A Pilot Study of the Impact of Three-Dimensional Stereoscopic Models of Pelvic Anatomy on Short- and Long-Term Retention in First-Year Medical Students

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Abstract

Despite proliferative use of anatomical virtual models, there are few studies exploring whether stereoscopic models help medical students retain information regarding three-dimensional (3D) relationships of structures. This pilot study examined first-year medical students' exposure to a virtual 3D stereoscopic pelvis model and their corresponding short- and long-term retention. Participants were administered a series of tests before and after their 3D learning experience, including a pre-3D test, a mental rotation test (MRT), a short-term post-3D test, a block exam, and a long-term post-3D test. Students also completed a survey exploring their satisfaction with 3D imaging in general and its effectiveness in teaching anatomical material. Exam results were analyzed using a repeated measures ANOVA, and the pre-3D test scores within the 3D groups, were compared using one-way ANOVA's with each of the other performance measures. Final results showed a significantly higher difference in the students' pre-3D test and their immediate short-term retention post-3D test scores. Results also showed a significantly lower difference in students' pre-3D test and their one-month long-term retention test scores. There was no significant difference in the students' pre-3D and six-month long-term retention test scores. However, small sample sizes suggest further research on correlations between stereoscopic imaging of pelvic anatomy and other complex regions and students' short- and long-term retention.
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Key words: virtual 3D anatomy, stereoscopic pelvis model, 3D relationships, anatomy education, medical education, retention

Introduction

Virtual and augmented technologies have been proliferative enterprises in several fields, including anatomical sciences education where they have allowed students to take a journey through the human body. In response to the use of these technologies, the educational researcher in the anatomical sciences is compelled to ask whether these popular and somewhat novel forms of technology and their applications to computer models and simulations are indeed effective in improving student learning and retention.

Medical students are generally expected to remember the basic science they learn in their pre-clinical education in order to be more prepared for the years devoted to their clinical clerkships (Emke et al. 2016). Insufficient retention of anatomical content is noted in the literature (Prince et al. 2005, Zumwalt et al. 2010), even during the ongoing years of medical education (Swanson et al. 1996, Yu et al. 2008). Moreover, many physicians are concerned about the adequacy of anatomy curricula in preparing medical students for their future careers (Waterston and Stewart 2005, Staśkiewicz et al. 2007). Autonomous physicians even feel that their residents have not retained the degree of anatomical knowledge that they should have acquired from their medical education experiences (Hinduja et al. 2005). Therefore, anatomy faculty should research additional educational strategies to make anatomy teaching and learning more effective (Bergman et al. 2011) and to enable medical students to learn copious volumes of basic science content in a limited timeframe.

An increasingly popular strategy for aiding learning in anatomy involves the use of computerized three-dimensional (3D) models. Recent review papers have cited studies that discuss a combination of positive, negative, and neutral learning outcomes of students' experiences with 3D anatomical models (Azer and Azer 2016, Hackett and Proctor 2016). While some of these studies showed the positive impacts of virtual 3D learning versus traditional learning methods (Nicholson et al. 2006, Ruisoto et al. 2012, Müller-Stich et al. 2013), others showed no significant difference between the two (Hu et al. 2010, Codd and Choudhury 2011,

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Keedy et al. 2011, Metzler et al. 2012). The review by Azer and Azer (2016) alone referenced a few studies that showed negative results regarding virtual 3D learning effectiveness (Garg et al. 2002, Levinson et al. 2007, Khot et al. 2013). There are additional studies not mentioned in either review that showed the positive impacts of virtual 3D learning versus traditional learning methods (Qayumi et al. 2004, Brown et al. 2012, Cui et al. 2017). Therefore, there is a need for more research on the effectiveness of computerized 3D anatomical models on student learning and retention.

There have been a number of studies exploring the use of 3D anatomy to help students understand the relationships of anatomical structures to each other in 3D space (Brazina et al. 2014, Murgitroyd et al. 2014, Azer and Azer 2016, Cui et al. 2016, Estai and Bunt 2016). In fact, several studies have explored the creation of pelvic models, some using plastinated pelvic cross sections (Beyersdorff et al. 2001, Sora et al. 2011, Feil and Sora 2014) and some using CT and MR imaging and various cross-sectional techniques (Tan et al. 1998, Beyersdorff et al. 2001, Parikh et al. 2004, Sergovich et al. 2010). In addition, one study explored the creation of a pelvic model using computer programing (Moody and Lozanoff 1998). However, all of these studies are descriptive in nature as they merely report how the models were constructed (Moody and Lozanoff 1998, Beyersdorff et al. 2001, Parikh et al. 2004, Sora et al. 2011, Feil and Sora 2014). Therefore, there is a need to explore the impact of similar pelvis models on student learning.

Although pelvic 3D models have been shown to help improve medical students' understanding of radiological sectional images (Höhn et al. 1995, Tan et al. 1998), there are mixed results on the effectiveness of 3D anatomy in improving student learning in general (Azer and Azer 2016). Although one study showed that virtual reality images of the pelvis were not as effective as physical models or more advantageous than static images in improving student test performance (Khot et al. 2013), these virtual reality images were not experienced stereoscopically by the students. Even the studies using stereoscopic models and showing a positive impact on student performance (Luursema et al. 2006, Luursema et al. 2008, Hilbelink 2009, Luursema and Verway 2011, Luursema et al. 2017) did not feature models of the pelvis. Although several studies featured the creation of stereoscopic models, such as structures of the head and neck (Nguyen and Wilson 2009, Brewer et al. 2012, Cui et al. 2016), of the paranasal sinuses and cervical vertebrae (Chen et al. 2017), and of the female pelvis (Sergovich et al. 2010), only a few studies evaluate the impact of these stereoscopic models on student learning (Brewer et al. 2012, Roach et al. 2014, Cui et al. 2017). None of these studies have evaluated long-term retention on pelvic stereoscopic learning.

