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A measure of the effectiveness of incorporating 3D human anatomy into an online undergraduate laboratory

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Abstract

Results of a study designed to determine the effectiveness of implementing three-dimensional (3D) stereo images of a human skull in an undergraduate human anatomy online laboratory were gathered and analysed. Mental model theory and its applications to 3D relationships are discussed along with the research results. Quantitative results on 62 pairs were analysed using a doubly-multivariate analysis of variance repeated measures design. Results revealed statistically significant differences in group means for the main effect of treatment groups 2D and 3D and for the variables of Identification and Relationship with the 3D group outperforming the 2D group on both dependent variables.

Introduction

There is a large demand for undergraduate students in allied health professions to be trained in human anatomy. Students enrolled in these programmes must take at least one course in human anatomy, as well as an anatomy laboratory as part of their required curriculum. The difficulty is that anatomy is three-dimensional (3D) in nature. In order to understand anatomical structures, the laboratory portion of the study of anatomy is typically achieved by a hands-on dissection. However, more and more courses are being offered online. Studying the laboratory portion of anatomy from a two-dimensional (2D) representation, such as from a text or a standard PowerPoint presentation, may not adequately permit students to learn the many spatial relationships that exist within human anatomy. Students must be able to visualise this 3D organisation in their minds to fully understand the workings of and relationships that exist within the human body (Shaffer, 2004). This has been the historical goal of the human dissection laboratory.

Now that there are numerous commercial 3D human anatomy visualisation programmes available as well as the technology for developing one's own stereo-imaging, it is possible to include 3D images into online human anatomy laboratories. Contemporary digital programmes can be detailed, spatially correct, clinically relevant, relatively inexpensive and safe to use. Most are also fairly simple to incorporate by instructors with little actual human anatomy laboratory training (A.D.A.M. Online Anatomy, 2005; Neotek, 2004; Primal Pictures, 2004).

The purpose of this study was to determine whether 3D stereo images could be inexpensively created and to determine the effectiveness of those 3D images in an undergraduate online human anatomy laboratory.

Mental model theory

Human anatomy is a 3D area of study. Many relationships within the body must be seen in association to be understood. This is true when studying the anatomy of the skull. Much of the detail can not be fully appreciated unless one performs a dissection in order to understand the complex relationships that exist within this region. The organisation of nerves, bones and foramen within the skull is extremely complex. Understanding the origin and termination of each of the 12 cranial nerves, for example, is generally a focus of anatomical education in any health-related field. The study of human anatomy is concerned with learning individual structures and also learning the spatial relationships that exist between those structures. Mental model theory addresses the issue of how students learn such complex systems. According to Jonassen (1995), 'mental models are the conceptual and operational representations that humans develop while interacting with complex systems' (p. 1). Bayman and Mayer (1984) describe mental models as referring to 'the user's conception of the "invisible" information processing states and transformations that occur between input and output'. Mental model theory has its basis in cognitive psychology.

It has been a challenge for instructional designers to find ways of helping students form appropriate mental models within web-based environments. Mayer (1989) lists seven criteria he believes should be contained within instructional materials in order to increase the chances that students will build appropriate and good mental models and, therefore, understand complex systems.

According to Mayer's (1989) review, a 'good model is: (1) Complete—it contains all the objects, states, and actions of the system; (2) Concise—it contains just enough detail; (3) Coherent—it makes intuitive sense; (4) Concrete—it is presented at an appropriate level of familiarity; (5) Conceptual—it is potentially meaningful; (6) Correct—the objects and relations in it correspond to actual objects and events; (7) Considerate—it uses appropriate vocabulary and organisation' (p.59). With appropriate mental models, a student is able to understand causal relationships that exist within a complex system, even if they are not explicitly taught. The use of 3D models permits the learner to observe relationships among structures and to form appropriate lasting mental models of the relationships.

Current environment

The incorporation of gross anatomy laboratories into undergraduate nursing schools and allied health curricula is generally seen as a cost-prohibitive endeavour, particularly because these programmes are typically not funded to the same degree as medical schools (American Association of Colleges of Nursing, 2003). In the vast majority of allied health programmes, common ways to learn anatomy include text books, 2D images and the dissection of species such as cats or dogs. Although dissecting a cat or dog does expose the student to dissection skills, the spatial relationships that exist within those species may be very different from those found within the human body. Allied health courses are being offered more frequently as distance learning courses. This is being done to accommodate students who are working on degrees while continuing to work at full-time jobs (American Association of Colleges of Nursing, 2003).

