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Using Virtual Reality to Complement and Enhance Anatomy Education

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Using Virtual Reality to Complement and Enhance Anatomy Education

The use of digital three-dimensional (3D) models to aid learning and teaching in anatomy education has become common place over the last decade. More recently, virtual reality (VR) has been explored by a number of universities as a means of further engaging students with virtual models. This paper describes the development and evaluation of a pilot VR anatomy resource at the University of Dundee. Students were exposed to a collection of 3D anatomical models in VR to evaluate the potential usefulness and adoption of this technology for anatomy education.

Keywords: virtual reality; education; anatomy; medicine

Introduction

The use of digital three-dimensional (3D) models to aid learning and teaching in anatomy education has become common place over the last decade. There are now several computer programs and mobile applications commercially available that provide useful compliments to traditional anatomy education, allowing users to interact with 3D models of human anatomy through rotation, magnification, and even virtual 'dissection' (Lewis et al., 2014). In addition, several researchers and Universities have created their own such models and tested them on various student populations with generally positive results (Nicholson et al., 2006; Codd & Choudhury, 2011; Allen et al., 2015).

More recently, virtual reality (VR) has been explored by a number of institutions (Marks et al., 2017; Moro et al., 2017; Maresky et al., 2018) as a means of further engaging students with virtual models. For example, Maresky et al (2018) tested the viability and efficacy of an anatomically correct VR simulation of the heart, utilising 3D digital models for teaching cardiac anatomy to first year undergraduate medical students. Students exposed to the VR simulation scored 23.9% higher ($P < 0.001$) than the control group on the post-intervention test. The authors concluded that although

cardiac anatomy could be difficult for some students to learn, VR offered an immersive experience which helped to highlight the 3D relationships and size differences between structures.

The term 'Virtual Reality' (VR) as it is used here, refers to the interaction with an artificial object or environment through computer software or website, using an immersive head mounted display (HMD), such as the Oculus Rift and HTC Vive headsets (https://www.oculus.com/en-us/ & https://www.vive.com/uk/). As most students do not currently have access to high-end VR HMD's at home, these are most likely to be used on campus either during taught classes or for complementary study.

This paper outlines a pilot study undertaken by the Centre for Anatomy and Hunan Identification (CAHID) at the University of Dundee, to investigate student responses to VR anatomy resources and to inform potential investment and developments in this area within the department. CAHID is unusual in that it has invested heavily in its cadaver dissection facilities. In 2014, it opened a new mortuary allowing for Thiel embalming, making it the first place in the UK to offer full body dissection of Thiel embalmed cadavers. This method of embalming closely simulates a living patient, retaining life-like tissue colour and flexibility (Eisma et al. 2013), making it highly valuable for anatomical and surgical training and research. It is with these facilities in mind, that the authors wished to investigate if VR could still prove a useful addition to traditional methods of anatomical education.

Method

A collection of 3D digital models (created by MSc Medical Art students, alumni and their programme lead) were already being used to supplement anatomy teaching in CAHID. These models were created in variety of ways for various projects. However, most were modelled using either Pixologic ZBrush and/or Autodesk Maya, with some

being based on CT data and others created from scratch. The models were all uploaded to Sketchfab[1] where numerous 3D properties of the scene and model could be adjusted, including camera options, material properties and lighting. Sketchfab features a VR editor where the scale, viewing position and floor level can be set for each model, in preparation for viewing with a VR device (figure 1). ~~Annotations and audio were added at this stage.~~ Up to 20 annotations could be added per model (with between 0 and 18 being used in this study), consisting of a title and description of up to 1024 characters. Annotations were displayed as numbers, with the text only becoming visible once selected, an example can be seen in figure 2. Audio files of up to 5mb could also be added. ~~Sketchfab also features a VR editor where the scale, viewing position and floor level can be set for each model, in preparation for viewing with a VR device (figure 1).~~ While it was not necessary for the models to be accessible via a web browser, Sketchfab was used as it offered the easiest means of displaying 3D models in VR. In addition, h~~H~~osting the models on Sketchfab in this way, allowed for an identical collection to be viewed ~~be viewed~~ both on a 2D monitor (PC, Mac or mobile device) as well in VR (figure 2). A collection of seven anatomical models was prepared (https://skfb.ly/6vJoP). An effort was made to include a range of anatomical structures, systems and scales (figure 3). The collection included one animated model (of an inferior alveolar nerve block), and one model with a looped voiceover (describing the features and course of the lymphatic system). All models (except for the animation) were also annotated. An 'orientation cube' was included to allow participants to practice moving around the model and activating annotations. Finally, the models were tested with an HTC Vive

[1] Sketchfab is the world's largest platform for publishing 3D models online. Models can be viewed in any mobile or desktop browser or Virtual Reality headset.

