University of Dundee

DOCTOR OF PHILOSOPHY

Does Virtual Haptic Dissection Improve Student Learning?
A Multi-Year Comparative Study

Erolin, Caroline

Award date:
2016

Awarding institution:
University of Dundee

[Link to publication](#)

Centre for Anatomy & Human Identification

UNIVERSITY OF DUNDEE

Does Virtual Haptic Dissection Improve Student Learning?

A Multi-Year Comparative Study

Caroline Erolin

Supervisors:

Professor Caroline Wilkinson

Dr Clare Lamb

Professor Roger Soames

Submitted to the University of Dundee toward the degree of

Doctor of Philosophy in Medical Visualisation

at the Centre for Anatomy and Human Identification

November 2016

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GLOSSARY

API – 'Application Programming Interfaces'

Biocular vision - where both eyes view the same image

Binocular vision - where both eyes view (slightly) different images, necessary to view a stereoscopic image

Boundary Element Method (BEM) - a numerical computational method of solving linear partial differential equations which have been formulated as integral equations (i.e. in boundary integral form) which can be used for creating deformable models

CAL - Computer Aided Learning

CT - Computed tomography scan. Used to create detailed images of internal organs.

Deformable spline - a spline is a curve that connects two or more specific points, or that is defined by two or more points. The term can also refer to the mathematical equation that defines such a curve

Finite Element Method (FEM) - a numerical computational method for finding approximate solutions of partial differential equations and integral equations which can be used for creating deformable models

GPU – 'Graphics Processing Unit' or graphics card

Haptic feedback - the use of the sense of touch in a computer user interface

Hybrid model - a combination of the other techniques for creating deformable models

An **isosurface** - a 3D surface representation of points with equal values in a 3D data distribution. The 3D equivalent of a contour line

Linked volumes - In a linked volume each element is linked to its six nearest neighbours. These links can be stretched, contracted, and sheared during object deformation and deleted or created when objects are cut or joined

NURBS - Non-Uniform Rational B-Splines, a mathematical representation of 3D geometry

Segmentation –the partitioning of a digital image into two or more regions

Spring-mass models - as indicated by their name, are based on meshes composed of springs (or spring-damper elements) and discrete mass points which can be used for creating deformable models

Stereoscopy - a technique for creating 3D depth perception by showing two slightly different views of a scene to the left and right eye of the viewer

Tensor-mass model - a volumetric extension of the basic spring-mass model based on a discretization of the entire interior of the deformable object into tetrahedrons

Voxel - a three-dimensional pixel or volumetric pixel

ACKNOWLEDGMENTS

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Name: Caroline Erolin

Signature:

Date: 09/05/2016

CERTIFICATE OF APPROVAL:

As supervisor of Caroline Erolin's PhD, I certify that the above statements are true to the best of my knowledge.

Supervisor: Dr Clare Lamb

Signature:

Date: 17/05/2016

As supervisor of Caroline Erolin's PhD, I certify that the above statements are true to the best of my knowledge.

Supervisor: Prof Caroline Wilkinson

Signature:

Date: 09/05/2016

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ABSTRACT

The past decade has seen the release of numerous software packages aimed at enhancing anatomical education. However, there has been little research undertaken by the manufacturers of these products into the benefit or otherwise of these packages for student learning. In addition, while many of the existing software packages include interactive three-dimensional models, none of them truly offer virtual dissection i.e. the cutting through anatomical layers with a haptic (tactile) interface.

This study investigated the haptic 'dissection' of a three dimensional digital model of the hand and wrist in anatomy education at both undergraduate (UG) and postgraduate (PG) levels. The model was used as a teaching and revision aid both prior to and after dissection of a real cadaver. A haptic enabled version of the model, allowing for real-time cutting was compared with a non-haptic version, using instead a keyboard and mouse 'point and click' style interface. Both versions were tested on students of gross anatomy in relation to test results and student experience.

The model was based upon Computerised Tomography (CT) and photographic slice data from the Visible Human Project female data set. It was segmented and reconstructed using Amira® 5.2.2. From here each structure was exported as a separate STL file and imported into Geomagic Freeform® Modelling ™. Once imported into Freeform® Modelling ™, the individual structures each required varying degrees of re-modelling where detail had been lost during the segmentation process. Some smaller structures such as the nerves, veins and arteries were modelled freehand.

The final model could be dissected using FreeForm® Modelling™, the same software in which it was created. Using FreeForm® Modelling™ as a prototype VR dissector, each anatomical structure could be selected and virtually 'dissected' with the PHANTOM®

Desktop™ haptic tool. Three methods of interacting with the model were identified: 1) using a cutting tool to cut through the selected layer; 2) using a selection paintball to first select and then delete the layer; and 3) using planes to cut the selected structure in standard anatomical views.

The study ran over five successive years and was split into three discreet phases. Phase one compared the results of PG students across control, non-haptic and haptic groups. Phase two compared the results of UG students between control and haptic groups. Phase three compared the results of UG students across control, non-haptic and haptic groups.

Due to small group sizes and a largely non-normal distributions the results were analysed using Mann-Whitney U tests. Results for all phases indicate that use of the model, both through haptic and non-haptic interfaces produced some significantly improved test results. The non-haptic version of the model performing equal or better than those with access to the haptic version. This is likely due to cognitive load being adversely affected by the addition of the haptic device. Some students reported that the haptic device was not intuitive to use and took some time to get used to, if at all. No student used either version of the model for more than five hours, with over 40% using it for less than one hour. It is possible that with increased exposure to the haptic device students may find it easier and thus beneficial. The findings of this study indicate that when used for a short period of time only (<5 hours) the haptic device may impede rather than enhance learning.

1: INTRODUCTION

This chapter will firstly outline the background to the study. Particularly looking at the role of dissection in anatomy education, learning theory, haptic and multi-modal interfaces and the existing software (these topics and more will discussed further during the literature review). This will be followed by giving the aims and objectives and finally the hypothesis.

1.1 BACKGROUND TO PROJECT

The Future of Dissection in Anatomy Education

There is considerable debate taking place over the role of dissection in the in the future of anatomy education (Rizzolo and Stewart, 2006). Those who speak out against it cite the increasing scarcity of donated bodies and costs of cadaver dissection as growing concerns (Aziz et al., 2002, McLachlan et al., 2004).

Decreasing hours are also being dedicated to the teaching of anatomy in the UK and US (Leung et al., 2006, Pryde and Black, 2005), in part as a result of increasing student numbers and an increase in course content from areas such as molecular biology. Some medical schools have even stopped teaching dissection altogether, such as the Peninsula Medical School, University of Exeter (McLachlan et al., 2004) and many universities[i] are turning to digital resources to respond to some of their educational requirements.

