Augmented Studio: Projection Mapping on Moving Body for Physiotherapy Education

Thuong Hoang, Martin Reinoso, Zaher Joukhadar, Frank Vetere and David Kelly*
Microsoft Research Centre for SocialNUI, *Melbourne School of Health Sciences
The University of Melbourne, Melbourne, Australia
{thuong.hoang; martin.reinoso; zaher.joukhadar; f.vetere; d.kelly}@unimelb.edu.au

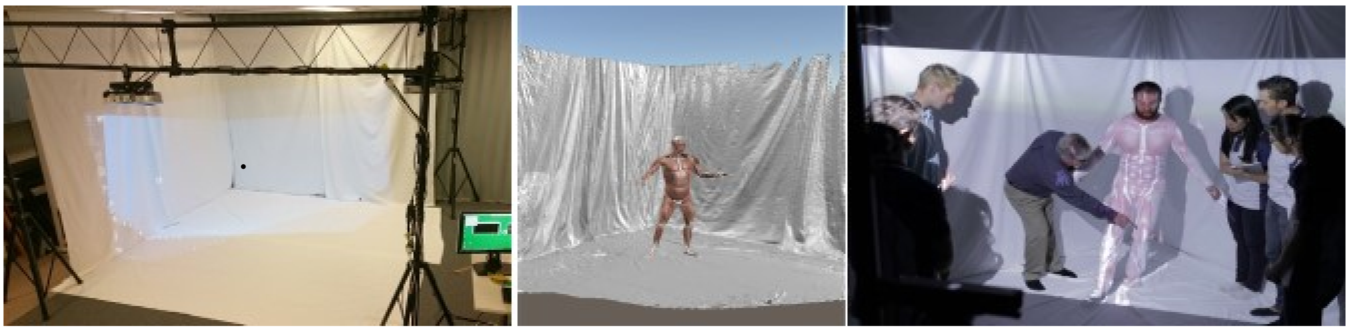

Figure 1. Augmented Studio setup: Left: the 3-sided stage, including scaffolding and 2 projectors with 2 Kinect sensors, set up in a physiotherapy practical classroom; Middle: the stage is captured virtually through projection mapping with a virtual anatomy model; Right: projected virtual anatomy model on a moving body for a physiotherapy practical class

ABSTRACT
Physiotherapy students often struggle to translate anatomical knowledge from textbooks into a dynamic understanding of the mechanics of body movements in real life patients. We present the *Augmented Studio,* an augmented reality system that uses body tracking to project anatomical structures and annotations over moving bodies for physiotherapy education. Through a user and learner centered design approach, we established an understanding that through *augmentation* and *annotation*, augmented reality technology can enhance physiotherapy education. Augmented Studio enables *augmentation* through projection mapping to display anatomical information such as muscles and skeleton in real time on the body as it moves. We created a technique for *annotation* to create projected hand-drawing on the moving body, to enable explicit communication of the teacher's clinical reasoning strategies to the students. Findings from our pilot usability study demonstrate a more engaging learning and teaching experience and increased communication between teacher and students when using Augmented Studio.

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INTRODUCTION
Physiotherapy is currently taught via multiple modalities, such as lectures, tutorials, demonstrations and hands-on training in practical classes. However, physiotherapy students often struggle to translate the anatomical knowledge from textbooks to dynamic understanding of the mechanics of body movements in real life patients. Moreover, one of the critical skills in physiotherapy, and other clinical domains, is clinical reasoning [1]. The students learn to negotiate the complexity of multiple factors, starting with the mastery of strong domain knowledge, such as human anatomy, to form hypotheses through patient inquiry and to test the hypotheses through examination [1]. Clinical reasoning is particularly difficult to teach because it requires students to critically review clinical decisions which are often ephemeral and tacit [2]. The best practice for learning such skills typically involves a class of students observing an expert therapist conducting a consultation with a real patient (or a surrogate patient). However, such settings do not make the therapist's clinical decision making explicitly available to students. One of the major difficulties for the students in learning clinical reasoning is the ability to identify medical cues to develop diagnostic hypotheses [3].

We are interested in the potential of visualization tools such as augmented reality (AR) for physiotherapy education. We aimed to answer the question '*how can augmented reality technology enhance physiotherapy teaching and learning?'*, by conducting a focus group and field study with physiotherapy teacher and students. Our findings highlighted the two aspects of AR technology that are valuable to physiotherapy education: *augmentation* and *annotation.* Augmentation is the core strength of AR, which can be used in the context of physiotherapy education to provide augmented visualization for better clinical understanding of human anatomy and musculoskeletal structures. Annotation equips the teacher with the ability to explicitly communicate their experience and clinical reasoning strategies to the students [4].

In this paper, we present *Augmented Studio* (see Figure 1), an augmented reality system that uses body tracking to project anatomical structures and annotations over moving bodies. Augmented Studio enables *augmentation* through projection mapping to turn a human body into a display surface, showing the anatomical information such as muscles and skeleton in real time as the body moves. The moving body of a volunteer student becomes a live canvas for the teacher to illustrate clinical reasoning, through *annotations,* in the form of colored hand drawing on the projected body. The annotations enhance teacher and student communication with the purpose of transferring the real life knowledge and experience of the teacher to a class of students.