Studies exploring virtual pelvic models are important because such models have the potential to elucidate a very complex region of anatomy that is often difficult to understand (Parikh et al. 2004, Pujol et al. 2016), especially since an understanding of 3D relationships is extremely important in the learning of anatomy. As a result, students' visuospatial abilities (SA) should be assessed. One component of SA is spatial relation ability (SR), which refers to an individuals' ability to rotate two-dimensional and 3D images both accurately and expediently within their minds (Berney et al. 2015). Studies have shown positive correlations between SR and certain learning tasks (Hegarty et al. 2007, Berney et al. 2015). In the literature, SR has been assessed using the mental rotation test (MRT), an instrument of questions that asks participants to turn drawn figures of stacked cubes within their minds until they are in positions identical to the featured figure (Berney et al. 2015, Cui et al. 2017, Meyer 2019). Thus, the MRT was used to assess SR in the student participants in this study.

The purpose of this study is to explore the impact of virtual 3D stereoscopic pelvic anatomical structures on first-year medical students' short- and long-term retention of the corresponding information. Because long-term retention is not specifically defined in the literature (Custers 2010), long-term retention for the scope of this study refers to anatomical information retained two weeks or longer beyond the learning experience. Short-term retention refers to anatomical information retained immediately after the learning experience.

Methods

In this study, first-year medical students were invited to four 3D learning sessions during which time the attendees took a pre-3D test as a baseline assessment to measure their knowledge of the 3D relationships of structures within the pelvis prior to virtual 3D pelvic model exposure. The students observed a presentation of the virtual 3D stereoscopic pelvic model. Then they were administered a post-3D test to measure the impact of the model on their short-term retention. Assessments for measuring long-term retention were administered to the students one week, one month, and six months after their 3D learning sessions. This study was approved by the Institutional Review Board (IRB) of the University of Mississippi Medical Center (IRB protocol # 0241), and informed consent was obtained from all participants.

CT Data and 3D Model Reconstruction

The virtual 3D models mentioned and evaluated in this article were reconstructed from the de-identified routine computerized tomographic (CT) data supplied by the Department of Radiology at the University of Mississippi Medical Center (UMMC). Transverse computerized tomographic (CT) images were obtained via a Siemens SOMATOM Definition CT scanner (Siemens, Erlangen, Germany), using routine high-resolution imaging techniques, allowing for voxel dimensions

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of 0.35 mm in the axial dimension. A total of 708 slices (1.5 mm in thickness) were acquired from the mid-abdomen to the mid-thigh regions. The raw data from the CT scans were imported and saved as de-identified Digital Imaging and Communications in Medicine (DICOM) format files (Martin et al. 2013). The virtual 3D models were developed using Amira® software, version 5.6 (FEI, Hillsboro, OR) using a Dell Precision T7600 computer (Dell Inc., Round Rock, TX) with a NVIDIA Quadro K6000 video card (NVIDIA Corp., Santa Clara, CA). The DICOM format axial CT images (N = 708) were uploaded and rendered using similar techniques described in previous papers (Cui et al. 2016, Chen et al. 2017).

The 3D structures of the muscles, arteries, veins, and sciatic nerves in the pelvis and upper thigh were created for this study. Appendix 1 provides a list of these structures included in the pelvic model. This model was used in this educational study to measure its effectiveness in improving first-year medical students' short- and/or long-term retention of the anatomical factual information pertaining to muscles, arteries, and nerves of the pelvic region. Figure 1 provides an image of this model in an oblique anterolateral view.

Participants

A total of 145 first-year medical students enrolled in the medical gross anatomy course at the University of Mississippi Medical Center were invited to participate in this study involving the pelvis model. These students were invited during the first week of Block Three of medical gross anatomy to attend one of four identical 3D sessions of the virtual 3D stereoscopic pelvic model. Only two of the proposed sessions were attended; there were 16 students in the first session and 6 students in the second session. Although these sessions were offered during medical gross anatomy, they were not officially integrated into the course, so participant involvement was strictly voluntary. The names and grades of all student participants remained anonymous throughout the study.