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[i] http://www.primalpictures.com/CaseStudies.aspx

Those who defend dissection however, claim that it teaches skills which are either difficult or impossible to learn by other means, (Aziz et al., 2002, Rizzolo and Stewart, 2006), such as:

- Exposure to death, and the development of a 'professional' attitude ('the first patient')

- Teamwork and communication skills

- 3D learning and spatial awareness

- Exposure to anatomical variability

- Encourages differential diagnosis

- Manual dexterity (importance of touch)

Some of the items on this list can be addressed by other teaching modalities and technologies, such as use of a simulated patient and virtual ward environment to facilitate teamwork and communication. Others however are more difficult to address. Exposure to death (in a controlled environment and with support available) is not possible via other means and can help students in developing empathy and a 'detached concern' necessary for good practice (Aziz, 2002). The normal anatomical variability often seen in the dissection room is also not easily replicated in models (either traditional or virtual), but is something of particular importance to medicine, especially for surgery, as well as other professions such as forensic anthropology.

Brenton et al. (2007) discuss the changing approaches to anatomy education and make the important recommendation that more research should be undertaken into the relative value of different teaching methods before new approaches are included. This backs up an earlier statement by Heylings (2002):

"It has been argued that the pedagogical reasoning behind the key teaching approaches in anatomy should be properly researched prior to curricular change" (Heylings, 2002, p702).

It may be that digital resources can both impart some of the skills commonly attributed to traditional dissection teaching, as well as addressing some of the concerns over costs and resources. However, rather than choosing between cadaveric dissection and new technologies, there may be more value in utilising such technologies to enhance existing teaching practices rather than replacing them (Aziz et al., 2002, Biasutto et al., 2006, Rizzolo and Stewart, 2006).

Learning Styles and Theories

It has been demonstrated that different individuals prefer to learn through different 'styles' (Kolb, 1984, Honey and Mumford, 1992, Fleming, 1995), such as visual, aural, read/write and kinaesthetic learners (VARK) (Fleming, 1995). Teaching in a variety of ways gives students more opportunities to learn through a style that suits them. Anatomy as subject inherently involves a number of different leaning modalities, including lectures (aural, visual and read/write), textbooks (visual and read/write), traditional and digital models (visual and kinaesthetic) and dissection (kinaesthetic).

In addition to individual differences, Dual-coding theory proposes that all learners have two primary channels through which information is processed: visual and verbal (auditory), with each channel having a maximum load that it can process. If images are presented alongside text, the visual channel is responsible for processing all of the information and can be overloaded, while the auditory channel remains unused. However, if narration is paired with visuals, not only does this prevent too much load in the visual channel, but it also allows the brain to process and synthesize information from two different sources (Mayer and Mureno, 2002).

There are also a number of factors particular to anatomy education that should be considered. Anatomy is an inherently three-dimensional (3D) subject and spatial relationships are particularly important (Marks, 2000). Research by Stull et al (2009) suggested that students with active control over a 3D object, compared with passive

observation (i.e. kinaesthetic and visual learning as opposed to visual alone) were better able to identify anatomical features from a variety of orientations.

Haptic and Multi-Modal Interfaces

The study of anatomy and dissection in particular is multisensory (Aziz et al., 2002, Topp, 2004). It combines the act of doing – tactile (or haptic) feedback - with a highly visual experience. The word 'Haptic' (from the Greek haptesthai, meaning "to touch") relates to the sense of touch, and 'haptic feedback devices' are a type of hardware used with a variety of computer packages. Haptic feedback can be produced in a number of ways from applying forces, vibrations and or motions to the user. Aziz et al. (2002) emphasise the value of touch in dissection and cite it as one of the many reasons why they believe virtual anatomy will not fully replace cadaveric dissection.

"This touch experience begins in the human anatomy laboratory. Actual dissection is a journey into the body and, by touch, the student develops a synaesthetic map of human structural organization... Dissection is a necessary exercise in the development of touch-based skills which can then be transferred to palpation, percussion, and auscultation" (Aziz et al., 2002, p25).

The relationship between visual and haptic interfaces is known to be complex with no simple answers relating to which modality dominates the other (Ernst and Banks, 2002, Jones et al., 2005, Chen et al., 2011). Rather, the wider context and factors such as whether or not visual and haptic cues reinforce or contradict one another, appear to play a larger role. It has also been demonstrated that the addition of haptic to visual feedback increases student interest in the exploration of virtual objects (Jones et al., 2002)

Existing Software

The past decade has seen the release of numerous software packages aimed at enhancing anatomical education. However, there has been little research undertaken

by the manufacturers of these products into the benefit or otherwise of these packages for student learning.

In previous 'virtual anatomy' research, the primary emphasis seems to be on the *replacement* of cadaveric dissection (McLachlan et al., 2004, Hoffman and Murray, 1999, Ward et al., 2008) with only a few exceptions highlighting the benefits of integrating new technologies with existing teaching practice (Rizzolo and Stewart, 2006, Biasutto et al., 2006, Aziz et al., 2002). It is interesting to note, that although many of the existing software packages try to offer the replacement of cadaveric dissection through interactive three-dimensional anatomical models, none of them truly offer virtual dissection i.e. the cutting through anatomical layers with a haptic interface

1.2 AIMS OF PROJECT

This study aimed to evaluate the potential benefit of integrating new technologies with existing methods of teaching. The project aimed to create a three-dimensional digital model of a localised region of human anatomy (the hand and wrist) which could be virtually 'dissected', through a haptic interface. This region was chosen due both to its size (fitting on a computer screen at close to life size) and complexity (students could benefit from additional study). The study also aimed to investigate whether students with access to the haptic software would attain better results and report a better experience than those using the non-haptic version, and in turn if the non-haptic group would attain better results than the control group.

The model was used as a teaching and revision aid both prior to and after dissection of a real cadaver. The impact of the model was assessed in a number of ways; anatomy tests were given to all groups, the quality of the dissections were evaluated, and students who used either version of the model were asked to complete a feedback questionnaire.

The objectives included:

- The creation of an anatomically accurate three dimensional digital model of the hand and wrist. This model would be created by the author to ensure anatomical accuracy and compatibility with a haptic interface.

- The creation or adaptation of an interface to provide the user with a Haptic Dissection Simulation experience to enhance kinaesthetic learning and compliment cadaveric dissection.

- The creation of two written dissection and user guides to facilitate interaction with and dissection of the model.

- Testing of the software on relevant student populations, followed by a comparison of anatomy test results, dissection evaluations, and questionnaire feedback.

1.3 HYPOTHESES

Hypothesis 1

Those students who use the Non-Haptic Dissection Simulator will attain higher test results and produce a better quality cadaveric dissection than those without access to the Non-Haptic Dissection Simulator.

Null Hypothesis 1

Those students who use the Non-Haptic Dissection Simulator will not attain higher test results or produce a better quality cadaveric dissection than those without access Non-Haptic Dissection Simulator.