The contribution of the paper is the design process, implementation, and pilot usability study of Augmented Studio. We established an understanding of how augmented reality technology can enhance physiotherapy education, through augmentation and annotation. We developed an augmented reality system by combining body tracking with projection mapping to enable augmentation and annotation of anatomical knowledge on a moving body. We created a technique called *annotation sleeve* to enable drawing on the projected anatomical model. We conducted a pilot usability study with graduate physiotherapy students and teachers, by running practical classes in the Augmented Studio environment. All participants unanimously agreed that the system enhanced their learning and teaching experience. Our findings also showed increased communications between the teacher and the students using the annotation capability.

RELATED WORK

The application of augmented reality in medical education has been widely implemented in multiple areas, including anatomy, surgery, and real time visualization [5]. To further understand the needs for AR technologies in this area, we summarized the challenges faced in physiotherapy education. We then reviewed previous work on three types of display technologies for physiotherapy education: head mounted display, screen based, and projection-based AR.

Clinical reasoning and Anatomy in Physiotherapy

Clinical reasoning is identified as one of the top sought-after skills in physiotherapy graduate [6]. Clinical reasoning is defined as the entirety of thinking and decision-making processes related to clinical practice [7]. Learners struggle to learn how to detect key features to generate diagnostic hypothesis and how to integrate different facets of information [3]. A review of teaching approaches highlights the needs for explicit instructions and a focus on understanding of basic science mechanisms [4], which, in most cases, is anatomical knowledge.

A modern curriculum for anatomy education uses multiple pedagogical resources, including cadaveric dissection and virtual simulation [8]. Cadaver lab assists students' understanding of 3D anatomical structures through exploration. However, this resource is often limited due to preservation and maintenance cost. Virtual simulation is described in the following sections, using AR technologies.

Head mounted AR

Augmented reality is an interactive medium in which virtual information is overlaid on real world objects [9]. The power to change the perception of reality lends itself to many applications of information visualization for medical education. Kancherla et al. [10] proposed an AR technology that uses a head mounted display (HMD) to allow the overlay of bones over the body. The initial prototype was limited to a low polygon count model of the elbow joint, which could be scaled to match the patient. In the first stage of the development, the system animated the movements of supination (stretching forearm) and pronation (palm facing down) of the forearm at the elbow joints. Virtual Reality Dynamic Anatomy (VRDA) was an improvement on the previous system [11] to extend to a knee-joint model. The system overlaid the digital knee-bone model using an optical see-through HMD and a complex array of motion sensors located around the knee for alignment of the virtual model [12]. The subjective experience reported from the user was described as being akin to powerful and convincing x-ray vision. Continuing with the development, Rolland et al. [13] presented a tool to train medical practitioners in performing surgical operations, using a dedicated optical tracking system and head mounted projection display.

In addition to HMD, a virtual reality (VR) system built by Sakellariou et al. [14] combines haptic and auditory navigation of a 3D representation of the pelvic and abdominal region through vibrotactile gloves and 3D sound. A comparative user trial with student and expert surgeons was conducted with pre- and post-assessment. The results indicated that the VR system provides better comprehension of the spatial relationships of the anatomical structures, with a strong user preference over traditional teaching methods.

Screen-based AR

Another form of AR system uses a computer screen to display augmented information to the users. Magic Mirror, initially known as mirracle [15], is a system that uses body tracking to show organs and internal human anatomy on the user who stands in front of the screen. The display acts as a mirror that overlays virtual anatomical structures on the body, whose movements are tracked by a depth camera in real time. A survey was conducted with medical students and surgeons to rate the precision, usability and learning potential of the system. The results showed the system provides a helpful visualization for anatomy education.

Projection based AR

Spatial augmented reality [16] uses projection to change the user's perception of the physical environment. An example of projection-based anatomy education system is the Spatial Augmented Reality on Person (SARP) [17], which uses a single projector with Kinect tracking to project muscles, skeleton, and internal organs on the body for anatomy education. The authors built a game called Augmented Anatomy where players need to identify the anatomical structure that are projected on their body. An expert, student, and online survey showed positive comments on engagement and increased interest in the subject. The authors also demonstrated reduced identification errors through successive usage.

Rather than being used in an education context, AnatOnMe [18] is designed to improve doctor and patient communication in a clinical setting. Doctors can project on the patient body pictures of internal organs or bones, by pointing a hand-held projector on the patient's body, to educate the patients of medical concepts relevant to their consultations. A design experiment was conducted to assess patients' preferred projection surface: on wall, on a mannequin model, or on the body. Results did not indicate any significant difference in preference between projection on mannequin model and on-body. An expert review with therapists, however, revealed that the hand-held form factor prevents them from having physical contact with the patient, which is a common work practice in physiotherapy.

Although there has been a large body of work on augmented reality systems for anatomy education, previous works are limited to visualization and identification of anatomical structures. Moreover, existing applications are focused on a single user, which does not translate to a classroom model.

In addition to dynamic visualization of anatomical models during movements, Augmented Studio provides annotation capability to enable virtual hand-drawing on the moving body to illustrate anatomical concepts for teaching purposes. Our system uses large-scale projection mapping that is suitable for a classroom model with multiple students. We applied a user and learner-centered design approach to develop the system, specifically targeting maximum student benefit.