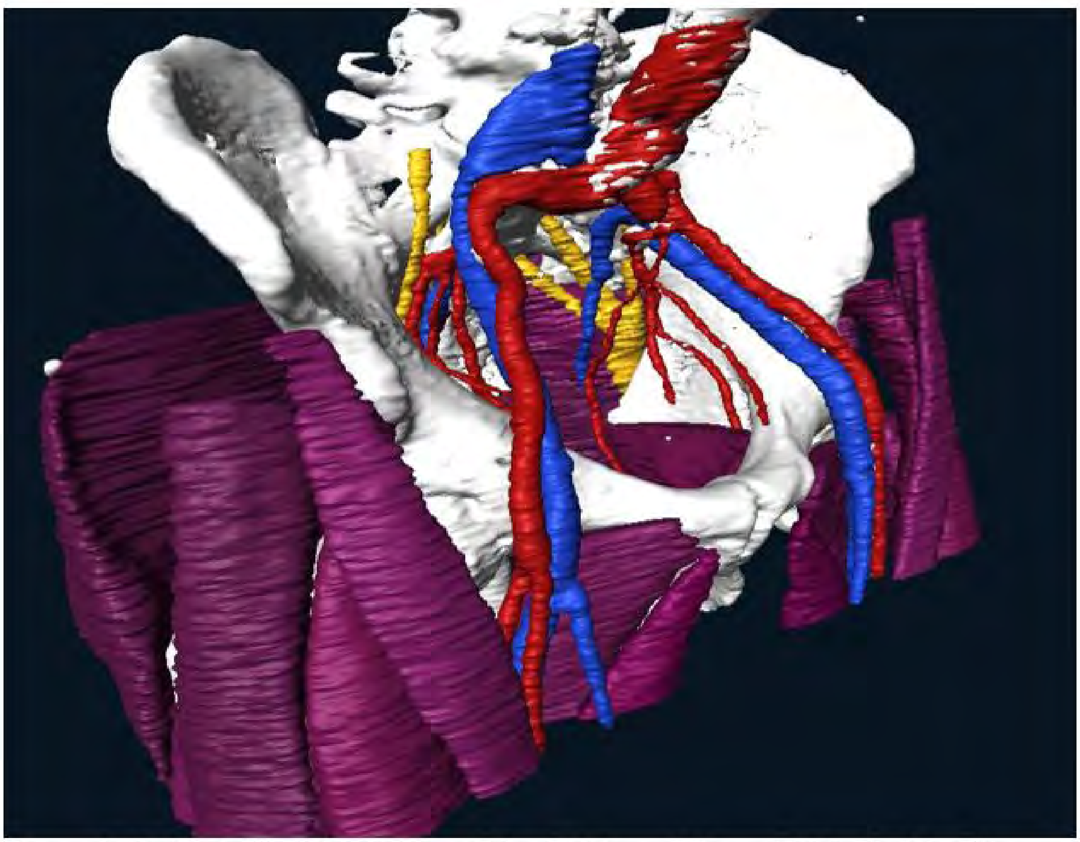

Figure 1. *Anterolateral View Image of the Pelvic and Upper thigh Model. This image provides a two-dimensional view of the model which can be rotated in three dimensions on a two-dimensional screen as well as projected in monoscopic (non-stereoscopic) and stereoscopic formats.*

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The participants were recruited from two groups (groups A and B based on their designated lab assignments for medical gross anatomy), and each group was given two opportunities to attend a 3D session for a total of four offered sessions. These sessions were offered after both groups had been exposed to the dissections of the external male and female genitalia. Several group A students attended the first 3D learning session while their group B counterparts were completing the dissections of the medial compartment of the thigh and the gluteal region. In turn, the following day, several group B students who had already completed dissections from the previous day attended the second 3D learning session while their group A counterparts completed dissections of the posterior compartment of the thigh and the popliteal fossa. No other students attended the additional sessions that were offered.

Experimental Design

This project was a one-semester, mixed-methods study, incorporating qualitative data in the form of survey information collected from first-year medical students as well as quantitative data in the form of numerical scores assigned to various assessments. These assessments included the ten-question, multiple-choice quizzes administered as pre-3D, immediate post-3D, one-month post-3D, and six-month post-3D tests and ten pelvis- and upper thigh-related multiple-choice exam questions. Additional assessments included the mental rotation test (MRT) to measure student spatial orientation and mental rotation capabilities (Vandenberg and Kuse 1978, Shepard and Metzler 1971) and the ten pelvis-related questions on the third block medical gross anatomy exam. The pre-3D and immediate post-3D quizzes had corresponding answer sheets on which the participating students wrote their answers, and the students were also provided a paper-based survey. All other quizzes were administered through TurningPoint Audience Response technologies. Exam data were collected using ExamSoft. Figure 2 provides an illustration of this experimental design.

Quizzes

The questions for the pre-3D learning session, post-3D learning session, one-month long-term retention, and six-month long-term retention assessments came from a thirty-question bank of multiple-choice questions pertaining to the pelvis and upper thigh. The questions on each quiz came from the same question bank, but were not identical, in order to prevent medical students from learning the answers to questions rather than relying on their own knowledge of the anatomy. One third of the questions were basic identification questions (easy in level of difficulty) that helped to serve as an embedded control for the other two thirds which included questions pertaining to three-dimensional relationships of anatomical structures; one third of the questions were intermediate in level of difficulty and one third of the questions were advanced in level of difficulty. These questions were reviewed by anatomical faculty members for validity purposes. Appendix 2 provides samples of the easy, intermediate, and advanced questions on these quizzes.

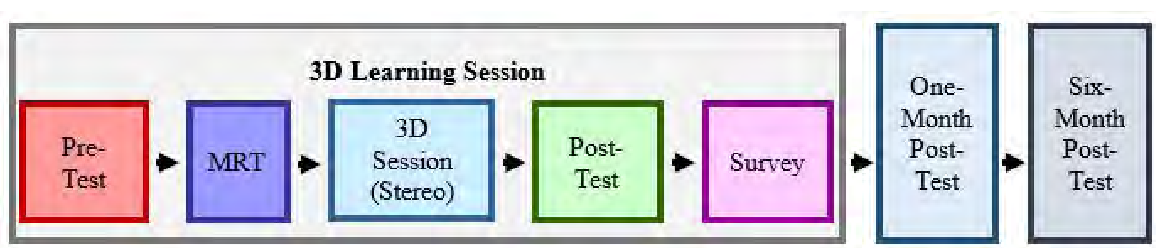

Figure 2. *Schematic of the 3D Learning Session Components and the Long-Term Retention Post-Tests. This figure depicts the 3D learning session which included a pre-3D test followed by a mental rotation test (MRT), the fifteen-minute learning session incorporating the virtual 3D stereoscopic pelvic and upper thigh model, an immediate post-3D test, and a survey. This figure also depicts the one-month and six-month long-term post-tests which were administered after the 3D learning session.*

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Each quiz consisted of ten multiple-choice questions projected on a screen using PowerPoint. Each student was given thirty seconds to answer each question before the presenter moved to the next question.

Exams

First-year medical students at the University of Mississippi Medical Center take four exams in their medical gross anatomy course in addition to a National Board of Medical Examiners exam at the end of the course. The third block exam pertains mainly to anatomical information regarding the pelvis and lower limbs, but all four exams are cumulative. A total of ten questions from the Block Three exam pertaining to the material covered and similar in format to the questions in the 3D learning sessions on the pelvis were analyzed for correctness for both the students who participated in the 3D learning sessions and for students who did not attend the 3D learning sessions.