VR headset (using an HP VR ready desktop), and the most up to date version of Mozilla Firefox (as of February – July 2018) in a dedicated room.

Study Design

Ethical approval for this study was granted by the University of Dundee research ethics committee. Participants were recruited through the student body of CAHID at the University of Dundee. They could be from any programme or year of study, so long as they had completed at least one module of anatomy featuring human dissection. Although there are differences in the anatomy modules between programmes, they are broadly similar in that all utilise the same core resources. The level of detail and focus of modules varies, however as participants were not being tested on their anatomical knowledge this was not considered to be a problem. Upon receipt of a signed consent form participants were sent a link to the collection of online interactive 3D models to view prior to attending the VR session in person. ~~Before viewing the same collection of models in VR~~ Participants were asked to confirm that they had viewed the models online and if they had not done so were shown the models (online, via a monitor) in advance of viewing them in VR (there was only one instance of this). ~~it was confirmed that they had done this and~~Participants then read and signed the associated risk assessment before viewing ~~. Participants then viewed~~ the models using the HTC Vive VR headset. Before they looked at the anatomy collection however, they first viewed the 'orientation cube'. Once they felt comfortable activating annotations and moving around this practice model, the anatomy collection was loaded. At least one of the authors was always present to load and change models for the participant upon their request. Participants were told they could spend as little or as long viewing

each model as they chose. Once all the models had been viewed in VR, participants were asked to complete the online user evaluation survey. This was completed at the end of the session with the researcher in the next room. The survey was split into four parts and largely consisted of Likert scale and open answer questions:

- Part one asked participants about themselves and their prior experience with digital models and VR.
- Part two asked participants for their feedback on viewing the models online.
- Part three asked participants for their feedback on viewing the models in VR, using the HTC Vive headset.
- Part four asked participants for suggestions on future developments.
- A copy of the user evaluation survey can be viewed here.

Results

Testing and feedback took place between April and July of 2018. As described above, after viewing the models both online and in VR participants were asked to complete an anonymous online user ~~experience~~ evaluation survey. As the questions alternated between positive and negative phrasing (to avoid acquiescence bias) the internal consistency of the scales was initially affected. However, if the responses to the negatively phrased questions were reversed, a Cronbach's alpha score of .713 was recorded for the 'online' questions and a score of .842 for the 'VR' questions, being regarded as 'satisfactory' and 'good' respectively.

18 participants completed the study of which ~~77.8% (~~14~~)~~ were female and four~~22.2% (4)~~ male. 16~~88.9%~~ were aged between 18-29 years, with the remaining two~~der~~ being aged between 30 and 39 years. Participants consisted of students from a

range of programmes, all of whom had previously undertaken at least one gross anatomy module featuring human dissection. There were five participants from 2nd year medicine, five MSc medical art students, four PhD students, two MSc anatomy and forensic anthropology students, one MSc forensic art & facial identification student and one undergraduate forensic anthropology student (figure 4).

When asked if they played computer games, eight~~44.4%~~ answered 'no', four~~22.2%~~ 'yes, but rarely', and ~~33.3%~~six 'yes, occasionally'. Asked if they used any 3D digital anatomy resources (such as online, mobile apps etc), eight~~44.4%~~ answered 'no' and ten~~55.6%~~ 'yes'. Various resources were mentioned, notably Sketchfab and the *Essential Anatomy* app, being named six and five times respectively. Five~~27.8%~~ participants had some prior experience of using VR while 13~~72.2%~~ did not. A variety of headsets including the HTC Vive, Oculus Rift, PlayStation VR and mobile VR where indicated by those who had used VR previously. No participant reported having access to a VR system at home.