METHODOLOGY

We adopted a user-centered design approach by conducting a focus group and a field study with physiotherapy students and a teacher at the University of Melbourne, to answer the question '*how can immersive technology enhance physiotherapy teaching and learning?'*.

Findings from the study indicated that augmentation and annotation are the strength of augmented reality technology in physiotherapy education. The findings informed the design of *Augmented Studio,* an augmented reality learning system for physiotherapy education. The development of Augmented Studio is guided by learner-centered design approaches [19], focusing on the needs of the learner. One dimension of this approach is an understanding of domain knowledge [20], which is provided by Augmented Studio through the projection of anatomical information directly on the body. The concept of scaffolding in learner-centered design [21] refers to additional support provided for the students to engage in activities that they are learning to master. Augmented Studio allows the teacher to draw virtual information on the body, to illustrate their expert clinical reasoning to the students. The teacher uses this annotation capability as a scaffolding tool to provide additional assistance for student's learning.

We conducted a pilot usability study to evaluate the extent to which Augmented studio benefits physiotherapy teaching and learning. The following sections of the paper provide the details of the focus group, field study and pilot usability study.

USER-CENTERED DESIGN

Focus Group

We recruited eight participants from a cohort of final year graduate physiotherapy students through convenience sampling. The participants were presented with a brief presentation on current examples of immersive technology (virtual and augmented reality) in physiotherapy education. Before the presentation, the participants answered a questionnaire regarding their experience with current physiotherapy education methods, in terms of *confidence, satisfaction, education tools, skills mastery* and *feedback.* After the presentation, the participants answered the same questionnaire to discuss their opinions on the potentials of each technology for physiotherapy education. The answers were recorded on a 5-point Likert scale. One researcher prompted the participants to answer each of the questions, then invited a group discussion on the topic of the question. No statistical analysis was performed on the data, as they were used as a probe to encourage discussion. Another researcher took notes with audio recordings.

The focus group indicated that AR technology can provide an exciting and engaging learning experience. The findings from the focus group highlighted two areas of potential for technological innovations in physiotherapy education: providing tactile sensation and enhancing the understanding of surface anatomy.

Tactile

The participants indicated that the demonstrated motor skill learning is most useful for first and second years of learning.

The participants had reservations about the ability of the technologies to reduce cognitive load and increase their "sense of feel". It was discussed that the sense of feel is assisted by the anatomic understanding of the students.

Anatomy

The study highlighted the need for anatomy education. One participant stated that "*the ultimate product would be an augmented reality that overlays the internal anatomy on a real patient, rather than referring to anatomy textbooks"*.

Field Study

The focus group highlighted the potential of immersive technology to be used for anatomy visualization. We then conducted a pilot field study at the Department of Physiotherapy at the University of Melbourne. The focus of the study was to understand the pedagogical practices in physiotherapy in terms of manual skills teaching, in order to inform the design of a teaching assistant system using immersive technology.

Study Design

We observed six practical classes over the first semester of first year students of the Doctor of Physiotherapy program at the Department of Physiotherapy at our university. The majority of the classes were taught by Daniel (anonymized name) and one class was taught by Mary (anonymized name). Practical classes in the first semester of the physiotherapy program focused on assessment skills. The six classes taught the students manual skills for assessing patients balance, conducting clinical practice, and skills related to different parts of the body, including foot, neck, spinal, and thoracic area.

The duration of the class was two hours. Each class covered a number of assessment skills. For each skill, a student would volunteer to act as a patient, or mock patient. The teacher demonstrated the skills in the role of a therapist on the mock patient while the other students gathered around to observe. After the demonstration, the students broke out in group to practice the skills on each other, or peer-to-peer (P2P) practice. The teacher approached each group to provide feedback. The same process was repeated for each skill. The teaching approach as observed in our study is commonly adopted across multiple institutions [22].

Data collection

We used two methods to collect data: observations and informal conversations. The researchers were introduced by the teacher to the students at the start of the class. During the demonstration, the researchers observed the teacher and the students as well as their interactions. During P2P practice, the researchers followed the teacher as he/she approached each group to provide feedback. The researchers also spent time observing the students' P2P practice. When time permitted, the researchers also undertook informal conversations with the students. The researchers took hand written notes throughout the class. The class required the students to wear tight-fitting sportswear; therefore, neither video nor voice notes were used to respect the students' privacy.

The observation data was coded and we performed an inductive thematic analysis to derive trends and themes, which are presented below.

Anatomical references

Throughout the classes, especially during P2P practice, the students constantly referred to the skeleton mannequin in the practical room to verify skeletal structure. This was noticed especially in the class regarding the foot, when the students were required to identify the cuneiform bones that form the arch of the feet.

Correct anatomical identifications were a major theme extracted from the interactions between the teacher and students during skills demonstrations. Throughout the demonstration, the teacher consistently elicited verbal comments from the students, to identify the part of the skeletal and/or muscular structure that the teacher was performing on.

Informal conversations with the students during P2P practice indicated that they often struggle to translate their anatomical understanding onto the patient's body. This was confirmed by the teacher based on their teaching experience.

Body annotation

In Mary's class focusing on thoracic anatomy, the students were instructed to use crayon to mark and draw the locations of the rib bones and the outline of the lungs. Both Daniel and Mary confirmed that the practice of on-body drawing is common in physiotherapy classes. A study by McMenamin [23] who surveyed students using professional body painting as a tool for anatomy education proved the benefits of such practice in physiotherapy education.

