# Evaluation of Neuroanatomical Training using a 3D Visual Reality Model

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***Abstract:*** As one of the more difficult components of any curricula, neuroanatomy poses many challenges to students -- not only because of the numerous discrete structures, but also due to the complicated spatial relations between them, which must be learned. Traditional anatomical education uses 2D images with a focus on dissection. This approach tends to underestimate the cognitive leaps required between textbook, lecture, and dissection cases. With reduced anatomical teaching time available, and varying student spatial abilities, new techniques are needed for training. The goal of this study is to assess the improvement of trainee understanding of 3D brain anatomy, orientation, visualization, and navigation through the use of digital training regimes in comparison with current methods. Two subsets of Health Science and medical students were tested individually after being given a group lecture and either a pre- or post-dissection digital lab. Results suggest that exposure to a 3D digital lab may improve knowledge acquisition and understanding by the students, particularly for first time learners.

**Keywords:** Neuroanatomy, Virtual Brain Model, Spatial Abilities

## Introduction:

Typically, undergraduate medical education in anatomy is comprised of a group lecture, a gross dissection with the help of anatomical manikins and a potential clinical case, as well as self-study with 2 dimensional (2D) images in atlases. This approach, the current gold standard in education, focuses heavily on the use of 2D anatomy as a means of teaching students, primarily because it is the most easily accessible teaching aid. Thus its pedagogy consequently relies heavily on the student's ability to transform their 2D knowledge into a three-dimensional (3D) intuitive understanding. This cognitive leap, though highly underestimated, is incredibly important, and is a main struggle for students to master. Anatomical understanding can be achieved using 2D methods, however the relationships between structures is not well represented as it is not always possible in a 2D space, which makes explicit the struggle for learners. Understandably, clinicians are heavily invested in the acquisition and use of 3D data [13], which is often found in sequential 2D digital formats like scans, x-rays and MRIs. As mentioned, it is imperative that clinicians understand that these 2D images represent a 3D space and that as students they learn how to create a spatially relevant 3D representation of a patients anatomy based on 2D information [11]. This mental schema is necessary to efficiently and effectively interact with and treat patients in practice and may only be achieved through learning spatial anatomy. This is particularly difficult in neuroanatomy due to the sheer number of structures as well as the ambiguous separations and intricate associations between them.

In addition to inadequate traditional teaching methods, the amount of time dedicated to anatomy, and therefore to neuroanatomy, has significantly decreased. Over the past 100 years, the time spent by medical students in anatomical lectures and labs has decreased from over 500hrs to less than 200hrs [2,4,7]. This means that students, already having difficulty with learning both 2D and 3D anatomy are receiving less instruction and practice time in both areas. This deficit has been noted post-graduation as US medical residency directors believe that their residents need a refresher course on anatomy due to serious deficiencies [3,13]; and an increase in morbidity and mortality is observed due to errors in comprehending 3D patient information [1].

Spatial anatomy has been related to spatial abilities [6,8,22] a person's ability to perceive and reorient 3D objects in space, though the impact of visual spatial ability (SA) or 3D learning in science education has been largely ignored [14]. Objective measures of SA can be measured in a variety of ways, one of the most straightforward involves using a mental rotation test (MRT) originally developed by Shepard and Metzler [25] and adapted by Vandenburg and Kuse [26].

Globally, the world is making a push towards a digital environment. Younger generations perceive most of their life using 2D displays, and education is starting to occur in the same fashion. The Association of Faculties of Medicine of Canada has put forth a 6 tiered program to further medical education standards; one of which is to focus on the impact of visuo-spatial thinking and 3D learning on science education [14]. Many institutions, and surgical departments, are starting to create 3D environments to assist in the education of their medical students, residents and fellows and some have specifically started to use computer assessments to teach and test their students in neuroanatomy [18]. Growing evidence suggests that teaching in a virtual 3D space may make learning easier for discreet structures [17] and positive effects of 3D visualizations on anatomy and embryology learning have been previously suggested [12, 20].

With the development of these new teaching technologies and methods, effectiveness of computer-assisted teaching in medical school has been the subject of multiple studies. For example, Marsh developed a 3D temporal process of embryonic development model, and subsequently used a knowledge test to assess volunteers. Their results suggest students improved long-term retention of the material, mostly when they had some prior embryologic knowledge [12]. Other studies have also shown that multimedia-aids help in the long-term memorization of material for patients [19]. Conflicting results in older studies suggested that medical students who learned a topic using computer-assisted instructions instead of attending a lecture or viewing printed material performed sometimes lower [23], or equally as well [9,24] though, considering technological advancements since the 1990s, these results may not emulate the learning conditions which are producible and presented now. Consequently, we cannot rely on information of older studies to fully judge the performance of computer-aided teaching, but we also recognize the need for student-instructor interaction.