Hypothesis 2

Those students who use the Haptic Dissection Simulator will attain higher test results and produce a better quality cadaveric dissection than those without access to the Haptic Dissection Simulator.

Null Hypothesis 2

Those students who use the Haptic Dissection Simulator will not attain higher test results or produce a better quality cadaveric dissection than those without access to the Haptic Dissection Simulator.

Hypothesis 3

Those students who use the Haptic Dissection Simulator will attain higher test results and produce a better quality cadaveric dissection than those using the Non-Haptic version.

Null Hypothesis 3

Those students who use the Haptic Dissection Simulator will not attain higher test results or produce a better quality cadaveric dissection than those using the Non-Haptic version.

1.4 CHAPTER SUMMARY

This chapter has provided a brief overview of the background to the study as well as outlining the aims and objectives and finally the hypothesis.

Chapter 2: 'Review of the Literature', will explore a variety of topics in relation to this study in more depth. While they may at first appear to span a wide range of subject disciplines, they are all relevant to various aspects of the study. Chapter 3: 'Materials and Methods', describes the creation of the model and the interface, along giving an

overview of the research design. Chapter 4: 'Results and Discussion', details the results from each phase of the study and discusses how they relate to the hypothesis. Finally, chapter 5: 'Conclusions and Future Work' summarises the findings and relates these to suggestions for future work.

2: REVIEW OF THE LITERATURE

This chapter will explore the literate relating to a variety of topics relevant to the current study. The primary search engine used was 'Web of Science' (http://wok.mimas.ac.uk/). Typical search terms included (but were not restricted) to the following:

- Virtual anatomy / dissection

- Anatomy / medical education

- Learning theory

- Kinaesthetic learning

- Cognitive load

- Dual coding

- Split attention

- Stereoscopy and anatomy/medicine

- Virtual reality medicine

- Multi-modal

- Haptics

- Haptic anatomy / dissection

- Surgical simulation

- Tissue properties

This is a diverse list of subjects and as such it was not possible to explore each of them in the depth that might be expected if this study was more firmly entrenched in one specific field. Being multidisciplinary in its approach, pragmatic limits had to be set for how much enquiry was undertaken into each area. Many of the topics covered are out-with the author's area of expertise, but were included due their relevance to some aspect of the current study.

2.1 CURRENT APPROACHES TO ANATOMY EDUCATION

Numerous methods exist for teaching anatomy including lectures, dissection, the use of prosections, books and more recently the integration of computer aided learning (Aziz et al., 2002). This section will explore current approaches to anatomy education and discuss how these might be used together to enhance student learning.

The Dissection debate

Dissection has been practiced in the UK for the teaching of anatomy since around the 16th Century and forms a crucial part of most modern anatomy and medical curriculums (McLachlan and Patten, 2006). However, as described in the introduction there is some debate over its future role anatomy education. The Peninsula Medical School at the University of Exeter is the first in the UK to have removed dissection from its curriculum all together (McLachlan et al., 2004). In its place students receive tuition and experience in surface anatomy using both living models and simulators, as well as utilising a variety of imaging modalities including, ultrasound, radiographs, CT and MRI scanning. These are frequently used together in problem-based learning activities. The school also utilises 3D medical animations and digital models to support student learning (McLachlan et al., 2004), and purchased an Anatomage Table in 2015[ii] to allow for life size viewing of the Visible Human Project male and female data sets[iii]. The Peninsula Medical School is primarily concerned with producing graduates with excellent clinical skills and as such their program seems well tailored to this end. However it must be remembered that not all medical students will go into clinical practice but that many will go on to work in

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[ii] https://www.plymouth.ac.uk/news/virtual-dissection-table-a-first-for-plymouth-medical-and-dental-school-schools

[iii] https://www.nlm.nih.gov/research/visible/visible_human.html

surgery, where some of the skills taught in cadaveric dissection (such as the use of instruments) might be of more or equal use. McLachlan and Patten (2006) suggest that it may be worthwhile researching the disciplines entered into by graduates who have experienced different educational interventions at an undergraduate level. For example, would lack of exposure to cadaveric dissection in their undergraduate course make them less likely to undertake a career in surgery?

In contrast to the Peninsula Medical School, the anatomy department at the University of Dundee (based with the Centre for Anatomy and Human Identification (CAHID)) has invested heavily in its cadaver dissection facilities. In 2014 it opened a new mortuary allowing for Thiel embalming[iv], making it the first place in the UK to offer dissection of Thiel embalmed cadavers. Developed by Walter Thiel at the University of Graz Austria, it is a method of embalming that closely simulates a living patient, retaining life-like tissue colour and flexibility (Eisma et al, 2013). In addition to being used across all of the undergraduate and postgraduate anatomy modules, Thiel embalmed cadavers are also used for specialist training courses in a range of subjects including ultrasound-guided regional anaesthetics (UGRA), thyroidectomy, laparoscopic colorectal, bariatric and urology surgery, and orthopaedic surgery (Eisma et al, 2013). In addition to medical and anatomy students, the University of Dundee also teaches anatomy to students from forensic anthropology, biomedical engineering and forensic and medical art degrees.

It can be seen from these two examples, that different institutions are approaching the same issues in different ways, and it will be up to prospective students to decide which is best suits their learning objectives.

In addition to the debate over the future of dissection, there are number of technological developments which are being utilised within modern anatomy education. The following

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[iv] http://cahid.dundee.ac.uk/thiel-cadaver-facility

sections will look at a range of these and explore the literature to discover what impact they are having.

The Visible Human Project (VHP)

The National Library of Medicine's Visible Human Project® aimed to create detailed datasets of the normal male and female human bodies consisting of transverse CT, MR and cryosection images.   The male cadaver was cut in the axial plane at 1 millimetre intervals resulting in 1,871 slices.   Each slice was digitally photographed resulting in 15 gigabytes of data. The photos were rescanned in 2000 at a higher resolution, resulting in more than 65 gigabytes of data. The female cadaver was cut into slices at .33 millimetre intervals, resulting in over 40 gigabytes of data.

Figure 1, An example of a cross sectional photograph from the visible human female data set

Planning for the VHP began in 1989 with the male data set being completed in November 1994 and the female in November 1995 (Figure 1). The project can be viewed at the National Museum of Health and Medicine in Washington, DC: access to the data sets can be   obtained   by   completing   a   license   agreement   found   at: http://www.nlm.nih.gov/research/visible/getting_data.html. The long term goal of the

VHP is to connect image based anatomic data (models, software applications, cross sectional viewers) with text based data in one unified resource of health information for healthcare professionals, students, and lay people (Jastrow and Vollrath, 2003). There are currently efforts to add to the project with higher resolution images and using cadavers from different ethnic backgrounds (Spitzer and Scherzinger, 2006). Visible human projects have also been undertaken in China and Korea (Park et al, 2006) with the results being made available to researchers.

