Augmented Studio: Projection Mapping on Moving Body for Physiotherapy Education

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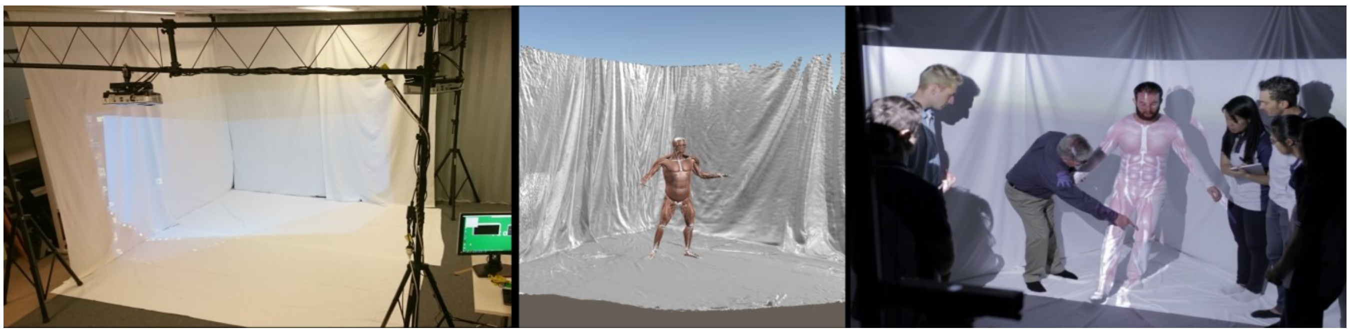

Figure 1. Augmented Studio setup: Left: the 3-sided stage, including scaffolding and 2 projectors with 2 Kinect sensors, set up in a physiotherapy practical classroom; Middle: the stage is captured virtually through projection mapping with a virtual anatomy model; Right: projected virtual anatomy model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

ABSTRACT

Physiotherapy students often struggle to translate the anatomical knowledge from textbooks to 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 enable projected hand-drawing on moving body, for explicit communication of teacher's clinical reasoning strategies to the students. Our findings from a design evaluation study demonstrate a more engaging learning and teaching experience and increased communications between the teacher and the students using Augmented Studio.

Author Keywords

Projection mapping; spatial augmented reality; annotation; physiotherapy education.

ACM Classification Keywords

H.5.1 [Multimedia Information Systems]: Artificial, augmented, and virtual realities; K.3.0 [Computers and Education]: General

INTRODUCTION

Physiotherapy is currently taught via multiple modalities, such as lectures, tutorials, demonstration 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, as well as other clinical domains, is clinical reasoning [12, 20]. The students learn to negotiate the complexity of multiple factors, starting with the mastery of strong domain knowledge, such as human anatomy, to form hypothesis through patient inquiry and to test the hypothesis to examination [20]. Clinical reasoning is particularly difficult to teach because it requires students to critically review clinical decisions which are often ephemeral and tacit [33]. 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 hypothesis [1].

We are interested in the potential of visualization tools such as augmented reality (AR) in the area of physiotherapy education. We aim to answer the question of '*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 [9].

In this paper, we present the *Augmented Studio,* 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 in to 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 evaluation 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 anatomical model. We conducted a design evaluation study with graduate students and teacher in physiotherapy, 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 Augmented Studio 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 [21]. We reviewed previous work in this area, focusing on three types of AR display technologies: head mounted display, screen based, and projection-based AR.

Head mounted display

Augmented reality is an interactive medium in which virtual information is overlaid on real world objects [2]. The power to change the perception of reality lends itself to many applications of information visualization for medical education. Kancherla et al. [22] proposed an AR technology that uses head mounted display (HMD) to allow the overlay of bones over the body. The initial prototype is limited to a low polygon count model of the elbow joint, which can be scaled to match the patient. In the first stage of the development, the system animates 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 [3] to extend to a knee-joint model. The system overlays 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 [37]. The subjective experience reported from the user was described as powerful and convincing x-ray vision. Continuing with the development, Rolland et al. [36] presented a tool to train medical practitioners in performing surgical operation, using a dedicated optical tracking system and head mounted projection display.

In addition to HMD, a VR system built by Sakellariou et al. [39] combines haptic and auditory navigation of a 3D representation of the pelvic and abdominal region through vibrotactile glove and 3D sound. A comparative user-trial experiment 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 method.

Screen-based AR

Another form of AR system uses computer screen to display augmented information to the users. Magic Mirror, initially known as miracle [5, 25], is a system that uses body tracking to show organs and internal human anatomy onto the user who stands in front of a 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 a positive response that the system provides helpful visualization for anatomy education.