To our knowledge, little has been attempted in the means of illustrating a combined overview of neuroanatomy focused on teaching general structures and their spatial relationships, and developing knowledge to include clinical cases and illustrations therein. This project is aimed at creating an intermediate learning adjunct to further supplement the information delivered in 2D during a lecture and in a 3D lab, easing this cognitive transition. The goal of this study is to assess the acquisition of anatomical knowledge by medical and health science students using a 3D digital brain model after lecture and either pre- or post- dissection lab. We hypothesize that exposure to a 3D digital model before a gross dissection lab will demonstrate higher post-test scores in comparison to those receiving a post-lab, 2D or no 3D digital experience. The highest post-test scores will be achieved by students with high SA regardless of their intervention

## 1. Methodology:

First Using the Amira 5.1 software package (Visage Imaging, Inc.) to create and visualize a 3D digital brain model we were able to render several neuroanatomical structures essential to the medical curriculum. These structures were originally generated using manual segmentation of the male visible human data set slices (slice thickness of 1mm, courtesy of the US National Library of Medicine). Slices were viewed independently and intrinsic structures were manually highlighted and added to a user defined label. By compiling all labels, a 3D volumetric representation of each structure was visible (Figure 1).

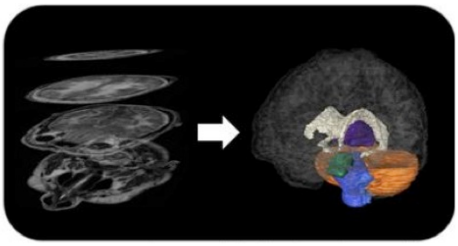
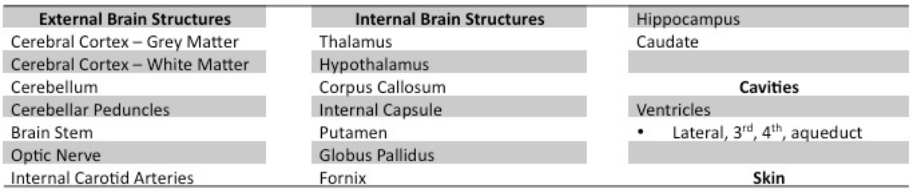


**Figure 1:** Data in sequential slice form is manually segmented into structures to form a 3D digital Model

Following this step, each 3D volume was reconstructed as a smoothed surface rendering in Amira. Table 1 depicts all 18 distinct structures created.

After creating the individual surfaces comprising the model, each component was used to create a series of videos aimed at illustrating the most important anatomical features focused on in the curriculum, which were visually realized through stereoscopic presentation. The videos were designed upon the principles of syncretion, a theory developed by Miller [15] wherein the learner builds a whole from the inside out, and its reverse approach, dissection. The combination of syncretion and dissection ensures that the best views of each structure and surrounding area are possible. These videos and additional snapshot still images of them were used as the digital teaching tools within both experimental models. More in depth descriptions of segmentation and videography within Amira may be found in Nguyen [16].



| **External Brain Structures** | **Internal Brain Structures** | Hippocampus |
|---|---|---|
| Cerebral Cortex – Grey Matter | Thalamus | Caudate |
| Cerebral Cortex – White Matter | Hypothalamus | |
| Cerebellum | Corpus Callosum | **Cavities** |
| Cerebellar Peduncles | Internal Capsule | Ventricles |
| Brain Stem | Putamen | • Lateral, 3rd, 4th, aqueduct |
| Optic Nerve | Globus Pallidus | |
| Internal Carotid Arteries | Fornix | **Skin** |

**Table 1:** Summary of the 3D reconstructions created from the Male Visible Human Data Set

Since the use of a digital model is applicable to various levels of learning and understanding, two subject groups were tested individually using the model and its representative structures for their curricular needs. The first group was volunteers from Health Science students, and the second group was students from the second year of medical school. Because of curriculum requirements and allocated time for each group, the methodologies for both were not the same.

### *2.1. Experiment A: Health Science*

13 Subjects were recruited from a second year heath science anatomy course in which neuroanatomy had not been taught. On Day 1 participants were exposed to a 40min group lecture covering testable material given by an expert in the field. This experience was akin to what they would experience in a traditional lecture setting. Participants were then randomized into one of three testing groups: control, 2D and 3D. Two days following the lecture, students participated in their assigned 15min self-directed pre-lab (none, 2D or 3D) as well as a 25min gross dissection lab, and a 12min post-test & survey. The survey component was designed to assess previous exposure to neuroanatomy, and allowed for a post-hoc division of first time and previously experienced learners. Following their lab experience students completed a Vandenburg- Kuse Mental Rotation Test (MRT) [26] requiring approx. 6 min. The pre-lab designed for this study consisted of a digital slide presentation containing relevant information linked both to the previously received lecture, and the lab to follow (depicted in Figure 2). The difference between 2D and 3D groups was the availability of 3D image snapshots of the 3D digital model (as opposed to 2D images) and an interactive video of the model to the 3D group only.