In part two of the survey 'Viewing the models online', all participants confirmed they had viewed the models online ahead of the VR session. A variety of devices ~~had~~ were reported as having been used including laptops, mobile phones and tablets, with viewing times for the collection reported as ranging from 10 to 35~~0~~ minutes, with an average (mean) time for viewing the collection of 22.6 minutes. When asked if they agreed with the statement 'I enjoyed viewing the models (online), the majority (16~~88.8%~~) of participants 'agreed' or 'strongly agreed', with one participant ~~(5.6%)~~ selecting 'neither agree nor disagree' and another ~~(5.6%)~~ selecting 'disagree'. Fourteen~~77.8% of~~ participants 'disagreed' or 'strongly disagreed' that loading times were long, with two each ~~(11.1%)~~ answering 'neither agree nor disagree' and 'agree'. 17 participants~~94.5%~~ found the models to be a useful study aid, with only one

participant ~~(5.6%)~~ neither agreeing nor disagreeing. Most (16~~88.9%~~) found the collection easy to navigate, although there was one participant who ‘strongly agreed’ with the statement that it was ‘difficult to navigate the collection’. All participants found the annotations to be a useful addition, with the majority (14~~77.7%~~) also thinking that the voiceover was helpful. Finally, although the majority (11~~61.1%~~) found the models easy to interact with, a sizable minority (7~~27.8%~~) did not.

In part three ‘Viewing the models in virtual reality’, all participants agreed they enjoyed viewing the models in VR (compared with 16 participants~~88.8%~~ for viewing the models online). The majority of participants (16~~88.9%~~) ‘disagreed’ or ‘strongly disagreed’ that loading times were long, with just two ~~(11.1%)~~ answering ‘neither agree nor disagree’. 17 participants~~94.5%~~ found the models to be a useful study aid, with one participant ~~(5.6%)~~ neither agreeing nor disagreeing. Most (16~~88.8%~~) ‘disagreed’ or ‘strongly disagreed’ that the collection was difficult to navigate, although there were two participants who ‘agreed’ with this. 17 participants~~94.4%~~ found the annotations to be a useful addition (with one participant neither agreeing nor disagreeing) with the majority (16~~88.9%~~) also agreeing that the voiceover was helpful. Most participants (16~~88.9%~~) ‘disagreed’ or ‘strongly disagreed’ that it was difficult to move around the models, although one participant did ‘agree’ with this and another selected ‘neither agree nor disagree’. A sizable minority (5~~27%~~) reported motion sickness or other discomfort. When asked if overall, they preferred viewing the models online or in VR, 17 participants~~94.4%~~ selected VR with just one participant choosing the online models. Results for sections two and three are compared in figure 5.

In part four participants were asked if they would use VR resources for viewing anatomical models if they were available in CAHID. Half of the participants~~50%~~ said they would use such facilities ‘frequently’ and eight~~44.4%~~ said they would do so

‘occasionally’, with just one participant choosing ‘rarely’. When asked what type of content they would be interested in seeing developed, most (13~~72.3%~~) opted for ‘interactive ‘dissectible’ models’, with three~~16.7%~~ choosing ‘interactive animated models’, and two~~11.1%~~ choosing ‘interactive models (such as those used in this study)’. Finally, participants were asked if there were any regions or topics that they thought would benefit from being available in VR. As expected, there were a wide range of answers, with most participants suggesting a range of topics and regions. Common themes that arose however included, the musculoskeletal system, juvenile osteology and embryology, clinical anatomy and pathology, and animations.

There was one outlier to several of the questions worth noting. The participant who selected ‘disagree’ for question 9.1 (‘I enjoyed viewing the models) was also the only participant not to find the online models a useful study aid. However, this same individual agreed that they enjoyed viewing the models in VR (question 11.1), although they reported feeling disorientated and perhaps for this reason answered question 13 by selecting that they preferred viewing the models online (being the only individual to do so). They were also the only participant not to say they would use the VR resources in CAHID frequently or occasional, rather choosing ‘rarely’. Interestingly they also answered ‘no’ to questions four and five indicating that they do not play computer games or use any 3D anatomy resources.