Students in human anatomy laboratories are generally tested on their identification of anatomical structures by identifying which structure is labelled on a laboratory practical examination. Laboratory practical exams consist of labelled structures on a human cadaver specimen. Students may work in groups of four to five to learn the anatomy, and then are responsible on an individual basis for accurately identifying and spelling the anatomical structure that is indicated. Additional questions can be incorporated to determine if students are able to apply that information to relationships between and among the anatomical structures that they have studied. Questions regarding spatial relationships that exist between structures are often considered 'second level' or 'higher order' questions, as students must be able to integrate what they are viewing into some sort of context or mental model. To the extent that students can or can not see the relationships that exist between and among structures, one can then determine the value or effectiveness of the imaging method.

Research questions

This study sought to determine whether desktop 3D stereo-imaging of human anatomy is more effective than 2D images in an online anatomy course. It did this by asking whether or not students using 3D stereo-images performed significantly better than those using 2D images of the skull on two independent measures: identification and spatial relationships.

Two research questions were developed for this study.

1. Does the use of 3D stereo images result in significantly higher scores for undergraduate students in learning the anatomy of the skull when compared with 2D images of the same structures, as measured by scores on a practical examination of identification?
2. Does the use of 3D stereo images result in significantly higher scores for undergraduate students in learning the anatomy of the skull when compared with 2D images of the same structures, as measured by scores on a practical examination of spatial relationships?

Methods

The research questions were addressed by an experimental design consisting of quantitative data analysis of the test scores for the undergraduates on both a laboratory practical and a spatial relationship examination of the skull bones and features.

Volunteers in this online class were given identical study guide lists of 80 anatomical terms and 20 relationship questions they were to study over the course of 1 week. The list of terms was developed from the Grant's Dissector (Sauerland, 1999). Volunteers were stratified into two groups based upon pretest scores and were subsequently assigned to either the 2D or the 3D group. Each group was permitted access to only their assigned materials via the Blackboard Learning System™. Each group was given a PowerPoint to view that contained either 2D or 3D images, but identical content. Volunteers in each group were also granted access to an audio video interleaved (AVI) movie file of their exact 2D or 3D PowerPoint but with a narration by an anatomy professor with 25 years of teaching experience. Online materials were posted for one week, and volunteers were given no additional instruction on the materials during that time. Volunteers were brought back into the laboratory after one week for a practical examination, utilising actual human skulls.

The independent variables are the instructional material treatments as defined by 2D or 3D, while the dependent variables or outcomes, are the test scores on the measures of identification and understanding of spatial relationships on the laboratory practical examination. An effort was made to maintain independence among the treatment groups by conducting the instruction over a short period of time and by separating the group materials online with permissions granted via the Blackboard Learning System™. In addition, volunteers were encouraged to work independently when studying the materials and were assigned times to arrive for the laboratory practical examination so that all volunteers were not in the laboratory at the same time. Administration times for the practical examination were staggered so that there was approximately 20 minutes between the time that one group finished and the next group arrived. Students reported to one part of the building upon arrival and left as a group once the examination was completed. This was done to minimise interaction between groups. Each individual examination took no longer than 1 hour, and each examination accommodated 30 volunteers at one time.

The PowerPoint presentation developed for each group was created according to Mayer's (2001) principles of design and the AVI movie was the same PowerPoint, but was narrated to encompass all structures found within the study guide list for the skull. Both PowerPoint presentations were designed so that volunteers were exposed to a 2D coloured and labelled image first, then a subsequent unlabeled image of an actual skull in the same orientation as the first image. If the volunteer was assigned to the 3D group, the image of the actual skull was a 3D image created from 2D. The 2D coloured images were taken from Grant's dissector (Sauerland, 1999) as well as from appropriate Bassett Collection Atlas (1952) 2D images. The 3D stereo-images were derived from the Bassett collection of stereo images or were created by taking digital images of the skull and superimposing them using Pokescope® Stereoscopic Software (2005) to gain the 3D effect. Images were created if appropriate images were not found within the Bassett Collection Atlas.