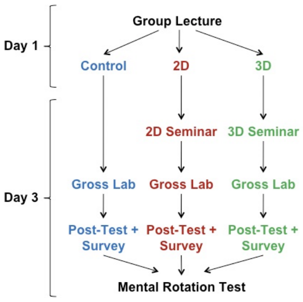


**Figure 2:** Health Science Experimental Design

### *2.1. Experiment B: Medicine*

118 Subjects were recruited from second year medicine in which neuroanatomy was just taught as a group lecture. The experiment was incorporated into the normal curriculum during the neuroanatomy lab. For that reason, both group experimented both approaches, in a different order. The subjects were randomly split into 2 groups to start with the digital or traditional gross dissection labs. Group A participated in the Digital Lab first and were given 1.5h, and Group B the Gross Lab for approximately 1.5hr; both groups could leave the lab whenever they wanted and their time in each lab was recorded. The groups then switched to the other lab. A knowledge post-test and user-interface questionnaire/survey were administered directly after the digital lab lasting approximately 20 min. Because the labs were part of the curriculum, which lacked flexibility, a full experimental cross could not be completed, nor a formal MRT; and the test had to be administered after the digital lab. The digital lab was designed similarly to pre-lab of Experiment A, though was of a higher difficulty containing more structures as well as a more in depth 3D video.

## 2. Results:

### *2.1. Experiment A: Health Science*

Figure 3A illustrates mean post-test scores achieved by each of the three testing groups, and all participants overall as a reference. There was no statistical difference found in comparing achieved means of the three groups as $p > 0.05$ in all cases (Control vs. 2D: $p = 0.308$, Control vs. 3D: $p = 0.210$, 2D vs. 3D: $p = 0.946$. As well, Figure 3B illustrates mean post-test scores achieved by both experience groups and all participants overall as a reference. There was no statistical difference found in comparing achieved means of these 2 groups as $p > 0.05$.

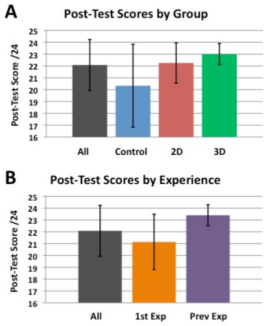


**Figure 3:** Mean Post-Test Scores. A) Based on Intervention Groups, B) Based on Experience Groups

Figure 4 focuses on on correlations between MRT and post-test Scores. The correlation is minor for the 3D (Fig 5B: R=0.147) and previous exposure (Fig 5C: R=0.278) groups, moderate for all subjects (Fig 5A:  R=0.567) and the 2D group (Fig 5B: R=0.622) and finally is high for the control (Fig 5: R=0.935) and 1st exposure (Fig 5C: R=0.956) groups.

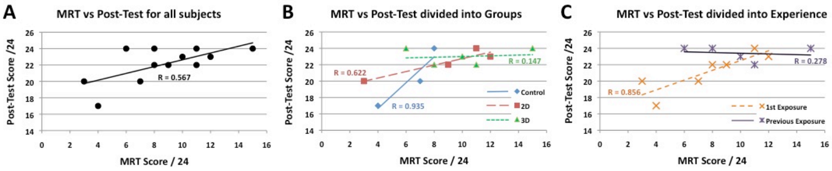
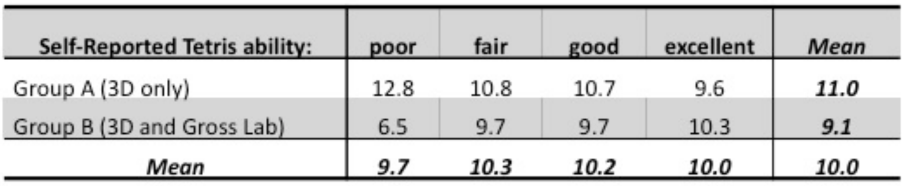


**Figure 4:** MRT Score vs. Post-Test Scores. A) For all Subjects, B) Based on Intervention Groups, C) Based on Experience Groups

*2.2. Experiment B: Medicine*

Group A, which started in the digital lab first, stayed longer in the digital lab than the second group (1.2h vs 50 min). The quiz average obtained between groups was not statistically different (11 vs 9.1) (Table 2) and no statistical differences were seen when looking into each group of questions specifically either. As mentioned previously, the test was done either after the digital lab alone or after both labs had been completed. Therefore the means of comparison was based on a post-hoc correlation comparison. In the user-interface questionnaire, students were also asked to rate their ability at playing the game “Tetris” as a means of subjectively deducing their SA. There was no difference in their scores correlated with their subjectively assessed ability in SA between groups 1 and 2 as seen in Table 2. The mean Quiz score result for group A was 10.7 out of 20 (std dev = 4.04) and the mean quiz score for group B was 9.6 out of 20 (std dev = 4.27).