Survey

This study also incorporated a 20-item survey to gather general demographic and background knowledge information, student perceptions of the 3D learning sessions, and student self-assessments of the effectiveness of the 3D sessions in improving their learning and understanding of 3D relationships of anatomical structures. The survey was administered at the end of the 3D learning sessions. Example items from the survey included Likert-scale items such as "The stereoscopic 3D model (viewed with the glasses) showed the 3D relationships of the materials better than the computer 3D model (viewed without the glasses)," and "The 3D model learning session helped me better understand the 3D relationships of the anatomical structures depicted."

3D Learning Sessions and Student Short-Term Retention

Prior to viewing the model, the participants in both 3D sessions were provided a brief introduction and administered a pre-3D test of ten questions that served as a baseline test of their current knowledge pertaining to pelvic anatomy. Students were then administered the 24-item mental rotation test (MRT) lasting eight minutes. The MRT's, which measures students' spatial visualization ability (SA) (Settapat et al. 2014, ten Brinke et al. 2014) were administered before and after the 3D sessions. The MRT version using redrawn figures was used. It involved participants determining which two of four drawings were the same as a sample drawing, but viewed from a different angle (Peters et al. 1995). Subsequently, the students attended the 3D learning session of the pelvis model. The 3D learning session presented immediately after the MRT and before the post-3D test lasted approximately twenty minutes. The session began with a brief one-minute orientation to prime the students to recognize the various anatomical planes in which the pelvic and upper thigh models would be presented. The remainder of the session included a virtual tour of the pelvic and upper thigh model structures with their attached labels displaying their names.

After the learning session, the students were administered a post-3D test of ten questions to assess their short-term retention of the anatomical information regarding the structures of the pelvis presented during the 3D session. These students then completed the survey described above.

Student Long-Term Retention

Two weeks after the administration of the 3D learning sessions, all of the first-year medical students were administered their Block Three exam which contained approximately ten questions regarding material that could be related to the pelvis model components. Given that this test was a block exam, it also contained questions pertaining to the lower limb. However, only student scores on the pelvic questions were selected for comparison and statistical analyses.

Two weeks after the Block Three exam, the first-year medical students were invited to answer ten post-test questions similar to those from the pre- and post-3D session tests. Students were also asked to answer the question "Have you revisited any anatomical information related to the content of this exam between the time of your 3D session and this current assessment? Please be specific (examples: name of courses, labs and lectures)."

Six months after the administration of the 3D learning sessions, the students were again invited to complete additional post-test and follow-up questions about whether they had revisited any anatomical information related to the pelvis between the time of the 3D session and the six-month long-term assessment. The individual student scores on the short-term retention quizzes for both groups were correlated with one another as well as to the number of pelvis questions answered correctly on their block three exam and on their long-term retention quizzes administered in the spring.

Data Analyses

The results of this study were analyzed using SPSS version 20.0. The pre-3D and post-3D test data of all first-year medical students who attended the 3D learning sessions were compared using a one-way ANOVA. In addition, the pre-3D test scores and the scores of only those students who attended the one-month retention and six-month retention test sessions were each compared separately using a one-way ANOVA. An ANOVA was also used to compare the average scores on the exam questions pertaining to pelvic anatomy content between students who were exposed to the 3D learning and cadaveric dissection sessions, who were exposed to traditional learning experiences (e.g., lectures on the pelvis, pelvic dissections and prosections) but not the 3D learning sessions, and who were exposed to neither lectures nor the 3D learning sessions (control group).

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Results

The 3D Learning Sessions and Student Short-Term Retention

The assessment data collected from the 22 students (16 in Group A and 6 in Group B) who attended the 3D sessions in this pilot study are summarized in Table 1. The A and B groups were based on the students' laboratory dissection groups in medical gross anatomy. The students in Group B had already been exposed to the gluteal region and medial thigh compartment dissections. Overall, the students who attended these sessions had a pre-test mean of 38% (35% for Group A and 47% for Group B) and a post-test mean of 47% (43% for Group A and 58% for Group B). Both groups of students scored an average of 13 on the mental rotation test (MRT).

The pre-3D test scores of the students who attended the 3D learning sessions were compared to their post-3D test scores using a one-way ANOVA. There was a significant difference between the students' pre-3D and post-3D test scores (p=0.038). The results of this analysis are presented in Figure 3.

Short-Term Retention Differences by High and Low MRT Groups

The pre-3D and post-3D test scores for the students who participated in the 3D learning sessions were compared according to whether the students received a high MRT or a low MRT score. This designation was determined by calculating the median score of the individual MRT scores so that scores ≤12.5 were deemed low while scores above >12.5 were deemed high. A one-way ANOVA revealed no significant difference between the pre-3D and post-3D test scores by high and low MRT scores (p=0.279). Nevertheless, the students with high MRT scores performed better on their post-3D test (M = 53, SE = 4.69) than the students with low MRT scores performed on their post-3D tests (M = 42, SE = 3.77).

Student Long-Term Retention

This subsection explores the long-term retention results from students' exams and their one-month and six-month long-term retention assessments. It also explores the differences in these assessments scores according to students who had low and high spatial abilities.

Exam Scores

The students who attended the 3D learning sessions took the block three exam in medical gross anatomy on the pelvis and lower limb along with the rest of the medical students in the class. The 3D session attendees' average on the ten questions related to the pelvic anatomy pertaining to the pelvic model was 81% (SD 0.12 ± 0.02) [81% (SD 0.10 ± 0.03) for the students in the first session and 82% (SD 0.16 ± 0.07) for the students in the second session]. These results are summarized in Table 2.

