that use head-mounted displays (Kancherla, Rolland, Wright, & Burdea, 1995), this system is much less intrusive for the learner to interact with. The webcam can be placed in a stationary position or held by the learner to create more degrees of freedom to interact with the AR system. This will be described in more detail below.

Augmented reality can be useful for multiple reasons in addition to the reasons we briefly mentioned previously. For instance, AR allows for full manipulation of the image, including translation, rotation, and scaling. Due to the nature of interaction with the 3ds images, using an AR system provides much of the same visual details that would be provided by an actual image. The use of an augmented reality system allows for a large database of images to be stored in one convenient location (i.e., desktop or laptop) that theoretically can be accessed at any time. This leads to a convenient learning simulation where structures can be studied at one’s convenience. Compare this to an actual cadaver, where the storage facilities need to be highly secure, the body can only be dissected once, and individuals interested in studying are limited by access to the cadaver during facility operation hours. Even fiberglass models, which do not have the ethical constraints of cadavers, nor the one-time dissection usability of cadavers, are limited by space constraints, are expensive to purchase and store, and require a large library different models to represent the entire human body. Also, fiberglass models limit the amount of biological diversity found between individuals, leading to a lack of training on one of the most fundamental aspects of anatomy – biological variation. With the AR system described in this article, once a database of images is purchased, all organs can be conveniently located on one (or more if desired) computer(s), and using the AR software, each organ can be re-sized to provide more in-depth detail of learning cues.

History of Augmented Reality in Medical Training

As described above, AR can be defined as a combination of real and virtual environments that utilizes computer generated images of objects that are then superimposed or composited within the real world (Azuma, 1997). Although the basic concept has stayed the same (i.e. overlaying virtual imagery/objects onto real scenes/objects), the technology has advanced considerably. Specifically, older systems required the use of large headsets or head mounted displays (Rolland, Meyer, Davis, et al., 2002; Rolland, Wright, & Kancherla, 1997) that could prove unwieldy in the context discussed here (e.g., studying anatomy for an entire semester). Fortunately, modern systems require no more than a video feed from a computer and a desktop powerful enough to run the AR software.

Previous research has examined the effects of computer based learning (Chariker, 2011), 3D imagery (Beerman, 2010; Hilbelink, 2009), and virtual reality (Roshahl, et al., 2006; Spitzer & Scherzinger, 2006) in a medical context. However, most AR studies in the medical realm have focused on the area of surgical simulators. For example, Bichlmeier and colleagues (2007) found increased performance when they used AR overlays to aid in the learning of surgical techniques. Clearly, there seem to be many benefits of using AR technologies, such as faster learning times, higher learner involvement, and more detailed knowledge, yet some argue that there is still no definitive evidence of the effectiveness of computer-based learning when compared to more traditionally modalities (Pereira, 2007).

This lack of scientific support is attributable to the fact that there has never been scientific validation of dissection methods of learning anatomy (Winkelmann, 2007). Winkelman’s review provided only 14 studies that consider the effect of dissection on anatomical learning. He concluded that more rigorous research methods should be used to better understand the effect of dissection on anatomical learning. There are obviously practical limitations to understanding the effects of dissection. For example, cadavers can only be used once, and medical students have a full curriculum, leaving little time for participation in research studies. Ultimately, current dissection methods (i.e., cadavers) have never been shown to be effective. Consequently, it is difficult to definitively determine whether a new system is better than current method. Therefore, it is pertinent to find a system that can use larger samples and demonstrate validity in classroom learning (Winkelmann, 2007).

In the following section, we describe the theoretical underpinnings that justify the design and use of an AR system in anatomical instruction, cognitive load theory.

Human Factors Principles and Augmented Reality Systems

Cognitive Load Theory (CLT) is a commonly used theory for understanding the potential benefits or limitations of a particular type of instructional design (Chandler & Sweller, 1991). Based on the psychological model of information processing (Wickens, 1992), CLT is defined as a multidimensional construct consisting of three types of cognitive “load” imposed by instructional information, including intrinsic load, extraneous load, and germane load (Paas & Merrienboer, 1994). Although CLT is not a distinctly human factors theory, some have suggested that it should be integrated with HF principles, such as workload (Keebler,
Ososky, Jentsch, & Fincannon, 2010). Given the heavy use of CLT in medical education, and its applicability to HF, it seems like the most relevant theory related to the AR technology proposed in this article.