The practical examination
After 1 week, volunteers were asked to return to the campus in order to take the laboratory practical examinations. Seven identical practical exam sessions were held over a period of 2 days. Each group was given the same 10-minute orientation to the examination after they entered the exam area. Each volunteer was then stationed in front of a test question that included a skull specimen(s) and the same study guide list of structures and relationship questions that had been provided to them via their learning system during the previous week. Volunteers were given 1 minute to correctly identify the structure(s) indicated on the skull specimen before advancing to the next question. The 1-minute limitation was established in order to give students adequate time to answer the question and to complete the examination in a reasonable amount of time. A total of 15 points was possible for the identification questions and 15 points were possible for the 15 relationship questions. The entire laboratory practical examination was worth 30 points.

Results

In order to determine if the materials developed for this study addressed Mayer's (1989, p. 59) criterion for creating effective mental modelling, one practising instructional designer, one instructional technology instructor and three instructors of human anatomy were asked to review the 3D PowerPoint and to indicate which, if any, of the seven criteria they felt were identified in the treatments. In nearly all cases, the reviewers indicated that the PowerPoint met the majority of Mayer's seven criteria, thereby indicating that the PowerPoint contained most of the necessary elements, according to Mayer, to create an effective mental model for the volunteers to learn human anatomy.

Descriptive statistics for scores on the identification and relationship subtests suggest that the mean scores for the 3D groups, for both variables of identification and relationship, were consistently higher than those of the 2D groups for both sections (See Table 1). Score distributions for each treatment group on identification and relationship subtests were normal with no outliers.

Table 1: Descriptive statistics by group and Wilks' lambda values

Subtests (n = *124 per group) mean (SD)*	*2D*	*3D*
Identification	9.5 (3.34)	10.19 (3.31)
Relationship	8.08 (3.63)	9.45 (3.46)
Wilks' lambda, *F* value		
Main effect	0.0479, $p < 0.0001$ F value = 596.74	
Treatment* outcome effect	0.938, $p > 0.1443$ F value = 2.00	

2D, two-dimensional; 3D, three-dimensional.

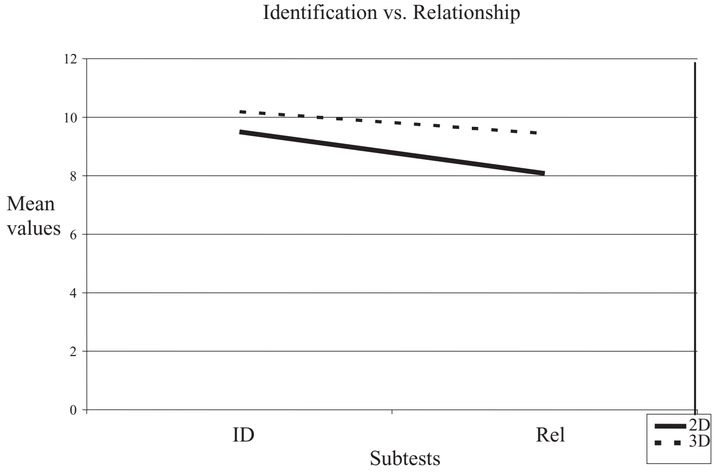

Figure 1: Visual display of differences between means 2D, two-dimensional; 3D, three-dimensional; ID, identification; Rel, relationship

In order to address the quantitative questions, a doubly-multivariate analysis of variance (doubly-MANOVA) repeated measures design was conducted. This model assisted in testing the differences between the two treatment variable means of 2D and 3D to the two outcome variables of identification and relationship.

The results of the doubly-MANOVA repeated measures design revealed a statistically significant difference in group means for the main effect of the treatment groups (2D vs. 3D) on both dependent measures of identification and relationship test scores (Table 1). The 3D group outperformed the 2D group on both dependent measures, (Wilk's Lambda [0.0479, $p < 0.0001$]). However, there is no significant treatment*outcome effect (Wilk's Lambda = 0.938, $p > 0.1443$).

The absence of an interaction effect suggests that the treatment group differences are consistent across the two variables. When graphed, it is clear that there is a between-treatment visual difference with the 3D group consistently outperforming the 2D group on scores of identification and relationship (See Figure 1); however, the test of interaction indicates the lines are not significantly non-parallel.

From the Cohen's *d* values, it can be stated that the difference between the 2D and 3D treatment groups on the outcome of identification is small: 0.215. However, the difference between the 2D and 3D treatment groups on the outcome of relationship is slightly larger at 0.359. This is also apparent from the visual display in Figure 1.