Session	n	Pre-3D Test Mean (%)	Post-3D Test (Short-Term Retention) Mean (%)	MRT Mean
Session 1 (Group A)	16	35	43	13
Session 2 (Group B)	6	47	58	13
Total (Average)	22	(38)	(47)	(13)

Given the fact that this study was conducted on a voluntary basis, there is an inconsistent number of attendees for any given lecture or 3D session.
n=number of students

Table 1. *Data Summary for 3D Sessions.*

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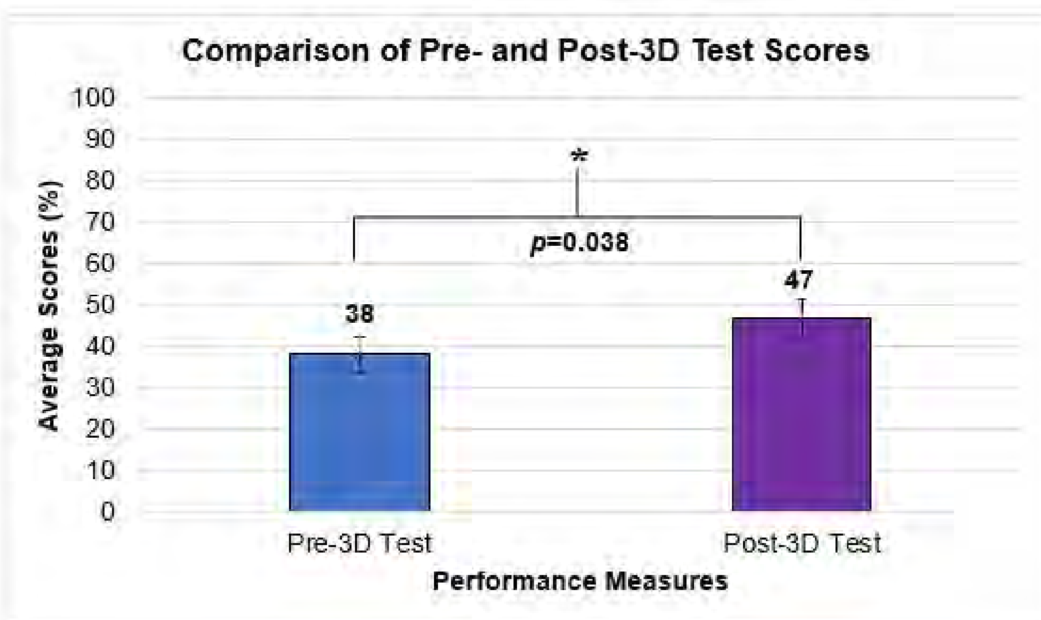

Figure 3. *Comparison of Pre- and Post-3D Test Score Averages. This graph shows the results of a one-way ANOVA of the pre- and post-3D assessment scores of the students who attended the 3D learning sessions. The average scores differ at the p<0.05 level.*

Session	n	Block 3 Exam Mean (per 10 pelvis Q's) (%)	Standard Deviation
Session 1 (Group A)	16	81	0.10 ± 0.03
Session 2 (Group B)	6	82	0.16 ± 0.07
Total (Average)	22	(81)	(0.12 ± 0.02)

Given the fact that this study was conducted on a voluntary basis, there is an inconsistent number of attendees for any given lecture or 3D session.
n=number of students

Table 2. *Data Summary for Exam Question Averages.*

Exam results from those students who (M = 85, SE = 0.021) were only exposed to traditional learning sessions in the medical gross anatomy course and those students (M = 81, SE = 0.025) who attended the 3D learning sessions that were not integrated into the curriculum were compared (ANOVA) with the exam results from students (M = 85, SE = 0.029) who attended none of the lectures associated with the content pertaining to the pelvis and upper thigh and who attended none of the 3D learning sessions. There was no significant difference in exam averages on the questions related to the pelvic anatomy pertaining directly to the pelvic model between any of these groups (p=0.502). Since there were only 22 students in the 3D learning sessions, the exam question averages of 22 of the students from both the traditional learning group and the control group were randomly selected to be included in the ANOVA.

One-Month and Six-Month Long-Term Retention Tests
Of the 22 students who attended the 3D learning sessions, a total of 14 students (eight from the first session and six from the second session) attended the one-month assessment. The students scored a mean of 21% (SD 12 ± 3.1) [22.5% (SD 13 ± 4.5) for Group A and 20% (SD 11 ± 4.5) for Group B]. In addition, a total of eight students (four from Group A and four from Group B) attended the assessment six months after the 3D learning sessions during which time they were assessed again for long-term retention. The students who took this assessment had a mean of 37% (SD 17 ± 6.0) [36% (SD 15 ± 6.8) for the students in Group A and 37.5% (SD 21 ± 10.3) for the students in Group B]. Because this study depended upon voluntary participation, the total number of students in attendance at each assessment

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measure was variable. The assessment data collected from the exam questions and from the students who attend the 3D learning sessions as well as the long-term retention assessment sessions in this pilot study are summarized in Table 3.

Session	n	One-Month Long-Term Retention Test Mean (%)	Standard Deviation	n	Six-Month Long-Term Retention Test Mean (%)	Standard Deviation
Session 1 (Group A)	8	22.5	13 ± 4.5	4	36	15 ± 6.8
Session 2 (Group B)	6	20	11 ± 4.5	4	37.5	21 ± 10.3
Total (Average)	14	(21)	(12 ± 3.1)	8	(37)	(17 ± 6.0)

Given the fact that this study was conducted on a voluntary basis, there is an inconsistent number of attendees for any given lecture or 3D session.
n=number of students

Table 3. *Data Summary for Long-Term Retention Assessment Sessions.*

The pre-3D test scores of the students who attended the 3D learning sessions were compared to their one-month retention test scores using a one-way ANOVA. There was a significant difference between the students' pre-3D and one-month retention test scores (p=0.006). The pre-3D test scores of the students who attended the 3D learning sessions were compared to their six-month retention test scores using a separate one-way ANOVA. There was not a significant difference between the students' pre-3D and six-month retention test scores (p=0.729). The results of both analyses are presented in Figure 4.