Each of the three areas of the CLT represents a different portion of instructional information. Intrinsic load is the mental load associated with the content of the domain being studied. Different domains, or courses within a domain, may require varying amounts of intrinsic load based on the complexity of the material. As an example, studying anatomy in an undergraduate course would have less intrinsic load than studying anatomy in a medical school course. Although they are the same domain, the level of detailed knowledge required for the medical course would be substantially higher than the undergraduate course. Extraneous load is based on the amount of irrelevant (i.e., extraneous) constraints imposed on the learner. These could range from ineffective teaching methods to assignments that do not aid in the learning of the material. Any factor that is not directly related to the topic material can be considered extraneous load. The final type of load in CLT is referred to as germane load. This can be any factor involved in instructional design that leads to stronger learning outcomes.

The AR system described in this article may reduce extraneous load and increase germane load. Specifically, through direct labeling of relevant structures on the AR heart model, students would no longer have to cross reference a textbook for information. Cross-referencing a textbook may indeed be a form of extraneous load (e.g., spending time looking between the anatomical structures and finding their label on an image in a textbook). Also, the AR model provides direct labeling on the structure that can be moved if needed. This is an example of germane load, allowing for stronger learning outcomes through an easily manipulated interface that contains all necessary information for the learner.

**The Simulated Medical Augmented Reality Training (SMART) System**

The current SMART system design was determined based on its simplicity and ease-of-use for those who are unfamiliar with augmented reality technology. The design of the system was created with one goal in mind: to develop an advanced technology medical training system that can enhance the users’ learning outcomes, and which is simple enough for anyone to set-up using relatively inexpensive materials.

Instructors, researchers, and practitioners alike will be able to set up the system using the following five steps. The system requires no programming knowledge and allows any student to pick-up a fiducial marker to engage with the augmented reality and begin using the augmented reality tool for learning activities immediately. Additionally, pilot testing was conducted with 5 undergraduate students at a large southeastern university. During pilot testing, the participants interacted with an augmented reality heart with the purpose of teaching basic anatomy. These participants were asked to evaluate the system to determine ease-of-use and worth as a training tool. This pilot testing of the SMART system suggested that the technology is simple enough for anyone to use and provides a favorable training tool. Thus, the current SMART system provides a simple system for learning anatomy that can be integrated into current anatomy curriculum or even replace some of the less cost-effective methods (e.g., cadavers, fiberglass models, etc.). Furthermore, SMART systems provide an opportunity for the development of learning systems for medical students, offering the potential to be used as a replacement for interactive learning with anatomy, where real-world anatomy interactions are not plausible.

**EXAMPLE OF A SIMULATED MEDICAL AUGMENTED-REALITY TRAINING (SMART) SYSTEM**

A standalone system using augmented reality can be built in a few simple steps. We will demonstrate how a basic version of the SMART system was created. To construct a fully prepared anatomical training AR system, a few key items are needed: A web-cam, a computer with a dedicated graphic card, fiducial markers, AR software, and a library of .3ds models. Below, we describe how we developed a system to teach anatomy in five simple steps.

**Step 1: Purchase augmented reality software and .3ds images.** First, purchase fiducial marker-based AR software (e.g., BuildAR Pro; [www.hitlabnz.com](http://www.hitlabnz.com)). This is a cost-effective route when compared to alternative head-mounted display AR systems, which can exceed costs of $30,000. There are free versions available; however, even or purchased versions of most of the software, the license is indefinite and will allow for a long-standing AR system.

Second, purchase 3D image files. 3D images (i.e., .3ds files) can be purchased from any online 3D image marketplace, and online marketplaces sell, digital image files of almost all anatomical structures. Although more expensive ($1,000 + USD) than individual organs, “packs” of models can be purchased that contain extensive amounts of structures. These may be preferable for medical students since they provide a broad diversification of human anatomy structures integrated into one package. The individual organs can be a more cost-effective route for undergraduate laboratories or
classrooms that need to study specific organs. Once purchased, these files can be shared to multiple computers. We recommend that you contact a representative from the company that you plan to purchase 3D files from to make sure that the files will work with your augmented reality software. In some cases, the texture files will not appropriately wrap to the 3D model, which will require additional technical support to fix.