Spitzer and Whitlock (1998) describe what they envisage as the ideal virtual human for anatomy education. They state that the subject would be of either sex and of any desired age or ethnicity. The virtual subject would appear, feel, smell, sound and react like a living person. They suggest the database might be rendered dynamic in time as well as space, so the student could witness development and aging. Essentially the final goal is to simulate living human anatomy, not cadaver anatomy. These are bold visions and are still some way from actualisation, however good progress has been made with the Visible Human (VH) data sets having been applied to a wide range of educational, diagnostic, treatment planning, virtual reality, artistic, mathematical, and industrial uses by nearly 2,000 licensees in 48 countries (NIH, 2010).

To create 3D anatomy from the VHP data set it is usually necessary to 'segment' the data (determine the exact surface location of an organ/tissue structure). This can be achieved through a number of software applications usually described as DICOM viewers. DICOM stands for 'Digital Imaging and Communications in Medicine' and is an industry standard for handling, storing, printing, and transmitting information in medical imaging (dicom.nema.org). Segmentation can be either manual or automated. There are problems with each approach: complete automatic segmentation is not possible for anything but the large, easily differentiated organs and structures, manual outlining of structures on the cross-sections is very time consuming and largely observer-dependent.

Furthermore, despite the relatively high resolution of the VHP data set (especially the cryosection images), details such as nerves and small blood vessels still cannot be clearly identified, due to their size and contrast being too small (Pommert et al., 2000). Many researchers therefore use a combination of approaches, for example, Schiemann et al. (2000) used a semi-automated method of segmentation for large structures and manual segmentation for smaller, more detailed areas. Some of the smallest details such as nerves and blood vessels frequently require modelling freehand (Pommert et al., 2000).

Malvankar and Temkin (2006) reported that a side-by-side manual segmentation approach for the visible human male and female was most effective. They also utilised digital atlas images to facilitate accurate segmentation.

Numerous models and applications have been created from the data sets ranging from 3D models to software to enhance viewing and labelling of the cross-sectional images. The Virtual Human Dissector (VHD) facilitates students learning to interpret 2D cross sectional anatomy, allowing users to study the 2D anatomical cross-section images and reconstructed 3D views simultaneously. Donnelly et al. (2009) tested the VHD's role in student self-directed learning (SDL) by comparing it with the use of prosections. Results showed that while both groups improved significantly between the pre- and mid-session tests, and again between mid and post-session tests, there was no significant difference between the two groups at any stage. SDL using the VHD was as effective as SDL using prosections.

A similar study compared the use of a physical 3D printed model with a virtual 3D model and textbooks for learning the anatomy of the equine foot (Preece, 2013). Students were split into three groups using either the 3D printed model, the virtual model or textbooks. They were then asked to identify anatomical structure on MR images. Interestingly it was the 3D printed group who significantly outperformed the other two groups scoring 86% compared with 63.68% for the virtual group and 62.61% for the

textbook group. The results suggest that there may yet be visuospatial advantages to physical models over virtual.

Jastrow and Vollrath (2003) in a review of both online anatomy projects and multimedia productions (books and CD-ROMs) based on the VHP, concluded that the VH data sets were ideal for creating educational materials and that there were are no comparable data sets in the public domain of similarly high resolution and quality. They went on to say that volume rendering and virtual reality applications are of such a high standard that realistic 3D visualization of anatomical structures is no longer a dream. Finally, they suggested that rather than replacing cadaveric dissection, modern computers and the 3D anatomy they offer, should be used to complement the knowledge gained from dissection, 'an irreplaceable method for learning structural relationships in three dimensions'.

3D Virtual Models for Anatomy Education

There are currently a number of 3D anatomy programmes of varying quality commercially available, including; Primal Pictures 3D Human Anatomy series, Argosy's Visible Body and 'InteractElsevier'. However, there has been little research undertaken by the manufacturers of these products into the benefit or otherwise of them in student education. Although many cite testimonials and case studies on the implementation of their software, these remain unsubstantiated. A number of researchers have however examined the question of how useful 3D virtual anatomy might be in the classroom.

There is a consensus of opinion that effective 3D learning is essential to the understanding of anatomy (Marks., 2000, Stull et al., 2009, Garg et al., 1999). Previous research indicates that achievement in a number of medical professions can be related to an individual's spatial ability (Anastakis et al., 2000, Cuschieri., 1995; Hegarty et al., 2009; Keehner et al., 2004). Although both high and low spatial ability individuals can acquire spatially demanding medical skills with practice, spatial ability continues to

predict performance after many learning sessions (Keehner et al., 2006). It can therefore be appreciated that interactive 3D digital models of human anatomy are seen by many as having the potential to influence greatly how anatomy is taught.

Jastrow and Vollrath (2003) in their review gave an overview of the numerous projects stemming from the VHP data sets. Many of these projects included anatomical 3D reconstructions and interactive 3D models. Although they do not discuss specifically if, or how, these projects have improved student learning, they conclude that real anatomy teaching can be supplemented by virtual reality and web-based instruction for the benefit of learners.

Brenton et al. (2007) discuss the significant changes facing anatomy teaching due to curricular constraints, limited availability of cadavers and technological developments in the areas of 3D modeling and computer assisted learning. The paper discusses the advantages and disadvantages of 3D computer models in teaching anatomy to undergraduate medical students. They give a 'work in progress' account of a project to develop two Web3D resources for undergraduate tuition of the nervous system. The first resource is a 3D model of the adult brachial plexus which is incorporated into existing classroom teaching. The second takes the form of online coursework teaching the embryological development of the brachial plexus. Both will be delivered over the 'WebSET framework', a collaborative environment which allows the educator to manipulate 3D models over the Internet in real time whilst providing an explanation to students. The aim is that this will embrace both self-directed study as well as 'virtual anatomy demonstrations'. The final results of the project have not yet been published with the authors stating that more research needs to be done to evaluate these resources before they are introduced into the undergraduate medical curriculum.

Stull et al. (2009) examined the use of orientation references in relation to learning 3D anatomy from digital models. Participants learned the anatomy of a vertebra by using

a handheld controller to rotate an on-screen 3D model. The bone model could optionally include orientation references (consisting of lines marking its axes) or not. The learning task involved rotating the on-screen model to match the orientation of targets. Learning outcomes were assessed by asking participants to identify anatomical features from different orientations. On the learning task, the orientation reference group (who used models containing orientation references) performed more accurately, directly and quickly than the control group (who used models without orientation references). High-spatial-ability individuals outperformed low-spatial-ability individuals (spatial ability was determined in a separate test requiring participants to mentally rotate and match 3D models). However, the use of orientation references elevated the learning outcomes of low-spatial-ability individuals to a level close to that of high-spatial-ability individuals. They concluded that the orientation reference technique was an example of one way of minimizing the problems encountered by low-spatial-ability learners when using virtual resources.