Long-Term Retention Differences by High and Low MRT Groups
The pre-3D test scores were compared to both the one-month and six-month retention test scores for the students who participated in the 3D learning sessions according to whether the students received a high MRT or a low MRT score, as previously described. A one-way ANOVA revealed no significant difference between the pre-3D and one-month retention test scores by high and low MRT scores (p=0.571). A separate one-way ANOVA revealed no significant difference between the pre-3D and six-month retention test scores

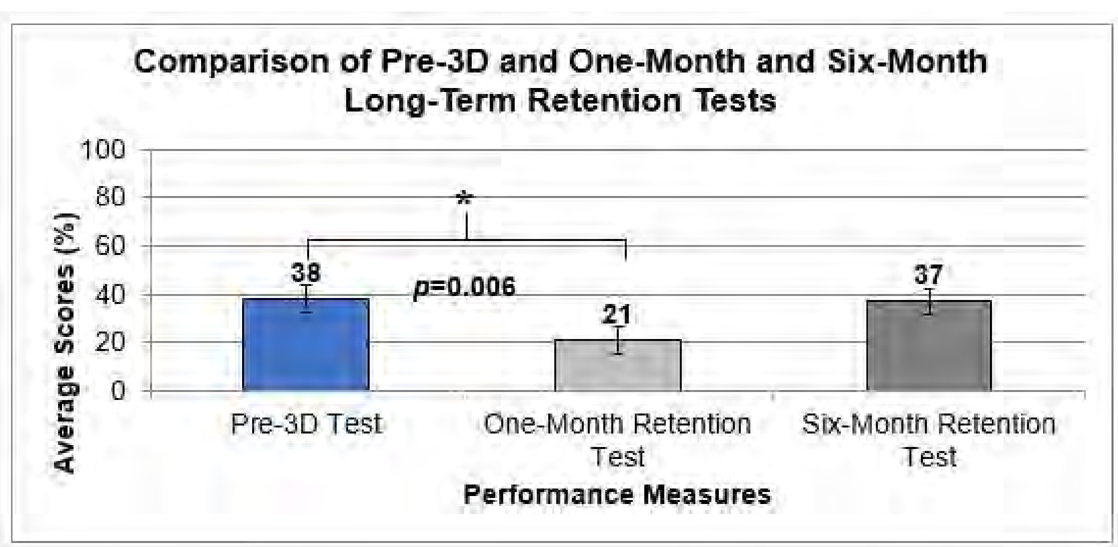

Figure 4. *Comparison of Pre-3D and One-Month and Six-Month Retention Test Score Averages. This graph shows the results of two separate one-way ANOVAs of the pre-3D and one-month retention assessment scores and of the pre-3D and six-month retention assessment scores of the students who attended the 3D learning sessions. The average scores denoted by the asterisk (*) differ at the p<0.05 level.*

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by high and low MRT scores (*p*=0.289). However, for both retention tests, the students with high MRT scores (one-month: M = 22, SE = 4.65; six-month: M = 38, SE = 8) performed better than the students with low MRT scores (one-month: M = 20, SE = 3.16; six-month: M = 35, SE = 8.66).

Discussion

A number of studies have demonstrated the positive impact of virtual 3D models on student performance in comparison to traditional learning methods (Qayumi et al. 2004, Luursema and Verwey 2011, Cui et al. 2017, Luursema et al. 2017) including several reviewed by Azer and Azer (2016) and Hackett and Proctor (2016). Several other studies also reviewed by Azer and Azer (2016) and Hackett and Proctor (2016) showed no significant difference between student performance in virtual 3D anatomy and traditional anatomy learning. In addition, a few of these studies showed that virtual 3D anatomy learning was actually not as effective as traditional anatomy learning methods (Garg et al. 2002, Levinson et al. 2007, Khot et al. 2013), but these studies presented the virtual 3D models in a monoscopic format, not a stereoscopic format.

Do Stereoscopic Pelvic and Upper Thigh Models Improve Student Short-Term Retention?

The added effects of stereopsis have the potential to provide the viewer with depth cues that are not tangible when models are simply viewed and rotated on a two-dimensional computer screen in a monoscopic format. While a study by Luursema et al. (2017) showed no significant differences in learning outcomes for medical students for the stereoscopic and non-stereoscopic learning conditions for the anatomy of the neck, the model used was very simple as it only included structures within the deep neck, namely the vertebrae and deep neck muscles. Another recent study on 3D vascular stereoscopic models of the head and neck reported positive results, including statistically significant differences in the comparisons between 3D and two-dimensional (2D) learning groups of first-year medical students (Cui et al. 2017). The most complex vascular structures in the head and neck of the human body were used in this study. These mixed results suggested that more research on the effectiveness of stereopsis in helping medical students learn other regions of anatomy is needed.

In this pilot study, our results have indicated there were significant differences in the pre-3D and post-3D test scores regarding the stereoscopic models. This significance suggested that the stereoscopic pelvic and upper thigh models improved short-term retention in the first-year medical students. This finding may be due to the fact that the stereoscopic models provided good spatial orientation and useful information about pelvic structures for these students. In addition, the students in the Group B 3D learning session performed significantly better on their post-3D tests than the students in the first 3D learning session. Their higher performance may have been due to their exposure to the thigh muscles and pelvic structures during their lab exercises. After all, cadaveric dissection has been regarded as necessary for understanding 3D relationships of anatomical structures to one another (Marks 2000), and works suggest that physically touching the human body can enhance student learning of anatomical vocabulary (Keller 1990, Graney 1996, Vermeij 1997). However, this group included only six students. More meaningful information could have been drawn from a larger sample size. Although the difference in the pre-3D tests scores between the two groups was not significant, the average scores of both the pre-3D and post-3D tests of the Group B were higher than those of the Group A students. Although a difference of a few points may not matter enough to achieve statistical significance, they may matter enough for students who are on the cusp of having one letter grade versus another, especially if the few points make a difference between passing or failing an exam, or even a course. Using virtual stereoscopic 3D models as supplements to cadaveric dissection could potentially foster higher learning gains in students.