Projection based AR

Spatial augmented reality [4] 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, 18], 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 subject interest. The authors also demonstrated reduced identification errors through successive usage.

Instead of being used in an education context, AnatOnMe [30] is designed to help doctor and patient communicate 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 patient's preference of the projection surface on wall, a mannequin model, or on body. The results did not indicate any significant difference in preference between projection on mannequin model and on-body. An expert review with therapists revealed that the hand-held form factor prevents them from physical contact with the patient, which is a common work practice in physiotherapy.

Limitations

Although there has been a large body of work on augmented reality systems for medical, especially anatomy, education, previous works are only 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.

Augmented Studio provides annotation capability to enable virtual hand-drawing on 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 user and learner-centered design approach to develop the system, specifically targeting for students' benefits.

METHODOLOGY

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

Our 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 [40], focusing on the needs of the learner. One dimension of the learner's need is an understanding of domain knowledge [43], which is provided by Augmented Studio through projection of anatomical information directly on the body. The concept of scaffolding in learner-centered design [14] 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 enhance student's learning.

We conducted a design validation 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 validation study.

USER-CENTERED DESIGN

We conducted a focus group and a field study to understand the practice and challenges of physiotherapy education.

Focus Group

We conducted a focus group with final year physiotherapy students to explore the potential of emerging technologies for physiotherapy education, especially for manual skills. We recruited eight participants from a cohort through convenience sampling.

The participants were presented with a brief presentation on current examples of the usage of immersive technology (virtual and augmented reality, VR/AR) in physiotherapy education [CITE]. Before the presentation, the participants answered a questionnaire regarding their experience with current physiotherapy education methods, in terms of *confidences, 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. Another researcher took notes. The session was video recorded.

The questionnaire was used as a probe to encourage discussion. No statistical analysis was performed on the data. The questions were presented as an open statement to prompt discussions. For example, the statement on *confidence* says: 'This technology could improve my confidence in manual therapy (MT) training'; on *satisfaction:* 'This technology could enhance the way MT is taught'; on *education tools:* 'I would use this technology if it was made available in my course'; on *skill mastery:* 'This technology would improve my skills mastery in MT'; and on *feedback:* 'This technology would facilitate unsupervised practice through augmented feedback'.

The focus group indicated that AR technology can provide an exciting and engaging learning experiences. 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 year of learning. Further questions revealed that the tracking technology may not be precise enough for the type of motor skill they are 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 anatomically understanding of the students.

Anatomy

The focus group highlighted the need for anatomy education. One participant quoted that “*the ultimate product would be an augmented reality that overlaid the internal anatomy on a real patient, rather than trying to think back to anatomy textbooks”.*

Field Study

The focus group highlighted the potentials of immersive technology on anatomy visualization. We then conducted a pilot field study in collaboration with the Department of Physiotherapy at [anonymized] university. The focus of the study is 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 5 practical classes over the first semester of first year students of the Doctor of Physiotherapy program at the department of physiotherapy at the University [name removed for review]. 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 5 classes taught the students manual skills for assessing patients balance, conducting nursing practice, and skills related to different parts of the body, including foot, neck, spinal, and thoracic area.

The duration of the class was 2 hours. Each class covers a number of assessment skills. For each skill, a student would volunteer to act as a patient, or mock patient. The teacher demonstrated 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 is repeated for each skill. The teaching approach as observed in our study is commonly adopted across multiple institutions [26].

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 skill demonstration by the teacher as well as the interactions between the teacher and the students. 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. If time permits, the researchers made 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.

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. It was noticed especially in the practical about 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 he (Daniel) was performing on.

Informal conversations with the students during P2P practice confirmed the findings that they often struggle with translating their anatomical understanding onto patient’s body. The teacher also confirmed the fact 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 [27] 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 regularly moved around the mock patient, which lead to the constant 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 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 [34].

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 [11] has proven beneficial in 74% of the applications. This displays have enhanced communication between teacher-student [11] and doctor-patient [30]. Researchers have found that the use of AR systems for anatomical purposes help not only spatial interpretation but also student motivation [10].

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 potentials of augmentation and annotation for physiotherapy education is aligned with the concept of scaffolding in learner-centered design [24]. Scaffolding is defined in educational psychology as the support provided to students for mindful engagement in learning [6], to understand the roots of new concepts and processes, as opposed to rote learning. Learner-centered design [43] 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 aim to design an augmented reality learning system that supports 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 [2]. AR is typically enabled through 3 main display technologies: head-mounted display (HMD) [29], projection [4] and mobile devices [13]. Of the 3 technologies, projection-based AR is the most suitable to for a classroom context, considering that the projection can easily be seen by a group of students. Augmented reality system enables 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 is focused around the understanding of dynamic anatomical knowledge on a moving body of the patients as well as implicit clinical reasoning, typically illustrated in the form of on-body annotations.