Observation viewpoint

During the demonstration of the manual skills, the teacher needed to regularly move around the mock patient, which lead to reshuffling of the students' positions in the classroom in order to optimize their viewpoints of the demonstrations. Furthermore, the demonstration generally involved fine motor skills. The students needed to come quite close to the teacher to be able to fully observe and understand the demonstration.

Note taking

The students were given a paper or electronic version of a practical handbook, which outlines the structures of each practical lessons for the semester. For each manual task, there was generally one photo or a simple diagram illustrating the skill. The researchers observed the students when they were taking notes during the teacher's demonstration. Some students took notes directly on the paper version. Some students took notes using a computer or tablet, either on the electronic version of the practical handbook or using a separate note taking application. There were three different types of notes, as observed by the researcher and confirmed through informal conversation with the students: A) textual description of the teacher's action; B) comments from the teachers on common mistakes or notes regarding the skills; C) personal notes and observations experienced by the student during P2P practice. Note type A was the most challenging due to the limited time allowed for observation and the extra cognitive load on the student to observe and take notes at the same time, which was proven by cognitive psychology researchers [24].

AUGMENTATION AND ANNOTATION – DESIGN GUIDELINES

The focus group highlighted the need and potential for enhanced anatomy visualization for physiotherapy students. Previous work has demonstrated that the use of 3D display technology in anatomical education has proven beneficial in 74% of the applications [25]. These displays have enhanced communication between teacher-student [25] and doctor-patient [18]. Researchers have found that the use of AR systems for anatomical purposes helps not only spatial interpretation but also student motivation [26].

The findings from the field study strengthened the importance of anatomical knowledge and understanding for students in physiotherapy. Our studies derive the design guidelines for a physiotherapy education support system, to focus on *augmentation* and *annotation.* The potential of augmentation and annotation for physiotherapy education is aligned with the concept of scaffolding in learner-centered design [27]. Scaffolding is defined in educational psychology as the support provided to students for mindful engagement in learning [28], to understand the roots of new concepts and processes, as opposed to rote learning. Learner-centered design [20] places a strong focus on the learner's needs, which include dimensions of domain knowledge and strategic knowledge. In the context of physiotherapy education, domain knowledge relates to anatomical understanding and strategic information is embedded in the teacher's experience and clinical reasoning decisions. We aimed to design an augmented reality learning system that supported augmentation and annotation, with the focus on the learner's needs.

Augmentation is the fundamental strength of augmented reality, which is defined as the capability to overlay virtual objects onto the physical world [9]. AR is typically enabled through 3 main display technologies: head-mounted display (HMD) [29], projection [16] and mobile devices [30]. Of the 3 technologies, projection-based AR is the most suitable for a classroom context, considering that the projection can easily be seen by a group of students. Augmented reality systems enable tracking to align virtual information to the physical world, which provides an opportunity to augment dynamic anatomical information onto the physical body. The interactions between the teacher and the students in a physiotherapy class are focused around the understanding of dynamic anatomical knowledge on a moving body of the patient as well as implicit clinical reasoning, typically illustrated in the form of on-body annotations.

Figure 2. Augmented Studio setup: projected skeleton model on a student volunteer

Annotation is a common application of AR systems to provide contextual information related to a real world object [31, 32]. Annotation is frequently used in physiotherapy education [8], especially in the form of body painting [23], for the teacher to explicitly illustrate their clinical reasoning decisions. Body painting, however, is a time consuming process, which often takes up to 40 minutes to paint a feature or section of the body [23]. In addition, body painting does not allow easy modification or annotation.

AUGMENTED STUDIO

Based on the design principles of augmentation and annotation, we designed and built the initial prototype of the Augmented Studio, to enhance student learning in physiotherapy using spatial augmented reality annotation on moving bodies.

The Augmented Studio provides a stage (approximately 3mx3m, as shown in Figure 3) in which a teacher can interact with a surrogate or student patient in a lecture or practical class setting. Skeletons and muscles models are projected directly onto the patient's body (see Figure 2), and move with the patient, allowing the teacher to explain the movements of muscles, joints and ligaments dynamically.

Spatial learning environment

The Augmented Studio can be set up in a classroom scenario in a lecture theatre or practical room. A patient (or surrogate) stands on the stage and the movements of the patient are mapped to the virtual skeleton or muscle model, which is projected directly on the body of the patient. Anatomical knowledge about human movements come to life on the stage as the teacher asks the patient to perform simple to complex movements to demonstrate the kinesiology understanding of muscles, joints, and bones in the body. The patient's body becomes a live canvas for the teacher to illustrate clinical reasoning. The teacher can draw annotations directly on the virtual body, through mouse input on a desktop system, which are rendered in real time on the patient's body. The annotations are displayed as colored hand drawings on the skeleton or muscle, to identify certain anatomical structures or to illustrate the joints or muscle connections. In a traditional practical class, the teacher uses still photos, figures, and diagrams which do not capture the real time and complex dynamics of the human movements.