The lack of significance between the pre-3D test and post-3D test scores according to high and low MRT scores suggests that student spatial ability might not have had a significant effect on their overall performance on the assessments. However, in terms of practical significance for the post-3D tests, the students with high MRT scores performed better than the students with low MRT scores.

Do Stereoscopic Pelvic and Upper Thigh Models Improve Student Long-Term Retention?

Some studies mention the need for exploring the impact of 3D models on long-term retention of anatomical information (Azer and Azer 2016, Van Nuland and Rogers 2016). Studies have been done to assess the retention of knowledge directly related to anatomy among medical students (Custers 2010, Malau-Aduli et al. 2013). The review study by Custers (2010) poses that over half of the knowledge learned in school, including medical school, is lost after a few years. The study by Malau-Aduli et al. (2013) suggests that medical students' perception of the clinical relevance of basic science information is one determinant of retention of that information. The fear is that if the clinical relevance of anatomical information is not made clear to students, they will more easily forget the information.

This pilot study explored the effectiveness of stereoscopic models on long-term retention in learning pelvic and upper thigh anatomy. It concluded that the 3D pelvis and upper thigh models had little impact on long-term retention. While a typical Ebbinghaus curve would predict an approximate

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80% drop in retention over a period of about one month (Ebbinghaus 1885, Custers 2010), the more modest 55% drop in retention over the same time period, as seen in this pilot study, could be due to the fact that the material pertaining to the pelvis might have had a higher level of meaning to the students since they were in medical school. Similarly, other studies have shown that while the Ebbinghaus curve holds true for both meaningful and meaningless information, the curve does not exemplify as drastic a drop in retention of meaningful information as it does for meaningless information (Briggs and Reed 1943, Hovland 1951).

On the other hand, there were no significant differences in student pre-3D test and six-month retention test scores. While this finding suggests there was no difference in the retention of the anatomical content pertaining to the pelvis and upper thigh six months past the learning experience, the six-month retention test scores were higher overall than the one-month retention test scores. These higher scores at a higher retention interval are very curious and there seems to be little explanation for why this might be the case unless those students who scored higher six months later had reviewed anatomical content pertaining to the pelvis and upper thigh between their one-month retention test and their six-month retention test.

Although a few studies have shown the positive impact of 3D anatomical models on slong-term learning (Hisley et al. 2008, Oh et al. 2009, ten Brinke et al. 2014), none of these studies feature virtual stereoscopic models or address long-term retention. The complexity of the anatomical structures and detail of the models may also contribute to the results. Thus, ways of improving long-term retention in medical students need to be explored further, especially studies featuring stereoscopic models in various anatomical regions.

The lack of significance between the pre-3D test and one-month retention test and between the pre-3D test and six-month retention test scores according to high and low MRT scores suggests that student spatial ability might not have had a significant effect on their overall performance on the assessments. However, in terms of practical significance for the one-month retention and six-month retention performance measures, the students with high MRT scores performed better than the students with low MRT scores.

There are some limitations to this study that should be recognized. The development of the models in this study was not previously evaluated by clinical or basic science experts before they were used by medical students. Some essential anatomy structures might have been missing from the models, especially since they do not include all of the pelvic contents. Perhaps it is important to involve clinicians and basic scientists in the process of developing a validated stereoscopic pelvis model and use their opinions to evaluate and guide the model development (Meyer et al. 2018). Due to the length of time of this study and to the participant dropout, the final sample size was relatively small. Given the amount of money spent on 3D virtual and augmented reality technologies (Bellini et al. 2016), there is perhaps an ethical obligation and duty for anatomy educators and experts to evaluate and ensure that these relatively novel learning tools are actually effective in improving the long-term retention of medical students to ensure greater ease of transfer of knowledge to their future clinical rotations.

Measuring the long-term retention of complex anatomical regions may have more significant benefits because the spatial relationships within these regions are difficult to comprehend via two-dimensional textbooks. Furthermore, the multiple-choice questions used in the pre-and post-tests should probably be identical to prevent the added variable of different questions. However, using similar, yet non-identical, questions helps to control for students who will attempt to search for the answers to the questions. Students who look up the answers to questions have the advantage of being able to answer the question correctly on the later retention assessments due to the fact that they are familiar with the questions, but not necessarily due to the fact that they remembered the anatomical information associated with the questions. Finally, the questions regarding the pelvic anatomy, given student averages, were probably too difficult for first-year medical students, so a bank of test questions should be presented to a team of medical gross anatomy faculty members to test for validity and inter-rater reliability.

Conclusions

The pelvic and upper thigh models used in this pilot study seemed to improve the short-term retention of the first-year medical students who participated in the 3D learning sessions. Although the models did not seem to improve the students' one-month long-term retention, students showed some gains in their six-month long-term retention, peculiarly suggesting that some of the students who participated in the assessment six months after the 3D learning sessions might have reviewed material pertaining to the pelvis and upper thigh. A similar study with a larger sample size of students and with more complete, valid pelvic and upper thigh models might provide even more definitive results concerning the effectiveness of pelvic and upper thigh models on first-year medical students' long-term retention.