The AR software used in this SMART system provides the ability to add elements to the digital AR images, such as video, text, images, or sound, without requiring a working knowledge of programming. One of the more useful features in the context of the SMART system is the text capability, which allows annotations to be placed directly onto the actual elements of the AR scene. Annotation provides integration of information as the trainee explores the anatomy, pointing out the names of structures or highlighting specific parts of an organ or system of organs. This increases the potential for learning capabilities, specifically through reducing user cognitive load during training as discussed previously. This also distinguishes AR from cadavers or fiberglass models. Without the presence of an expert, a textbook is usually necessary to cross-reference the visual information of the study material with its name and function. With an annotated AR system, the labels are placed directly onto the 3D model, eliminating the need for cross-referencing. As the user interacts with the stimuli, they will be able to see the names of all relevant structural information.

Step 2: Purchase hardware that can process an augmented reality system. To run the AR software most effectively, we recommend a computer with a dedicated graphics card since integrated graphics may not be supported. We also suggest a webcam because it will serve as the viewpoint for the visualization. When the webcam “sees” the fiducial marker, the AR program projects the 3D image onto the surface of the marker integrating the video feed of the webcam with the 3D imagery of the .3ds file. Figure 2 shows an example of a fiducial marker. Any webcam would suffice, as long as it can be easily held or fastened onto a mount. This gives trainees the option to place the camera on a mount or in a stationary position if they desire. AR software can also be used on a portable laptop computer as long as it has an appropriate graphics card to handle the software. A SMART system laptop allows for remote data collection, demonstrations, and conference and classroom presentations.

Step 3: Create fiducial markers. Fiducial markers (Figure 2) are usually a square pattern that indicates to the computer where in physical space (via live video feed) to place the AR objects. These unassuming markers are a requirement for marker-based AR systems. As described above, the fiducial marker allows the webcam to “see” where the computer needs to place the 3D image. Without the marker providing spatial feedback to the system, it would be impossible to integrate the 3D images with the live video feed (i.e., registration). Therefore, it is impossible to create an integrated AR visualization without a fiducial marker in this system. Some AR programs come with printable fiducial markers (e.g., BuildAR), but others may require you to create one. We utilized a program that allows for pre-constructed printable markers, or the ability to develop new markers. We have found that attaching the printable markers onto a background with a strong contrast (e.g., white poster-board, cardboard) makes it easier for the computer to recognize the marker, especially when the environment is cluttered or dark.

![Figure 2. A participant holding a fiducial marker on poster board](Image)

Step 4: Install software and setup fiducial marker. Download and install the AR software onto the designated computer. Next, one must place the fiducial marker on a flat surface so the program can recognize it. We printed the provided markers and loaded them into the program. Once the markers are recognized, and the computer is set-up (i.e., camera positioned, .3ds files downloaded), you can load your 3D images into the software. After the system knows which .3ds file to access, and recognizes the webcam, you simply point the camera at the fiducial marker, and the AR system will integrate the live video feed and the 3D image.

Step 5: Testing and tutorials. With markers and 3D images loaded into the AR software directory, you should be able to test the capabilities (e.g., scale, rotate, translate, etc.) of the system. Further, you can observe how a trainee will view the objects to ensure that everything is working appropriately. In order to aid in this process, tutorials are provided from most software developer’s websites. For training purposes, you can integrate annotations into aspects of the image. These will appear as the trainee explores the AR objects.

CONCLUSION

Setting up a functional augmented reality system for simulated medical training can be accomplished in five simple steps. Whereas current anatomy training utilizes techniques that are difficult to manage or hinder the learners’ ability through unfortunate instructional design, we believe this system may circumvent some of these issues and could lead superior educational outcomes. AR systems provide an avenue for training that present spatial relationships with relative ease, provide labels of relevant structures, and have direct applications in human factors research for medical training.
Now, more than ever, it is possible to create an augmented reality system that can be used for research or training purposes. These systems may be set up by anyone with a reasonable budget and will continue to improve as the technology advances. We hope that researchers are able to utilize this information to develop their own augmented reality systems and support the progression of this technology.

REFERENCES