The topic of 3D VR models for anatomy education inevitably relates to the earlier debate over the value of dissection. Aziz et al. (2002) focused on this question suggesting caution when integrating virtual anatomy programmes and advise, similar to Garg et al. (1999), against the simplistic view that a virtual modality is necessarily superior to the traditional one in anatomy instruction.

A highly relevant (to this current study) piece of research was undertaken by Codd and Choudhury (2011) examining the use of a 3D digital human forearm model in teaching anatomy. The model was created in Blender and accessed through a bespoke graphical interface which allowed students to rotate the model freely and select muscles for further information. To mirror the teaching methods used in the dissection room, students used the model resource in groups of four with textbooks and an anatomist available for support. Out of 46 potential participants, 39 took part in the study, a participation rate

of 85%. The group sizes were: traditional group n = 14, control group n = 13, and model group n = 12. Results showed that the forearm model significantly improved anatomical knowledge for the control group (who had not previously studied forearm anatomy) with no significant difference between the traditional methods (dissection room) group and the model group. Feedback was overwhelmingly positive; ten students were asked 12 questions each on topics such as enjoyment and relevance, all responses were positive bar one regarding presentation. When asked how the digital model compared with traditional teaching methods, the consensus was that the resource was much better than using textbooks alone, but not as useful as dissection. The resource was a compromise between performance and anatomical detail and was somewhat stylized in its presentation. The authors suggest this style of presentation was appropriate for the study as participants were learning the basics of forearm anatomy, and excessive detail may been overwhelming. Other limitations cited included not being able to highlight muscle groups or assign different colours to muscles to improve the clarity structures. Based on user feedback, Codd and Choudhury (2011) concluded that such a computer package should be used as an adjunct to reinforce traditional teaching methods rather than replacing them.

Virtual Human Dissectors

There are currently no haptic virtual human dissection models available (to the knowledge of this author), either commercially or for research purposes, with the exception of temporal bone dissection simulators. These come under the category of surgical simulators rather than anatomical dissection and will be discussed later. There are, however, a number of programmes which use the term 'dissector' when describing their software. Inwood and Ahmad (2005) describe what they call, an 'Instructional, Interactive, Multimedia Anatomy Dissection Software'. Created by two undergraduate medical students, for use by first and second year medical students it consisted of forty-

four fully narrated, QuickTime movies each demonstrating a different regional dissection. The authors claim that the successful design and implementation of this software demonstrates that computer aided learning (CAL) can be employed to *'augment, enhance and improve anatomy instruction.'* (Inwood and Ahmad, 2005, p613).

The 'Visible Human (VH) Dissector' (Touch-of-Life-Technologies, 2005, Spitzer and Scherzinger, 2006) claims to 'combine the power of cadaver dissection with the technology of virtual reality' (Figure 2). Based on the VHP data set it provides a virtual body with over 2000 individual anatomic structures. Although it describes learning from the VH Dissector as being 'similar to cadaver dissection', it does not involve the user either cutting though tissue (allowing for deeper kinaesthetic learning) or using a haptic interface. Rather, structures are selected and either added or removed in their entirety.
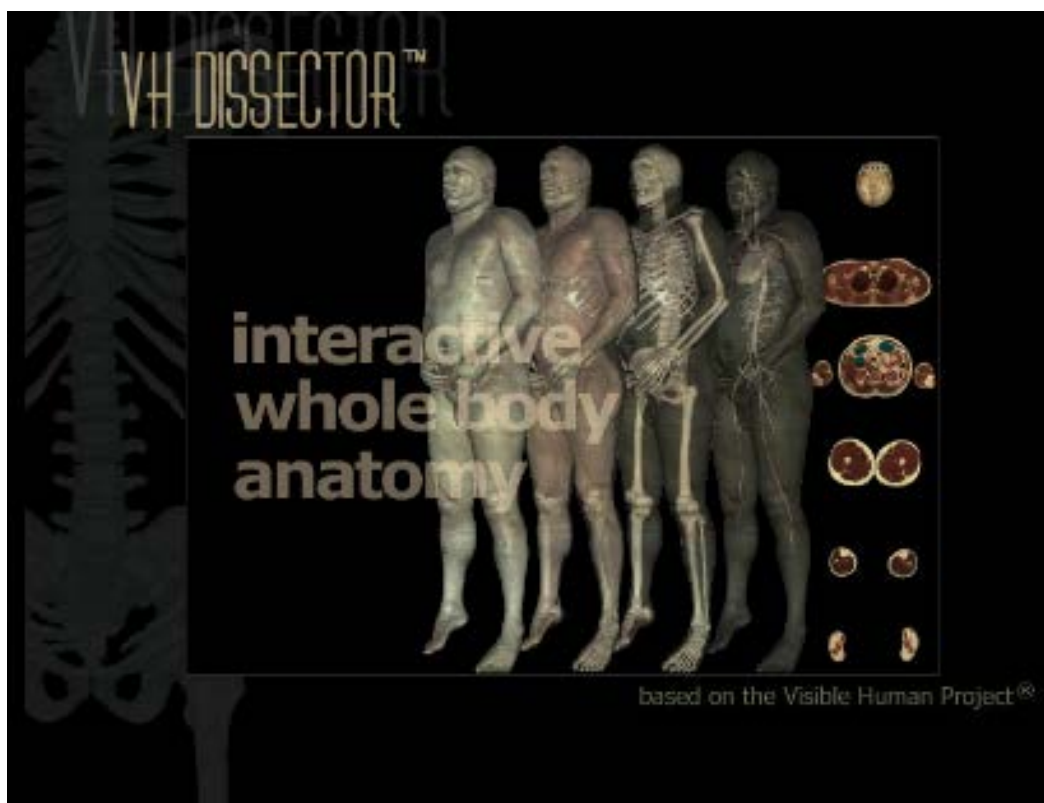
Figure 2, An image from the 'The Visible Human Dissector' webpage

The 'Virtual Human Dissector' (Donnelly et al., 2009), allows users to study real images of 2D anatomical cross-sections (from the VHP) and reconstructed 3D models simultaneously. The software is aimed at facilitating students' ability to interpret cross-

sectional images and understand the relationships between anatomical structures. It has proved to be as useful as using prosections for student self-directed study (Donnelly et al., 2009).

Another 3D anatomy education package which allows for the addition and removal of structures as well the use of cutting planes is VOXEL-MAN (http://www.voxel-man.de/). There are several packages available in the '3D Navigator series', including *Inner Organs* and *Upper Limb*. Although these do not utilise a haptic interface, the company also produce 'VOXEL-MAN Tempo', which uses two haptic devices for training and planning surgical access to the middle ear.