Thematic Analysis

A thematic analysis was undertaken for the open answer questions regarding viewing the models both online as well as in VR. This was conducted following the method outlined by Braun and Clarke (2006). Thematic analysis is used to analyse qualitative data and can be used successfully even where there are relatively low numbers of participants (so long as adequate qualitative data has been collected). After reading

through all of the comments several times (to become familiar with the content), they were manually coded on the PDF exported from Jisc Online Surveys. The codes identified elements of the data that appeared to be relevant to the investigation of this study. The entire data set was given full and equal attention in order to identify interesting features that may form patterns within the data. These codes were then grouped into potential themes. The themes combined different codes that were similar or considered the same aspect within the data. The author used mind-mapping to review the themes and compare them back to the initial data extracts to ensure they formed a coherent pattern. Some of the codes went on to form the main themes and sub-themes, whereas others collapsed into each other or were discarded. Finally, thematic maps were created that defined and named each of the themes and sub-themes (figures 6 & 7 below). This process was undertaken twice, once for feedback on viewing the models online and once for viewing the models in VR.

Many of the comments and resulting themes were similar for both viewing modalities. Comments on both the online and VR models complimented the quality of the models and the usefulness of the voiceover, for example:

"(T)he models were fabulous to use and well detailed."

"Loved the brain model and ear model, and lymphatics model would make a great study aid."

"I thought the voice over on the lymphatic drainage model was extremely useful as I learnt most from this model. I would have liked all models to have had this as an option."

There were also more critical comments regarding the speed of the voice over and various minor issues with annotations and orientation of the models, again for both viewing modalities, such as:

"The voiceover was great, but too fast. For the first-time user of the models I had to listen to it 3 times before I caught up to the voiceover."

"(T)he placement of the annotations was sometimes odd and the lines connecting them to their respective anatomical elements were sometimes misplaced."

The final shared theme between viewing the models online and in VR was that of feature requests. A number of suggestions for additional features were suggested, including:

"(It) would be useful that when you click on the number, the correspondent anatomical area changes colour. This would be particularly useful for example for the small intestines or especially for the nerves."

"(I)t would be nice if the model could be rotated without us having to move from our standing position."

"Might be useful to have a facility that allows the models to rotate as opposed to using the teleport system. A true zoom function could also be useful."

A theme that emerged only for viewing the models online was that of loading times, with comments such as:

"Loading did take quite long, despite the usual wifi connection being quick."

There were an additional three themes that emerged for viewing the models in VR only; firstly, that many participants found this to be particularly fun and engaging:

"An extremely useful and novel way to teach anatomy, especially for visual learners."

"VR provides enhancement in (the) anatomy learning environment. Not only (does) it resembles playing computer games which is fun, but (it) also add(s) new advantages such as the ability to view anatomical details in virtual reality which is especially … good for medical/dental specialist residents or any health professionals as a training field prior performing a complicated surgery."

Secondly, that some participants found there to be a notable learning curve associated with viewing the models in VR:

"It does take a bit of time before getting used to moving around the VR object."

"The HTC was difficult to navigate at first, the introduction to using the HTC was very helpful- especially with the split computer screen."

And finally, a sizable minority (5~~27%~~) reported motion sickness or other discomfort:

"I landed myself in the middle of a large temporal bone and this made me really panicky for a moment. I felt totally uneasy about viewing the ear model afterwards."

"Not during viewing the models, but afterwards I felt my eyes (short-sighted) were tired and somehow their unequal level of "short-sightedness" was more prominent."

"It feels quite disorientating"

To summarise, for the feedback comments on viewing the models online, three primary themes were evident in the data. These themes were labelled as 'Positive Comments', 'Issues', and 'Feature Requests'. The first two primary themes also had a number of sub-themes associated with them.

Positive Comments: This theme was defined as including all the feedback comments that described finding the online models as being useful in some way. Two sub-themes were identified as follows: The *quality* of the models and the *usefulness of the voiceover*.

Issues: This theme was defined as including all the feedback comments that described issues with any aspect of the online models. Three sub-themes were identified as follows: That the *voiceover was too fast*, issues surrounding the *annotations and orientation* of the models, and (slow) *loading times*.

Feature Requests: The final theme was defined as including all the feedback comments that requested additional features.

For the feedback comments on viewing the models in VR, the same three primary themes were again identified, although this time with a number of unique sub-themes associated with the first two primary themes.