Hardware setup

The stage area of the system is made up of four tripods connected with four cross beams, to create a 3x3x3m volume, called the stage. Two projectors and two Microsoft Kinect sensors are mounted on two adjacent beams. Projection screens are dropped from the beams opposite the projectors. White sheets are used to cover the floor. The result is a three-sided stage with two white walls and a floor for projection mapping. The projectors are positioned in way that their projected images cover the entire stage. Current size 3x3 supports group of classroom up to 15 students gathering around the projected body, similar number to traditional class as observed in design process. The design is scalable to larger size with addition of projectors.

The Augmented Studio setup can be deployed easily in existing medical classroom settings. Figure 3 shows the setup in a corner of a physiotherapy practical classroom. To minimize interference with classroom flow, we only use depth cameras to perform skeletal tracking of movements of body segments. Other technologies such as electromyography sensors [33] or embedded textile sensors [34] require intrusive and cumbersome sensors to track detailed muscle activities.

Calibration

Calibration is completed using the Microsoft RoomAlive toolkit [35]. The toolkit uses projectors and Kinects to estimate in real-time the 3D world coordinate of the stage using structured light calibration [16, 36], which enables projection mapping in the entire volume of the stage. In other words, the system can project virtual information on all surfaces within the tracking volume. After the stage calibration, we combine the result with body tracking using Microsoft Kinect to track a moving body within the stage. We developed an application using the Unity3D game engine that combines projection mapping calibration and Kinect body tracking to project onto the patient's body. The result is the ability to project a 3D virtual model, whose movements are controlled by a moving body, directly onto the physical surfaces of the same moving body. Implementing RoomAlive for a large scale is an important contribution to support classroom settings.

Model Preparation and Animation

While previous work adopted a time consuming and expensive process to reconstruct anatomical models from medical imaging [15], we opted for purchasing an off-the-shelf anatomical model which was verified by field experts to determine suitability and accuracy. We purchased a high polygon count muscular system model, including all major deep and external muscles. We invited a physiotherapy lecturer and an anatomy imaging researcher to review the model, both of whom validated its accuracy and deemed the model as fit for educational purposes. The model was properly rigged, which is the process that binds the 3D mesh of the model with an internal skeleton structure, for properly articulated animation of the model [37]. We employed the service of a 3D modeling artist to calibrate the rigged skeleton of the model for Kinect skeletal tracking [38], by adjusting the relative locations of the joints to the model to match with positions of the tracked joints relative to the human body, as reported by Kinect skeletal tracking. The model is then scaled to match the size of the human body that it is projected on.

Figure 3. Hardware setup of Augmented Studio: 3x3x3m tracking volume with three sided projection screen and two projectors

We used a single mesh model containing all the muscles. In order to have realistic muscle animation for anatomical teaching, we applied the process of manual skinning, completed by the 3D modeling artist, with the expert input of a physiotherapy lecturer. Skinning is the process of binding the 3D mesh to the skeleton rig to enable accurate deformation of the mesh during animation [39]. We conducted multiple iterations of skinning and validation via projection on a test subject to achieve maximal animation accuracy for physiotherapy lessons. The validation was completed with an expert lecturer in physiotherapy.

Annotation

Based on our findings from the field study, annotation via hand drawings directly on the body were used as a common learning method, to identify certain anatomical structures or to illustrate the joints and muscle connections. We developed an annotation capability that enabled hand drawings, via mouse input, over the virtual model and the physical body of the students.

Moving annotations

For drawing over the muscles we used an extension on Unity3D called *Paint in 3D*[1]. This extension does not use the classic model for collision detection based on simplified primitives. The extension uses Mesh Colliders[2] in Unity3D, which uses ray casting to draw colors on 3D meshes. The

[1] http://u3d.as/ayF

[2] https://docs.unity3d.com/Manual/class-MeshCollider.html

model we used has a high polygon count, making collision detection a time consuming and resource intensive task. Therefore, real time annotation on a complex model using this method is challenging.

Real time annotations on physical body

Spatial AR requires a physical substrate for projection, which, in Augmented Studio, is the skin surfaces of the human body. In the physiotherapy context, as observed from the field study, there is a need to annotate on both the body and the anatomical structures, such as skeleton and muscles.

When the virtual model and the physical substrate overlaps, for example, the muscular system model, virtual hand drawing annotation can be drawn directly on both the virtual model and the physical body. However, for the skeleton model, the virtual model does not cover the entirety of the body surfaces of the human body. Therefore, we designed a method called *annotation sleeve,* to enable real time hand drawing on both the virtual model and the physical body surfaces. Instead of painting directly on the anatomy model, we created transparent cylindrical convex simple polyhedrons that wrap around the body segments, such as arms, legs or trunks. The sleeve represents the physical body surfaces. The annotation sleeve is a simpler model for calculating collision detection, resulting in a faster performance, as compared to drawing directly on the complex muscular model.

With this solution we can use complex models with high polygon count for real time annotation. We reshaped the annotation sleeve to closely match the muscle mesh while still keeping a low polygon count. The annotation sleeve enables direct hand drawing annotation on complex models (see Figure 4 left) as well as creating a transparent surface to match with the physical substrate for drawing (see Figure 4 right). The low-count polygon with the annotation drawn on it is stretched based on the user's movement. The annotation sleeve is the virtual representation of the body surface, on which the virtual projections reside. Overall, the annotation sleeve bridges the virtual and physical world. Annotation sleeve can be modeled to represent the physical substrate of projection, which is the patient's body. This works particularly well for anatomical models of internal organs or skeletal structures.