Jacobson et al. (2009) researched the use of 'virtual patients', 3D reconstructions of cadavers from CT data, as a learning tool prior to dissection. Case studies were available for first year anatomy students to access remotely, although their use was an addition to regular teaching and not mandatory. In the first year, 34% of students accessed and reviewed the cases, giving positive feedback. The following year, images from the cases were included in examinations resulting in the majority of students accessing and reviewing the cases beforehand.

Virtual Haptic Animal Dissectors

Although there are no true VR haptic human dissectors available, there have been a number of attempts at creating VR haptic *animal* dissectors. The use of virtual frogs and pigs for dissection is becoming more frequent in classrooms, especially in North America where dissection of such animals is common place (Boothby, 2010). The majority of virtual animal dissectors (for example: Digital Frog, by Digital Frog International; CyberEd Dissection Series, by Plato; DissectionWorks, by ScienceWorks; and Frogguts, by Frogguts, Inc.) allow students to use a digital scalpel to dissect a 2D representation of the animal using the mouse and keyboard. Although the student is able to control the process actively, none of these products are 3D or offer any kind of physical/haptic

feedback. An exception is V-Frog, which uses a 3D model with the ability to make anatomical structures transparent or invisible (Tactus-Technologies, 2007), available at: http://www.tactustech.com. Boothby (2010) found that students had statistically higher post-test results when they participated in V-Frog (compared with the group dissecting a real frog). Earlier studies had shown that such virtual teaching methods can be as effective as those using animals (Balcombe, 2000).

Vafai and colleagues produced the first VR *haptic* frog dissector in 2006 (Vafai et al., 2006, Vafai and Payandeh, 2009) to identify the effects of haptic feedback on the virtual dissection training environment (Figure 3). Their goal was to test whether haptic feedback provided any real benefit to virtual dissection. The dissection process was broken down into three tasks; skin cutting, skin peeling, and placing internal organs in a tray, on which the students were tested for speed and accuracy. The authors conclude that although their preliminary user study supported their hypothesis that haptic feedback provides an additional benefit to virtual dissection, they were unable to prove this statistically.

Figure 3, The researcher Nasim Vafai demonstrating her haptic frog dissector

A haptic rat dissector has also been developed (Bruyns et al., 2001) for astronaut training, consisting of a 3D model based on CT data of anaesthetised *in vivo* rats. A joint project between the National Biocomputation Center, Stanford and the Center for Bioinformatics, NASA Ames Research Center, focused on the need to train astronaut crews in performing life science experiments in space. The authors developed an interactive virtual environment to simulate several tasks performed during animal dissection. The system worked both with and without haptic feedback and could be displayed using a stereoscopic workstation.

2.2 LEARNING STYLES AND THEORIES

Many of the arguments in favour of retaining dissection relate to learning and teaching theory. Dissection is by its very nature a practical 'hands on' subject in contrast to much of the learning which surrounds it (didactic lecture and books). It is well established that different individuals prefer to learn through different 'styles' (Kolb, 1984, Honey and Mumford, 1992, Fleming, 1995) such as visual, aural, read/write and kinaesthetic learners (VARK) (Fleming, 1995). By teaching and assessing a subject in a variety of ways, students are given more opportunities to learn through the style which best suits their needs (Fleming, 1995).

One of the most influential educational theorists, John Dewey, promoted the idea of active engagement with materials followed by reflection as being a primary source of learning (Dewey, 1997). This is supported by research by Stull et al. (2009) which suggested that students who had active control over a 3D object compared with passive observation were more able to identify anatomical features from different orientations after practice. Widely known as *kinaesthetic* learning (learning through 'doing', also

referred to as 'tactile learning') it is seen as being particularly important for individuals learning physical skills, such as dance and performing surgery.

Cognitive Load Theory (CLT) suggests that learning involves the active processing of information from sensory input and memory to working memory and long-term memory. If too much information is presented simultaneously working memory may be overloaded, thus impeding learning (Verhoeven et al., 2009). Each learning task has an intrinsic load, which is largely determined by the subject, with some tasks being more demanding than others. What the educator or educational material brings to the student is considered either extraneous or germane load. Extraneous load is ineffective for learning and is usually the result of badly delivered or unnecessary information, resulting in the student having to use additional thought processes to identify the relevant material (Verhoeven et al., 2009). Presenting information in the correct format can therefore help to reduce extraneous load (Koning et al, 2007). The educator, or designer (of educational materials) is instead striving for germane load, which becomes possible once extraneous load is reduced. Germane load contributes to learning through mental activities such as the organisation of information and in schema construction.

The split-attention effect is something that can occur when the learner's attention is split between two or more sources of visual information that must be combined for full understanding (and cannot be understood in isolation). A format where related visual information is spatially separated imposes an unnecessary extraneous load on the learner. Mental integration can be improved by presenting the different sources of information as closely together as possible (Schnotz and Kürschner, 2007).

Another theory that has its roots in CLT is dual-coding. As described in the introduction, dual-coding theory proposes that learners have two main channels through which information can be processed: visual and verbal (auditory), with each having a maximum load that it can process. Dual-coding theory proposes that visual and verbal information

sources are processed differently and through distinct channels. This process therefore creates two separate representations of information presented in both mediums and is less likely to overload the cognitive processes as a result.

Most if not all students of anatomy and medicine are adult learners. Andragogy is to adult education as pedagogy is to that of the child. Knowles et al (2014) describe six assumptions about the characteristics of adult learners that differ from those about children:

1. *The need to know* – Adults prefer to know why they need to learn something before they go about learning it.

2. *The learner's self-concept* – Adults have a self-concept as being responsible for their decisions and lives. They need to be seen and treated by others as being capable of self-direction.

3. *The role of the learner's experience* – Adults come into education with a greater volume of experience than children.

4. *Readiness to learn* – An adult's readiness to learn is oriented increasingly around the things they need to know in order to carry out their real-life roles.

5. *Orientation to learning* – In contrast to children's subject-centred orientation to learning, adults are life-centred in their orientation to learning.

6. *Motivation* – Motivation to learn increasingly comes from internal motivators (such as job satisfaction) rather than external (such as higher pay) motivators.

Understanding these differences can help the instructor to better facilitate opportunities for adult learners. Andragogy changes the role of the educator from that of didactically educating people to helping them learn.

In addition to the learning styles of the students and cognitive theories, there are also factors particular to anatomy education which must be considered. Anatomy is an inherently three dimensional subject and learning the 3D relationships of structures is of

utmost importance (as it aids in their correct identification which in applications such as surgery is critical). Marks (2000) discusses this and claims that a poor understanding of 3D anatomy at undergraduate level compromises the training of postgraduates when they come to use 3D clinical imaging technologies. Marks states that learning 3D spatial relationships may require both the deriving of information, as well as its reconstruction by the individual. This type of learning seems to require more time than that for 2D data. The question of how to best teach the 3D nature of anatomy is not addressed but the paper does raise a number of important questions including: What are the relative merits of different teaching methods (lectures, dissection, computer models)? What level of human anatomy should be included in the medical curriculum? At what point and how should it be taught and by whom?