Discussion

When reviewing the doubly-MANOVA repeated measures design, results reveal a statistically significant difference in group means for the main effect of the treatment groups 2D and 3D, and variables of identification and relationship with the 3D group performing higher on both dependent variables (Wilk's Lambda [0.0479, $p < 0.0001$]). The use of inexpensively created 3D stereo-images did result in significantly higher scores for undergraduate students in learning the anatomy of the skull, when compared with 2D images of the same structures as measured by subtest scores on a practical examination of relationships. Also, the use of 3D stereo-images resulted in significantly higher scores for undergraduate students in learning the anatomy of the skull, when compared with 2D images of the same structures as measured by scores on a practical examination of spatial relationships.

The volunteers who were assigned to the 3D group did outperform those in the 2D group on measures of identification as well as relationships. One way to explain that difference is to suggest that those in the 3D learning environment were better able to create appropriate mental models of the complex system of human anatomy as they looked at the images and studied the relationships. Mental models tend to be created by the individual in a way that works best for him or her. The learners in this study created their mental models in an individual and internal way, based upon what Staggers and Norcio (1993) stated as prior experience and/or instruction. Based upon the results, it also appears that the 3D materials, as designed in this study, did assist the users in creating appropriate mental models of the complex system of the human skull. Volunteers in the 3D group could more clearly see which structures inter-digitated with the others and how the different bones and features were positioned in relative space, and they learned this material prior to coming into the laboratory for the practical examination. They were able to create appropriate mental models of the structures better than those in the 2D group.

Although the effect sizes(s) were small, there is a practical significance to these findings. Being able to improve students' performance when learning human anatomy, even to a small degree, such as was found in this study, can have benefits in application beyond the classroom. For instance, a student who is better able to understand the relationships that exist within the complex system of human anatomy may be better positioned to accurately apply that information when dealing with patients. Understanding the nuances involved in the interrelationships of the structures involved in human anatomy may help future nurses and other health practitioners to better explain a condition or disease state to a patient. For example, they may have more confidence in their ability to understand and relay information on coronary artery disease or the effects of laparoscopic surgical techniques.

3D visualisation is routinely used in many fields beyond nursing and allied health where imagery of complex systems or designs is of importance. Some of these fields include forensics, dentistry, chemistry, surgery and other areas of health care as well as engineering (Aurbach *et al*, 2001; Brenton *et al*, 2007; Choi & Choi, 2007; Komoda *et al*, 1994; Sanchez, Adjouadi, Altman, Sanchez & Bernal, 2007). The 3D techniques mentioned in these papers are more complex than those represented in this study primarily because they offer greater interactivity for the user by permitting image manipulation and rotation. It can safely be said, however, that the use of all types of 3D visualisation is becoming more common in the fields of health care and engineering as researchers and professionals attempt to investigate complex systems within these disciplines. It makes sense then to expose the students in these fields to 3D visualisation technologies, if possible, throughout the educational process.

As 3D technology matures and evolves, there will be multiple issues regarding its effective implementation into online courses. Incorporating simple 3D technologies can augment the traditional classroom experience by permitting students to study and learn complex ideas in an inexpensive, yet effective way. 3D images that can be manipulated can offer the student additional viewpoints and more depth of field than standard 2D images, which may result in the creation of more effective mental models. Student preferences for the use of 3D stereo-imaging technologies will also be an important factor in determining how best to incorporate the technology.

Limitations

There were limitations to this study that should be noted. The sample was a diverse mix of undergraduate nursing students and wellness programme students as well as other allied health students. Future studies could involve the analysis of one type of student, either nursing or allied health for example, in order to make the results more specific and perhaps generalisable to that population. In addition, one specific region of the human anatomy, the human skull, was used for testing purposes for this study. It is likely that utilising a different region of human anatomy could lead to different results, in that each region has unique spatial relationships associated with it. Laboratory practical examinations were scheduled over the course of 2 days, which provided some of the volunteers with an additional day to study the material. In addition, because the materials to be learned were completely online, it is difficult to know precisely how much time and effort the students put into learning the material.

Finally, this is an area of study in which there are many important areas for future research that may impact the practical application of online instruction in undergraduate human anatomy and physiology courses.

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