User interface

Augmented Studio runs as a standalone Unity3D application (see Figure 6). We used two separate computers for calibration, as each Kinect sensor requires a dedicated computer. After calibration, the system runs on a single machine with multiple display output for the projectors, to which a single Kinect sensor is connected for body tracking.

When the system is running, a student who volunteers to act as a patient can step onto the stage and perform a T position by standing upright, legs together and outstretching both arms horizontally. Once the system detects the T position

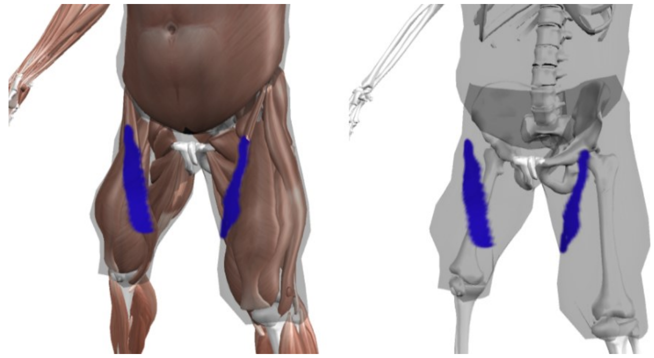

Figure 4. Annotation sleeve (in grey) with drawing in blue to highlight the satorius muscle: Left: on muscular model – the sleeve is modelled tightly around the muscles; Right: on skeleton model, the sleeve acts as a virtual represenation of the body surface for drawing.

(see Figure 2), it will lock the body tracking and projects the virtual model onto the student. The teacher and other students can gather around the volunteer and begin class.

At run time, the system displays the virtual anatomical model in the Unity3D workspace on the computer screen, that captures the movement of the volunteer, while showing the projection on the stage. The workspace allows panning, zooming, and rotation navigation. Currently the annotation capability is completed via a desktop interface using mouse input. The teacher on the stage can perform a gesture to indicate where he/she would like to draw on the volunteer's body, as shown in Figure 5. A student is positioned in front of the computer to draw annotation on the virtual model using mouse input, as indicated. Single point hand tracking can be incorporated in future version of Augmented Studio to enable direct annotation. The system supports three colors blue, green, and red. An eraser is also available. Color and eraser selection is performed via keyboard input.

Benefits

The Augmented studio presents an innovation of novel pedagogical practice delivering benefits to both the teacher and the students. The system aims at enhancing the student learning experience with augmented kinesthetic information and annotated information, provided by the teacher to support interactive observation with augmented visualization, for better clinical understanding of human anatomy and musculoskeletal structures. This will enhance appreciation by students of dynamic change in anatomical configuration of the body through three dimensions.

Compared to previous projection-based systems [17, 18], Augmented Studio provides a tracking volume that allows the volunteer to move freely within the stage without breaking the alignment of the virtual model.

PILOT USABILITY STUDY

We conducted a pilot usability study to evaluate annotation as an original design feature of Augmented Studio. Our hypothesis is that *Augmented Studio enhances the teaching* *and learning experience for physiotherapy education, through augmentation and annotation.*

Data collection
We recruited graduate physiotherapy students to participate in manual therapy classes, with additional content that was not part of their curriculum, using Augmented Studio. Each class was approximately 15 minutes and was taught by lecturers from the physiotherapy department, who had not been involved with the development of the technology. During class time, the researcher observed and took notes.

After the class, the students completed a questionnaire to evaluate the success of the system for the purpose of physiotherapy education. We adapted DeLone and McLean's model of information system success [40] and another similar approach to evaluate education systems [41] to structure the questionnaire into 5 categories: Learner experience, use intention, system quality, content quality, and overall experience. The participants answered each question in the categories with a 5-point Likert scale (1 for strongly disagree and 5 for strongly agree).

A group discussion with the teacher and participants was conducted at the end to discuss the learning experience, with regards to the communication among the students and towards the teacher. The researcher provided some discussion topics in the form of questions for the students and the teacher. The questions asked about their preferences, comments about performance and limitations, and suggestion for improvements. The participants were encouraged to discuss other topics outside of the provided questions. Video recordings were captured and the researchers took notes during the discussion.

The self-rated questionnaire and discussion enabled us to evaluate the experience of the teacher and students with Augmented Studio, in accordance with our design hypothesis. In this first iteration of the system, we did not aim to evaluate learning benefits in terms of student's performance and/or assessment outcomes.

Participants
Participants were graduate students of physiotherapy from the University of Melbourne. We recruited 9 students (age from 21 to 29, mean 24.7, SD 2.27), 2 teachers and 1 observing teacher. The students were from multiple year levels (2 first years, 3 second year and 4 final year), with 3 males and 6 females. The students and the observing teacher completed the questionnaires. All participants joined the discussion. The participants were recruited through messages posted on the LMS (learning management system) forums of the physiotherapy department.