Annotation is a common application of AR systems to provide contextual information related to a real world object [38, 44]. Annotation is frequently used in physiotherapy education [41], especially in the form of body painting [27], 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 [27]. The visualization on body painting does not allow easy modification or annotations.

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) 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, 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 comes to life on 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 body becomes a live canvas for the teacher to illustrate clinical reasoning. Using a computer, the teacher can draw annotations directly on the virtual body, which are rendered in real time on the patient's body. The annotations are colored hand drawing 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 diagram 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 4 tripods connected with 4 cross beams, to create a 3x3x3m volume, called the stage. Two projectors and two Microsoft Kinect sensors are mounted on 2 adjacent beams. Projection screens are dropped from the other 2 beams opposite the projectors. White sheet is used to cover the floor. The result is a 3-sided stage with 2 white walls and a floor for projection mapping. The projectors should be positioned in way that their projected images cover the entire stage. Each Kinect is assigned to one of the projectors and it must see most of the image that its projector is projecting and some of the projected image of the other project.

Calibration

Calibration is completed using Microsoft RoomAlive toolkit [19]. The toolkit uses projectors and Kinects to estimate in real-time 3D world coordinate system of the stage using structured light calibration [4, 35], 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 combined the result with body tracking using Microsoft Kinect to track a moving body within the stage. We developed a Unity application that combines projection mapping calibration and Kinect body tracking to project on the patient 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.

Figure 1. A setup of the Augmented studio with muscle model projected on a student

Model Preparation and Animation

While previous work adopted a time consuming and expensive process to reconstruct anatomical model from medical imaging [5], we opted for purchasing off-the-shelf anatomical model and verified with field expert 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 is fit for educational purpose. 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 [42]. We employed the service of a 3D modeling artist to calibrate the rigged skeleton of the model for Kinect skeletal tracking [23], 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.

In Augmented Studio, we only use depth camera to perform skeletal tracking of movements of body segments. This method of tracking does not provide sufficient information regarding muscle activities, such as contraction or extension. Other technologies such as electromyography sensor [31] or embedded textile sensor [28] are required to track such detailed muscle activities. Therefore, we used a single mesh model, containing all the muscles, as there was no need for individual animation of muscle activities. However, in order to have realistic muscle animation for anatomical teaching, we applied the process of manual skinning, via 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 [15]. 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

One of the observations from the field study is that the students and teacher uses crayon to draw on the body to identify certain anatomical structures or to illustrate the joints and muscles connections. This observation motivated us to design an annotation tool for Augmented studio. These annotations are drawings over the muscle surface.

Because the projections and movements are in real time, we focus on three objectives for this drawing annotations system:

- Drawing over the muscle surface must be fast and continuous, just as using a physical whiteboard.
- Drawings must remain fixed relative to the body as the patient moves into different postures.
- User can navigate around the avatar and zoom in to the area to draw.

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. From the user pointer location, a ray is cast in to the 3D

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

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

environment, if the ray collides with a surface, this surface is colored. With the use of this extension, drawing is possible, but is not fast or continuous. The model we use has a high polygon count, making collision detection a time consuming and resource intensive task. Therefore, real time annotation on complex model using this method is challenging.

Real time annotations on physical body

Spatial augmented reality 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 the virtual model. In order to solve the problem of real time annotation on complex anatomy model, we designed a method called *annotation sleeve.* Instead of painting directly on the anatomy model, we created transparent cylindrical non-convex simple polyhedral that wraps around the body segments, such as arms, legs or trunks. Jiménez in [16], explains how convexity is important for performance, and this approximation will run in real time.

With this solution we can use complex models with high polygon count, and paint over it on real time. The paint will be floating over the muscle, but close to it surface. Using Maya (3D modeling application), we reshape the basic figure to have similar surface as the muscle mesh but keeping it with as minimum faces as possible. The annotation sleeve enables direct hand drawing annotation on complex models. In some cases, such as a skeleton model, the sleeve creates a transparent surface for drawing.

Figure 2. Annotation sleeve

Figure 3. Projected annotation sleeve on the mock patient.

3D Annotations using 2D input

To navigate we use the same principle of interface detection on the annotation sleeve. Using the mouse, the user can click on a muscle area were the annotation will be drawn. The camera will focus on this area letting the user zoom in and out using the scroll wheel. Users can left click and draw the mouse (up down left right) to rotate around the selected area and have a better view of the area for drawing. The final system integrates colors blue, green, and red. An eraser is also available; this is used similar to drawing a color but removes it. Color and eraser selection is performed via keyboard input.