| Self-Reported Tetris ability: | poor | fair | good | excellent | *Mean* |
|---|---|---|---|---|---|
| Group A (3D only) | 12.8 | 10.8 | 10.7 | 9.6 | ***11.0*** |
| Group B (3D and Gross Lab) | 6.5 | 9.7 | 9.7 | 10.3 | ***9.1*** |
| ***Mean*** | ***9.7*** | ***10.3*** | ***10.2*** | ***10.0*** | ***10.0*** |

**Table 2:** Comparison of Post-Test Scores (/20) based on self-reported tetris ability (SA analogue) for Medicine groups 1 and 2

Both groups found that the 3D model was more helpful in finding structures and learning them (5.1/7 on the Likert scale) than the plastinated brain; commenting that the same structures were more difficult to find on plastinated brain. The group that started with the Gross Lab had a subjective impression that the 3D model helped them better (5.5/7) compared to the group that started with the Digital Lab (5/7).

## 3. Discussion:

Trending patterns in Figure 4A suggest that exposure to a digital pre-lab, boosts post-test scores which is consistent with a study by Venkatiah [27] who found combining dissection with electronic learning tools to be effective through increased post-test scores following a lab session. However, due to the small population of students enrolled in the first study, and lack of time for the participants of the second study, we were unable to attain significance in our result, and so this study is unable to support the original hypothesis. Further study, including the expansion of the current one is required to discern whether an actual difference in post-test performance exists as a result of specific 2D or 3D digital lab exposure.

A moderate correlation, consistent with our hypothesis, was illustrated in the entire data set (Figure 4A) between SA and post-test scores, which is supported by previous studies by Garg [6] and Fernandez [5]. The importance of SA to understanding spatial anatomy appears to decrease with exposure time or practice [22] and previous experience or training [21]. This result is particularly evident in Figure 4B where correlations between MRT and post-test scores decrease with increased exposure time to the model and in Figure 4C in which correlations decrease with previous experience (as assessed by post-hoc survey analysis) which is also consistent with Fernandez [5]. Trending in Figure 3B further illustrates how performance is boosted by previous experience. Since SA is generally thought to be innate [21], this could be a likely suspect for the data variability within groups seen in the above correlations despite the suspected improvements through practice [22] and training [21] which may have been partially limited due to the shortness of the experimental protocols. Overall, this data suggests that experience and learning may overcome bad mental rotation ability, but that for novices, good spatial reasoning will lead to a faster learning curve. For educators, this may mean that increasing the amount of practice or exposure time as well as the amount of training time received by students could better student learning and understanding regardless of innate SA .

A correlation based analysis was completed to determine whether there was a statistical difference between group A (3D only) versus the group B (3D + gross lab), in order to investigate the sensitivity of this methodology as a metric for future studies, and to establish an expected population variance for power analysis and sample size statistics calculations for follow-up studies to this research. Table 2 Illustrates that there is no significant difference between the post-test performance of group A and B when compared on the grounds of their self-assessed SA. Trends in the data though suggest that post-test scores are higher for group A than for group B, except for students who self-report as having high spatial reasoning skills. For students who self-report as having low or average spatial reasoning skills, post-test scores were higher in group A. These results suggest that 3D VR tools may act as a cognitive prosthetic to compensate for students with poor to even reasonable abilities [9]. Also, it seems that students with excellent spatial abilities may impose inefficiency by forcing learner to us the VR to the designer's method reducing their performance.

The fact that our post-test scores were not different between all group comparisons might be due to the methodology of our experiment. In the Health Science group, there was a plateau in their post-test results suggesting that the post test was too easy, and for the Medical Students, the post-test was done either after the digital lab alone, or after both labs; which make the interpretation of the results difficult.

## 4. Conclusion:

Students report that they enjoyed learning using VR-based presentation, since it helped them to visualize inner structures better than plastinated or cadaveric brains, and understand spatial relationship better than 2D images. Knowledge-based post-test scores were not however significantly different between groups; but we could see a trend in better results for novice students with lower spatial abilities with the 3D model. Thus, the use of digital media as an adjunct to gross anatomy labs shows promise for students with no previous exposure to the subject, and especially for students who have poor spatial abilities. Larger studies, with greater numbers of participants, should be done to more conclusively study the effects of digital media within the classroom. Ideally, this would enable subject matching based on SA, and offer the opportunity to use stepwise regressions to discern the true and separate effects of material exposure time and digital lab effectiveness.

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