Task
Each participant attended a 15-minute physiotherapy practical class in a group. The class focused on movement analysis and clinical reasoning skills related to the hip joints. The students were required to understand and be able to analyze a series of movements including kick, squat, single-

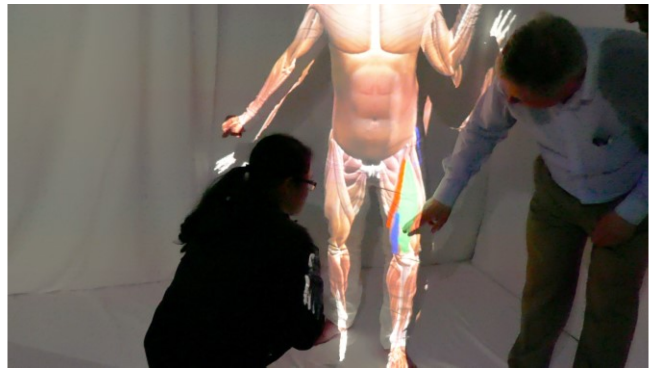

Figure 5. Projected annotation in the form of colored hand drawing on a volunteer's body in a classroom.

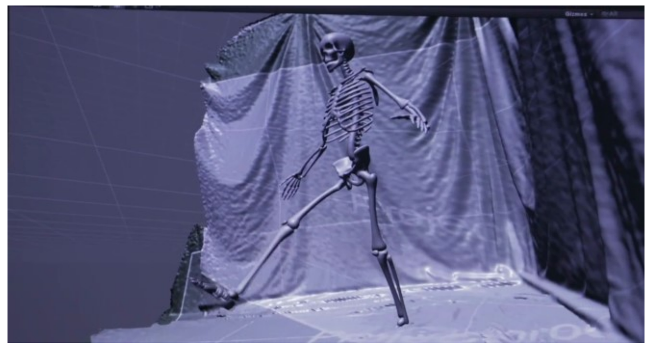

Figure 6. The desktop interface: skeleton model mapped to the volunteer movement on the stage; and the mesh model of the projection sheets that represent the stage

foot squat. The participants then completed the questionnaire and participated in the group discussion. The total time required for each participant was 45 minutes on average. The participants were compensated with a $15 gift voucher.

Procedure
We conducted the classes in one of the practical rooms in the physiotherapy building at our university. We transported all the infrastructure in a section of the practical class the day before. A 3x3x3m stage projection area was set up with two projectors and two Kinect sensors. We ran three classes throughout the day, with an average of three student participants per class. A lab member who is not involved in the development of the system volunteered to participate in the class as the patient. To maximize the projection effect, the volunteer wore a long sleeved white t-shirt and jeans.

Before the class, the participants were briefed with a written plain language statement and a verbal description of the system by the researcher. The class used two virtual anatomy models: skeleton and muscular. As indicated by the teacher during the class, the models were switched, by a researcher at the computer station next to the stage setup. We implemented a partial wizard of oz approach to annotation. The teacher used the annotation feature, by tracing a finger on the projection on the volunteer's body and indicating verbally that the gesture was for annotation. The researcher at the computer station would trace the same path on the virtual model on the screen using a mouse. The teacher could choose between three colors, green, red, or blue, which were also indicated verbally to the researcher. The resulting effect looked as if the teacher drew an annotation directly on the volunteer using their finger. This technique was intended to simulate the future capability of direct annotation for the system. The annotation remained on the body, even when the skeleton and muscle models were switched. Deletion of annotation was completed with a similar process. After the class, the students completed the questionnaires, then re-grouped with the teacher for the group discussion.

Results

We ran descriptive statistics on the questionnaire data. No formal statistical analysis was performed due to the nature of the pilot study. Coded analysis with a theoretical thematic approach [42] was ran on observation notes and group discussion transcript.

Table 1 shows the mean and standard deviation of the questionnaire data. It can be seen that Augmented Studio received a positive response on the majority of factors (mean>4.0). Among the highest scores are satisfaction, enjoyment, improvement with anatomical and kinesiology understanding, useful drawing and visualization, and compelling projection technology.

Such positive responses were also observed during the class. All participants expressed amazement during class, especially when the model switched over and they saw the projected skeleton on the volunteer for the first time. The class started with a muscle model projected on the volunteer.

The teacher also invited students to annotate, using the same method as the teacher, as a way of encouraging participation. During the group discussion, all the participants including teachers unanimously agreed that Augmented Studio enhanced their teaching and learning experience.

Category	Description	$\bar{x}$	SD
Overall	Assist learning	4.3	0.48
	Satisfaction	4.1	0.57
	Self-rated success	4.1	0.57
Experience	Better than traditional class	3.9	0.57
	Enjoyment	4.6	0.52
	Fulfil educational needs	3.9	0.74
	Improves communication	4.3	0.67
	Encouraging communication	4.3	0.67
	Efficient	3.7	0.82
	Would recommend to peers	4.8	0.42
	Would use regularly	4	0.67
Use Intention	Teacher proficiency	4.1	0.99
	Improves understanding of: * anatomical structures	4.6	0.52
	* kinesiology	4.1	0.74
	* anatomy movement	3.7	0.95
	Drawing is useful	4.5	0.53
	Visualization is useful	4.6	0.52
System Quality	Projection is compelling	4.5	0.71
	Projection quality	3.9	0.74
	Adaptability	4.4	0.52
	Responsive	3.4	0.84
Content quality	Model quality	4.2	0.42
	Model resolution	3.8	0.42
	Model accuracy	3.8	0.42
	Sufficient annotation details	4.0	0.67
	Model relevance	4.4	0.52

Table 1: Mean and SD values for questionnaire data from students and observing teacher

DISCUSSION

Overall, the pilot usability of Augmented Studio was a success. The system was greatly complimented by both the teachers and the students. There are two common themes arising from the observation notes and the group discussions. The benefits of Augmented Studio are its ability to enhance the student's learning experience and increased communications between the teacher and the students.