Positive Comments: This theme was defined as including all the feedback comments that described finding the viewing the models in VR as being useful in some way. Three sub-themes were identified as follows: That viewing the models in VR was *fun and engaging*, the *quality* of the models and the *usefulness of the voiceover*.

Issues: This theme was defined as including all the feedback comments that described issues with any aspect of viewing the models in VR. Four sub-themes were identified as

follows: The *learning curve* associated with using the VR hardware and navigation, that the *voiceover was too fast*, issues surrounding the *annotations and orientation* of the models, and *discomfort* (both physical and psychological) arising from the VR experience.

Feature Requests: The final theme was defined as including all the feedback comments that requested additional features.

Discussion and Future Work

Overall, the feedback for viewing the models both online and in VR was very positive, with the VR models receiving a slightly more favourable response than those online in terms of how much participants enjoyed viewing the models. Comments made in open answer questions indicate that most participants found the VR models to be particularly fun and engaging.

Loading times were generally less of an issue in VR, likely due to the highspeed wired ethernet connection available in the room. Participant's experiences of viewing the online models off campus will no doubt have varied due to the individual's location, internet connection and device used. This highlights the importance of using low poly models for online use where possible, especially where they will be accessed across a range of systems (Webster, 2017).

Participants felt that ~~found~~ both means of viewing the models ~~to~~ would prove to be ~~a~~ useful study aids, with the VR models scoring slightly higher in this regard. It should be noted that as the study was conducted after the end of the second taught semester, most participants were not actively using the models for revision, however they still clearly felt the models to be useful. Participants on the different programmes

will likely have found different models to be more useful, which may have impacted how they felt about the resource. However, it was felt that a variety of models demonstrating a range of anatomical structures, systems and scales should be included in order to demonstrate different ways in which VR could be used and to elicit feedback on preferences and suggestions for future developments. ~~Although~~ In addition, one participant made a ~~good~~ valuable point about the online models being more conducive to note taking and using alongside other resources:

"VR … felt more interactive and fun, but using the models online allowed me to make notes or compare the models to text books etc for revision or reference purposes."

There were fewer issues reported around navigating the collection indicated for the VR models than for those online. However, in hindsight this question could have been phrased better and may have been misunderstood by some participants. It referred to how participants found navigation of the whole collection, opening one model and then another etc. However, this could have been interpreted to mean how easy or difficult it was to navigate within an individual model scene. In addition, loading of the models during the VR sessions was performed by the researchers due to an issue with Sketchfab meaning this was not easily undertaken this whilst wearing the HMD.

One area where the online models scored slightly better than those viewed in VR was regarding the annotations. Although both modalities scored well here, with the majority agreeing/strongly agreeing that the annotations were a useful addition, there were slightly more who strongly agreed with this for the online models compared with viewing them in VR. This was likely due to some of the longer annotations not fully displaying when viewed in VR (this problem originated with the version of Sketchfab VR that was used), an issue that only became apparent as the study progressed.

Results from the Likert style questions indicated that there were fewer issues for

participants moving around the models in VR than there were interacting with them (i.e. rotating, magnifying) online. Initially this result appeared counter intuitive, as the authors expected more issues moving around the VR models due to the novel nature of this experience for most participants. In addition, in the open answer questions several participants also highlighted the learning curve associated with viewing and moving around the models in VR. It is possible that the 'orientation cube' was helpful in this regard, and that there was a researcher present to guide participants during use of the VR system. Whereas participants were largely unsupported in viewing the models online, with the exception of the initial email guidelines.

The voiceover (present on the model of the lymphatic system only) received positive feedback overall for both viewing modalities, with VR scoring slightly higher. Although not explicitly stated, this is likely due to scale of the model (life size) and immersion of VR, making it easier to follow along. A common critique of the voiceover (in comments relating to viewing the models both online and in VR) was that it was a little too fast.

Finally, a small but notable minority of participants experienced some level of discomfort either during or after viewing the models in VR. This included the commonly reported VR side effect of motion sickness but also other forms of discomfort such as tired eyes, disorientation and for one participant, panic at finding themselves 'within' one of the models, which left them uneasy about viewing subsequent models.