Keio University School of Medicine, Tokyo, Japan has recently reformed its medical education curriculum to make it more 'interesting and interactive' (Rao et al., 2009). Rao et al. were involved in the reform process and made several recommendations, including, '*the use of simulations of the dissection of the human body*. Towards this end, a number of anatomy software programmes were investigated, including ADAM (Animated Dissection of Anatomy in Medicine) Interactive Software (Kristmundsdottir, 1994), Primal Pictures (http://www.primalpictures.com/) and Touch of Life Technologies VH Dissector (Touch-of-Life-Technologies, 2005). Rao et al. (2009) noted however, '*that these programs, however sophisticated, should be used as an "adjunct" to dissection and not as a primary tool of learning*'.

2.3 ART AND ANATOMY

The histories of anatomy, medicine and the artworks which depict them are extremely complex covering several centuries, countries and cultures. These histories are also far from linear, with discoveries being made (and lost) at various times by various cultures (Rifkin et al., 2011). Discoveries in this context include both those of an anatomical/medical nature as well as those relating to artistic methods and technologies, such as printing and photography. In order to illustrate this close relationship of art to anatomy and medicine, key examples of how artistic depictions have enhanced communication and education of these subjects throughout history are presented.

Some of the earliest images to take a didactic approach towards conveying information about the human body come from the middle ages (5th to 15th Centuries) (Rifkin et al., 2011). Between the 11th and 14th Centuries illustrations depicting the systems of the body began to appear. Typically the body would be represented by a linear outline, with the internal anatomy represented diagrammatically within (National-Touring-Exhibitions, 1997), as seen in 'The Vein Man' from a late 13th century English anatomical manuscript (Figure 4a). A similar 'figural outline' convention was also being used in the Islamic world where five diagrams illustrating each bodily 'system' (bones, nerves, muscles, veins, and arteries) were used (Khalili et al., 2010) (Figure 4b). Although human dissection was taking place, these illustrations demonstrate a reliance on classical (Galenic) scholarship rather that direct observation (National-Touring-Exhibitions, 1997). As the printing press was yet to be invented, illustrations such as these were all produced by hand, usually to illustrate manuscripts belonging to cloister or university libraries (Rifkin et al., 2011).
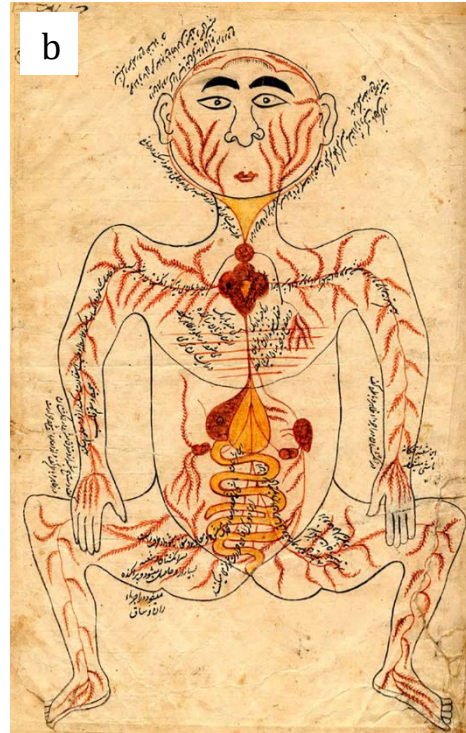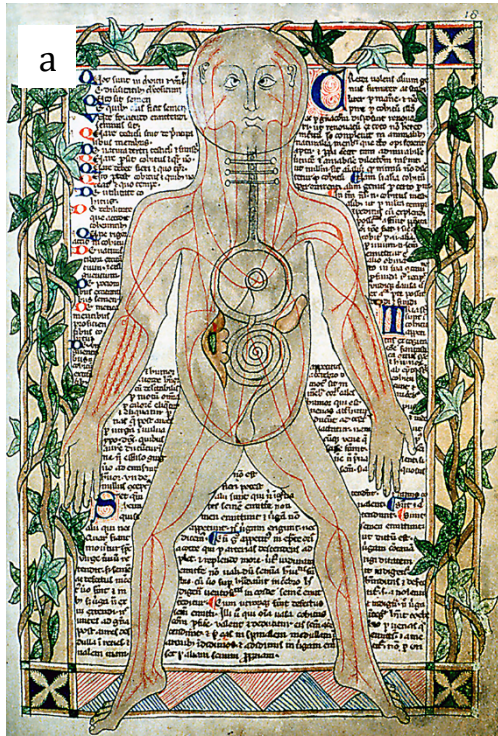
Figure 4a, 'The Vein Man', English, late 13th century, is an example of an early depiction of the bodily systems from Europe

Figure 4b, Anatomy of Mansur (Tasrih-I-Mansuri), Persia, 1396, is an example of an early depiction of the bodily systems from Persia

The mid-15th Century saw the introduction of the printing press and with it, the distribution of anatomical illustrations multiplied enormously. Illustrations also improved in accuracy when compared with their medieval counterparts and there was a new endeavour to document surgical scenes and interventions. Jerome Brunschwig's 1947 textbook for example includes images demonstrating the elevation of

Figure 5, Two illustrations from 1947 Brunschwig's textbook demonstrating the elevation of depressed skull fractures.

depressed skull fractures. (Van Hee, 2007) (Figure 5). The history of anatomical and medical illustration has been greatly influenced by developments in technology.

Advances in printing techniques would continue to influence anatomical art enormously over the coming centuries.