The annotation sleeve enables direct hand drawing annotation on complex models. In some cases, such as a skeleton model, the sleeve creates a transparent surfaces for drawing.

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 specifically well for anatomical models of internal organs or skeletal structures. The annotation sleeve is the virtual representation of the body surface, on which the virtual projections reside.

User interface

Benefits

The Augmented studio presents an innovation of novel pedagogical practice delivering benefits to both the staff and the students. The system aims at enhancing the student learning experience with augmented kinaesthetic 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 3 dimensions and the ability to track a full motion and change throughout range.

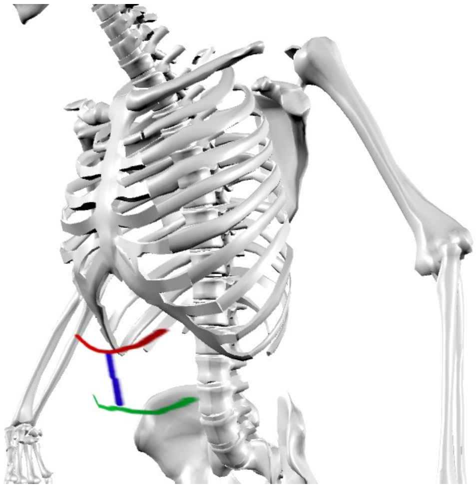

Figure 4. Annotation sleeve on skeleton model

DESIGN VALIDATION STUDY

We conducted a design validation study to evaluate Augmented Studio. Our design 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 contents that are not part of their curriculum, using Augmented Studio. Each class was approximately 15 minutes and will be taught by a lecturer from 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 [8], as well as similar approach to evaluate education systems [32], 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 preference, 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 do not aim to evaluate learning benefits in terms of student's performance and/or assessment outcomes.

Participants

Participants were graduate students of physiotherapy from [anonymized for review]. We recruited 9 students (age from 21 to 29, mean 24.7, SD 2.27), 2 teachers and 1 observing teacher. The students are from multiple year level (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 min 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 analyse a series of movements including kick, squat, single-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.

Procedure

We conducted the classes in one of the practical room 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 2 projectors and 2 Kinect sensors. We ran 3 classes throughout the day, with an average of 3 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 long sleeve 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 2 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. 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 3 colors, green, red, or blue, which was also indicated verbally to the researcher. The resulting effect looked as if the teacher drew annotation directly on the volunteer using their finger. This technique was intended to simulate future capability of direct annotation for the system. The annotation remained to be seen, 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. Notes from observation and the transcribed group discussion were coded with a theoretical thematic analysis approach [7].

Table XXX 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 on the volunteer, using the same method as the student, as a way of encouraging participations and

During the group discussion, all the participants including teachers unanimously agreed that Augmented Studio has enhanced their teaching and learning experience.

Category	Description	Mean	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 with system	4.1	0.99
	Improves anatomical understanding	4.6	0.52
	Improves understanding of kinesiology	4.1	0.74
	Improves anatomy movement understanding	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 details for annotation	4	0.67
	Model relevance	4.4	0.52

DISCUSSION

Overall, the design evaluation 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 enhanced student's learning experience and increased communications between the teacher and the students.

Enhanced experience

During the group discussions, all the participants unanimously agreed that their learning has 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 model only allows viewing 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.

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 she had been to a similar class a thousand times, but for the first time, she understood what the internal rotator muscle does, thanks to Augmented Studio.

Increased communication

It was noticed 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 interactions was not observed in traditional classroom. During the group discussion, this observation was validated by both the teacher and the students that the annotation capability of Augmented Studio encourages engagement and more interactions between the teacher and the students. By encouraging the students to annotate, the teacher could effectively gauge their understanding of the class contents. The observing teacher commented that the normal practical classroom is often very "dry, and awkward to manipulate the skeleton mannequin into the correct posture to illustrate the concept of muscle movements'. The students exclaimed that the annotations were "very helpful, relevant, and highly interactive".

Limitations and improvement

The participants highlighted areas of limitations and suggestions for improvement to the system.

We used 2 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 is the ability to highlight certain or groups of muscles by rendering it in a different color. Another comment from the participants is to be able to visualize different layers of the muscles. Both of those features can be supported through semantic labeling of 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, cannot be identified by the system. The annotation capability of Augmented Studio provides a mean to manually highlight muscles using hand-drawing. Future version of the system will implement semantic virtual model with labeling.

CONCLUSION

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 enable projected hand-drawing on moving body, for explicit communication of teacher's clinical reasoning strategies to the students. Our findings from a design evaluation study demonstrate a more engaging learning and teaching experience and increased communications between the teacher and the students using Augmented Studio.

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