Limitations Suggestions for Future Work

Although only ever intended as a pilot study to gather student feedback on VR anatomy resources (with a view to informing potential investment and developments within the

department), there were nonetheless a number of issues that limited the scope of the study that are worthy of further discussion.

Sketchfab was used to share and view the models both online and in VR. This was largely due to its ease of use and the fact that CAHID already had a sizable collection of 3D models hosted on this site. However, viewing models in this way requires the use of WebVR which is a relatively new technology and as such can frequently encounter issues, especially when browsers are updated. In addition, the Sketchfab platform itself is regularly updated, which while usually fixing bugs and adding new features, can also on occasion cause unexpected problems between the application and WebVR browsers. Unfortunately, such an issue occurred at the planned start of this study resulting in approximately a six-week delay. This may have had an impact on participant (i.e. student) recruitment as it meant the study started in April (2018) rather than February (2018), when most students had exams and/or coursework deadlines, likely resulting in a lower number of participants than first anticipated. Undergraduate students are also not around over the summer months, which explains why a larger number of MSc and PhD students took part.

It would have been ideal to create a bespoke VR viewer for testing these models which would have both been more stable and allowed for additional functionality such as that suggested in the feedback. Unfortunately, this was not within the skill set of anyone within the department but was also felt to be unnecessary for the purposes of gathering initial feedback. However, with the vast majority (17~~94.4%~~) of the participants saying they would use such facilities either 'frequently' or 'occasionally', if available within CAHID, ~~going forward~~ the authors ~~hope~~ plan to work with colleagues in Computing to develop such bespoke applications. In addition, the school of Science and Engineering, of which CAHID is a part, is considering investing in a suite of VR

headsets and accompanying computers to further integrate VR into teaching across the school. Another factor to be considered at this juncture however is the inherent difficulty of teaching more than one student at a time in VR. There are health and safety concerns to be addressed when multiple people use VR in the same space, and such it would likely be necessary for students to view and interact with models while seated. It would be possible for an instructor to guide multiple students through viewing models in this way. However, the authors feel the such resources are more suited to self-directed learning, and that providing a dedicated facility where students can book out time is likely the best way forward. It is anticipated that a further, larger study will take place in the future once such facilities are available to students.

In terms of what such an application should include, most participants (13~~72.3%~~) said they would like to see 'interactive 'dissectible' models', being developed, where individual structures could be made transparent or invisible. Other feature requests included; being able to highlight individual structures, rotating the models using the controllers (rather than the user moving around the model), and being able to scale the models (without them rising and falling in space as currently occurs within Sketchfab). As described above, a bespoke VR viewer has the potential to achieve the feature requests detailed here and is something now being investigated by the authors. In the meantime, the models as they stand on Sketchfab, along with new models created by centre staff and students can continue to be used and easily accessed both in VR on campus and online remotely.

Finally, it is worth remembering that VR technologies are moving at a fast pace with new headsets frequently being released. Many newer headsets such as the Oculus Quest (due to be released early 2019) utilise 'inside out' tracking, meaning the sensor/camera is placed on the device itself which looks outwards to determine its

relation to the environment, meaning they are much more portable than most current headsets (which use outside-in tracking where the headset is tracked by an external device). In addition, the Quest is an all in one device, with no need to be wired to a PC. Such advances will no doubt enable an easier integration of VR to the classroom as well making wider adoption in the home more likely.

Conclusion

Although only a pilot, this study has nonetheless been successful in gathering the feedback of students and identifying areas for investment and development within the centre. The authors have concluded that there is scope for investment in such technologies for the enhancement of anatomy education and plan to work with colleagues across the school to bring this about. It should be remembered that the authors are not seeking to replace dissection or other traditional methods of teaching anatomy but to produce a resource to be used in addition to these.

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Figure 1. Sketchfab's VR editor allows you to set the scale, viewing position and floor level for each model

Figure 2. Sketchfab allows you to view any 3D model in VR using a WebVR browser and a VR headset such as the HTC Vive or Oculus Rift

Figure 3. A collection of seven anatomical models (plus an 'orientation cube') was created for the study

Figure 4. Breakdown of programmes for the 18 participants

Figure 5. Results for sections two and three of the online user survey; comparing results for viewing the models online and in VR

Figure 6. Thematic Map for feedback on the online models

Figure 7. Thematic Map for feedback on the VR models