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APPENDIX

Three-dimensional structures	Methods	Average time (minutes)	Assemble ability	Stereoscopic presentation
Boney Structures				
Femurs	Volume rendering	10	No	Slow
Pelvic bones	Volume rendering	10	No	Slow
Sacrum	Volume rendering	10	No	Slow
Coccyx	Volume rendering	10	No	Slow
Vertebrae (L1-L5)	Volume rendering	10	No	Slow
Arteries				
Abdominal aorta	Surface rendering	90	Yes	Fast
Common iliac arteries	Surface rendering	210	Yes	Fast
External iliac arteries	Surface rendering	180	Yes	Fast
Internal iliac arteries	Surface rendering	90	Yes	Fast
Femoral arteries	Surface rendering	60	Yes	Fast
Internal pudendal arteries	Surface rendering	60	Yes	Fast
Obturator arteries	Surface rendering	60	Yes	Fast
Superior vesicle arteries	Surface rendering	60	Yes	Fast
Veins				
Inferior vena cava	Surface rendering	60	Yes	Fast
Common iliac veins	Surface rendering	90	Yes	Fast
External iliac veins	Surface rendering	180	Yes	Fast
Internal iliac veins	Surface rendering	60	Yes	Fast
Femoral veins	Surface rendering	60	Yes	Fast
Nerves				
Sacral roots	Surface rendering	60	Yes	Fast
Sciatic nerves	Surface rendering	60	Yes	Fast
Muscular Structures				
Gluteus maximus muscle	Surface rendering	360	Yes	Fast
Tensor fascia lata muscle	Surface rendering	240	Yes	Fast
Vastus lateralis muscle	Surface rendering	180	Yes	Fast
Vastus intermedius muscle	Surface rendering	180	Yes	Fast
Pectineus muscle	Surface rendering	180	Yes	Fast
Piriformis muscle	Surface rendering	180	Yes	Fast
Rectus femoris muscle	Surface rendering	210	Yes	Fast
Sartorius muscle	Surface rendering	240	Yes	Fast
Adductor longus muscle	Surface rendering	180	Yes	Fast
Obturator internus muscle	Surface rendering	360	Yes	Fast

Appendix 1. *List of 3D Stereoscopic Structures of the Pelvic and Upper Thigh Model. This table lists all of the structures included within the pelvis model, giving the method by which each structure was rendered, the estimated time in minutes taken to construct each structure using its respective rendering method, the ability of each structure to be removed from and added to the model during visualization, and the speed at which the structure is visualized in stereoscopic presentation. Structures constructed through volume rendering are visualized more slowly than those constructed using surface rendering.*

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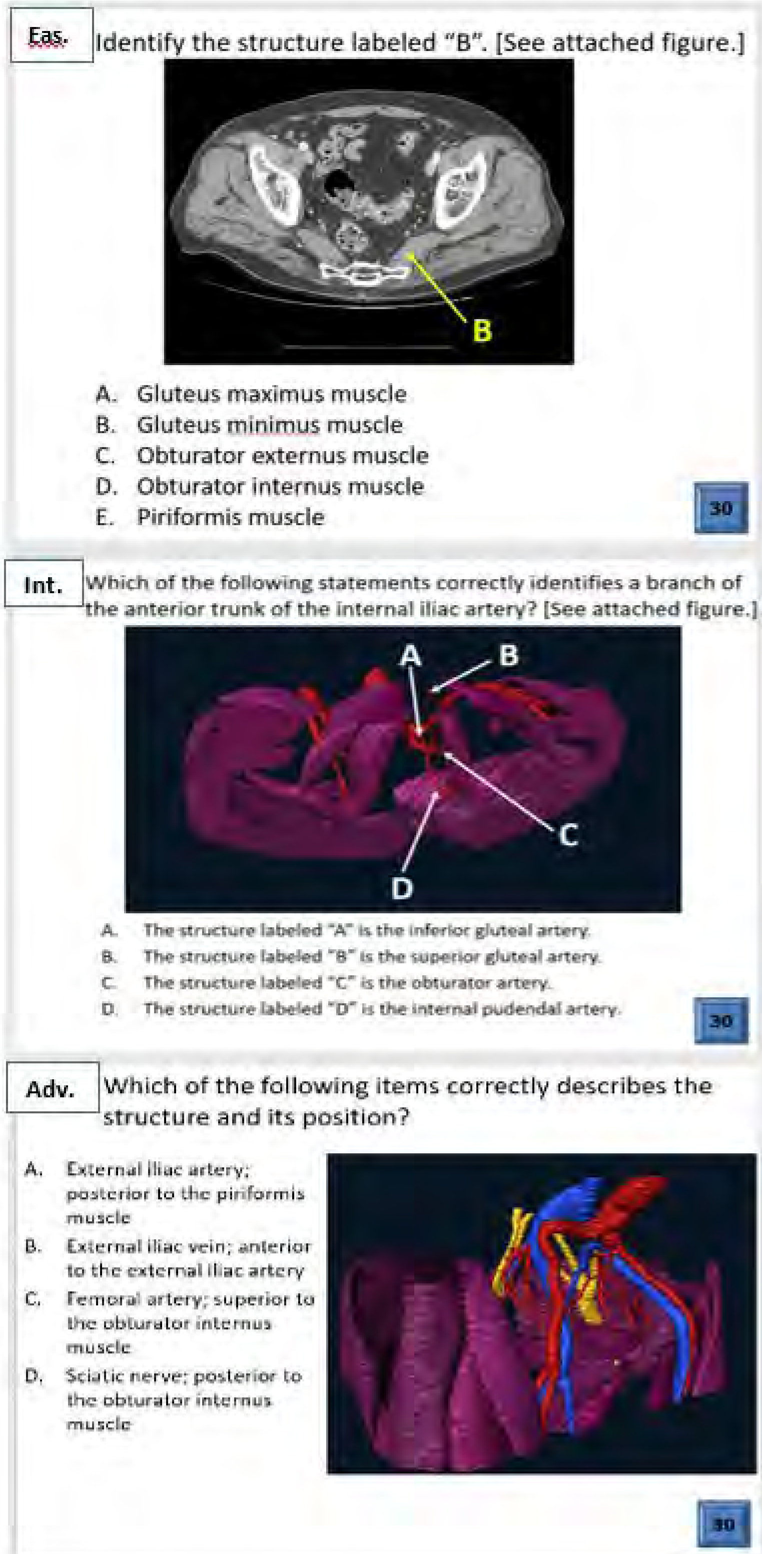

Appendix 2. *Sample Pelvic Anatomy Questions. This figure represents example easy (Eas.), intermediate (Int.), and advanced (Adv.) items from the 30-item test bank.*

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