Enhanced experience

Dynamic movements

During the group discussions, all the participants unanimously agreed that their learning had been enhanced in multiple ways. The students found it extremely useful being able to see dynamic movements of anatomical structures. Existing methods of learning anatomy using 3D models only allows viewing a static 3D anatomical model on a computer screen or a pre-recorded animation of movements. The students preferred Augmented Studio because it provides more relevant information with the ability map the 3D model to physical movements.

Scalable tracking volume for tracking and projecting in multiple directions. Current setup has two projectors at 90 angle providing front and side projection on the body. During pilot study, the teacher referred to and annotated on the side of the body in multiple occasions. The volunteer can also move freely around the tracking volume. Previous work [17] only has front view, requires the person to stand still, and does not have the annotation feature.

Cadaver lab

The students compared the experience to cadaver lab, which is proven to help the understanding of 3D anatomical structures for guided dissections by expert demonstrators [8]. The students saw the potential of Augmented Studio to provide similar anatomy learning benefits, with the advantage of seeing the body in movement. A participant commented that even in cadaver lab, you cannot see all the muscles clearly.

Annotations

The annotations on both the skeleton and muscle model helped clarify the attachment of muscles on the body and their functions during movements. One of the students commented that *"I have been to a similar class a thousand* *times, but for the first time, I understand what the internal rotator muscles do",* thanks to Augmented Studio.

The students uniformly agreed that the simple annotations of colored lines drawn on the body were exceptionally helpful. Three participants (P1, P2 and P4) commented that at times, just the drawing annotations were enough to illustrate the dynamics of the movements. One student explained that *"seeing (anatomical information) in movement is appealing"* (P1) and *"engaging"* (observing teacher), and that *"the line of pull of the muscle (annotation drawing) helps understand which direction the muscle is going"* (P6).

One student had such a positive experience that they commented that *"I gained more confidence for my upcoming test",* even though the material covered in the sample class was designed not to overlap with their curriculum.

Increased communication

One observation from the study was that the teacher encouraged the student to perform annotations during class, by tracing their finger on the volunteer's body. The researcher then drew the annotations in real time. Compared to previous notes from the field study, this type of interaction was not observed in the traditional classroom. During the group discussion, both the teacher and the students observed that the annotation capability of Augmented Studio encourages engagement and more interactions between the teacher and the students. Figure 7 captures a moment in the class when the teacher and a student were engaged in the annotations on the volunteer's body. Projection on the white sheets can also help to display other relevant contents for the class, similar to the white board in traditional classrooms. It is important that the system supports large scale projection to match classroom size, where students gather around the teacher and a volunteer mock patient.

By encouraging the students to annotate, the teacher could effectively gauge their understanding of the class content. The observing teacher commented that the normal practical classroom is often very *"dry, and awkward to manipulate the mannequin into the correct posture to illustrate muscle movements".* The students exclaimed that the annotations were *"very helpful, relevant, and highly interactive".*

Limitations and Improvements

Despite the positive responses to the Augmented Studio system, participants also highlighted some limitations and suggestions to improve the system. We used two projectors for the study to provide the front and side view of the projections on the volunteer's body. However, it was noted by the teacher and the students that they desired to see the posterior view to illustrate the activities of the hamstring muscle at the back of the leg. Future implementation of Augmented Studio can expand to accommodate more projectors to enable this.

One of the suggestions from the participants was the ability to highlight certain groups of muscles by rendering it in a different color. Another participant commented that they would have liked to visualize different layers of the muscles. Both of those features can be supported through semantic labeling of the anatomical model. Currently the virtual anatomical model used in Augmented Studio does not have any semantic information; in other words, individual muscles are not labelled, therefore, they cannot be identified by the system. The annotation capability of Augmented Studio provides a means to manually highlight muscles using hand-drawing. Future versions of the system will implement a semantic virtual model with labeling.

Figure 7. Teacher and student interaction through annotations on a skeleton model

Tracking issues were also noted by the researcher. However, during the group discussion, participants commented that they were not concerned that tracking did not always present a perfect match between muscles and their relative location on the body, because the anatomical visualization still matched their existing knowledge and understanding.

A final improvement identified during the field study is the requirement for annotations to extend to note taking. The current implementation of the Augmented Studio only allows for hand drawing annotations. There is a potential for future development to incorporate note taking for students during the class. Future study can focus on the advantage and drawbacks of annotations for the students.

CONCLUSION

We have presented the successful application of Augmented Studio to enhance teaching and learning in physiotherapy. We have drawn the connection between physiotherapy education and augmented reality technology through its capability in augmentation and annotation. These findings guided our design and implementation of Augmented Studio, focusing on its features of projection mapping to display virtual anatomical structures on the moving body and projected hand-drawing annotations to illustrate teacher's expert clinical reasoning strategies. Our pilot usability study highlights the true advantage of Augmented Studio to engage the students in a highly interactive communication medium with the teacher, leading to enhanced learning and teaching experiences.

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