By the turn of the century (14th-15th Centuries) the Renaissance had spread throughout Europe. The search for knowledge of what lies within the human body induced many, including Leonardo da Vinci, to perform human autopsies, and to begin to illustrate the anatomical texts written by Galen (National-Touring-Exhibitions, 1997). The vast majority of anatomists of this time believed Galen's concepts unconditionally. However they were not always able to match his texts with what they saw in the anatomy room. It was therefore extremely important for them to draw from direct observation. Leonardo da Vinci performed over 30 dissections on human corpses during his life time (Popham, 1994). He collaborated with the anatomist Marc Antonio della Torre, who taught at the Universities of Padua and Parvia. The work of Leonardo da Vinci represents a major step forward both in anatomical study as well as in its depiction (Figure 6). The acuteness of his observations and the accuracy with which he recorded what he had dissected was far in advance of anything previously known (Popham, 1994).
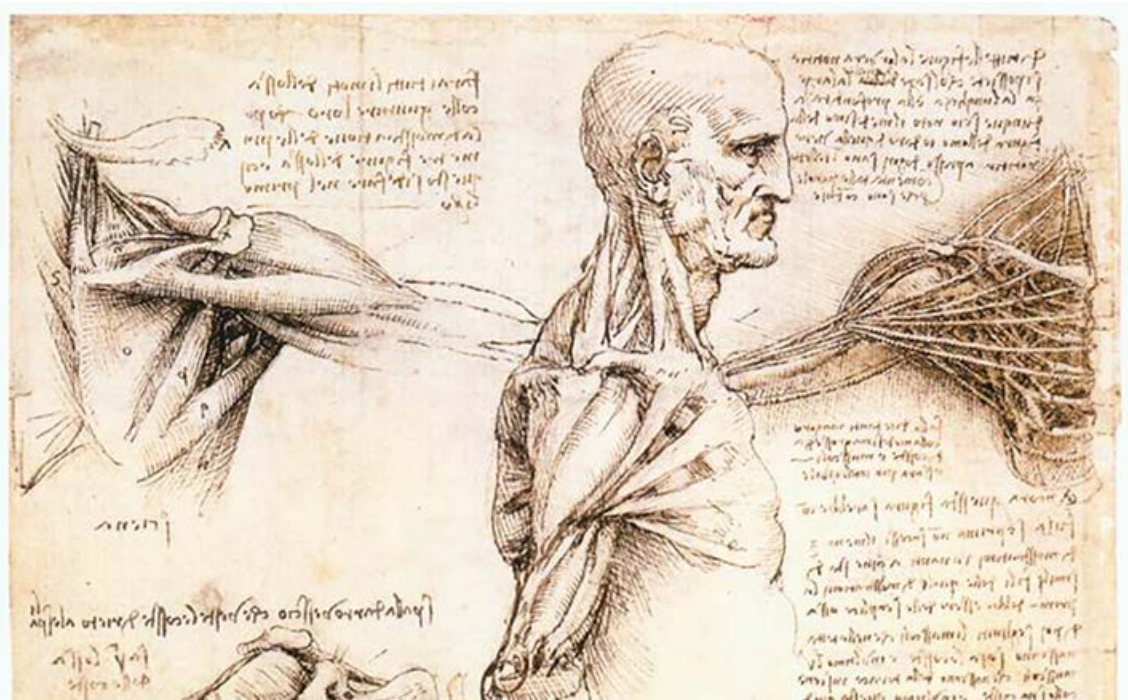
Figure 6, A drawing by Leonardo da Vinci, demonstrating his advanced observational and anatomical study

When the surgeon William Hunter first saw Leonardo's original anatomical sketches he said, *"When I consider what pains he has taken upon every part of the body, the superiority of his universal genius, his particular excellence in mechanics and hydraulics, and the attention with which such a man would examine and see objects which he has to draw, I am fully persuaded that Leonardo was the best anatomist, at that time, in the world."* (Hunter, 1784)

Unfortunately, the majority of anatomists at this time lacked the artistic abilities of da Vinci. In addition, the carving of wooden blocks for printing was difficult and required highly trained specialists in the editing offices (Van Hee, 2007). It was during the 1600s when the anatomist Andreas Vesalius worked with the artist Jan Steven van Calcar that we see the next major step in anatomical understanding and publishing. Andreas Vesalius was an anatomist, physician, and author of one of the most influential books on human anatomy, *De Humani Corporis Fabrica* (*On the Workings of the Human Body*). Vesalius is often referred to as the founder of modern human anatomy and was the professor of anatomy and surgery in Padua, Italy from 1537-1544. There he soon realised the benefits of medical illustration in teaching his students. In the first year of his professorship he provided his students with illustrations depicting the great Galenic organ systems. These tables were produced to illustrate the textbooks on anatomy of Galen which Vesalius at that time had no reason to doubt (Van Hee, 2007). He produced a number of these illustrations himself, including the example in Figure 7a.

Vesalius brought about a number of important changes to the study of anatomy. Most importantly, he stressed repeatedly the concept that students must not depend upon the teachings of their elders, but must explore the inner workings of the human body for themselves. Vesalius showed that much of Galen's teaching was inaccurate and often based upon the dissection of animals rather than humans (Van Hee, 2007). The vast majority of the illustrations that accompanied Vesalius's work were produced by his artist

friend Jan Stevens (Figure 7b). Originally from Calcar in Germany, they met in Venice where Jan Stevens was studying as a pupil of Titian (Van Hee, 2007). The illustrations in the *Fabrica* were both better drawn and printed than any previous anatomical texts. The result was accurate, detailed and meticulously printed (Rifkin et al., 2011).
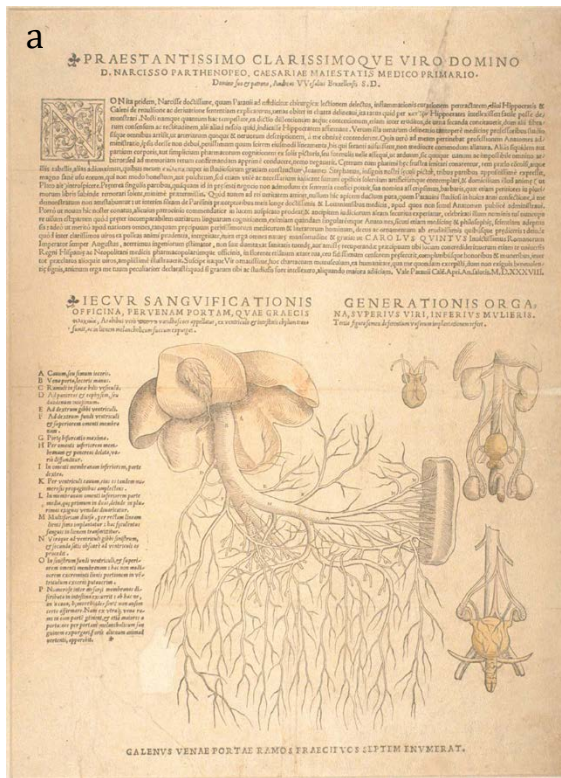
Figure 7a, One of Vesalius's early illustrated tables based on the text of Galen

Figure 7b, An example of one of Jan Stevens illustrations from Vesalius's *Fabrica.* The illustrations from the *Fabrica* were better drawn and printed than any previous anatomical texts.

As print technologies improved anatomical illustration began to achieve greater technical precision, and a hyper-realism developed which demonstrated the more sophisticated anatomical knowledge of the time (National-Library-of-Medicine, 2002). New styles of anatomical realism emerged which tended to depict either the reality of dissection, or sanitised, bodies and body-parts that seemed to float in the air (Figure 8a and b).

Figure 8a, Foetal dissection by William Cowper, with a background that illustrates the reality of the dissection room
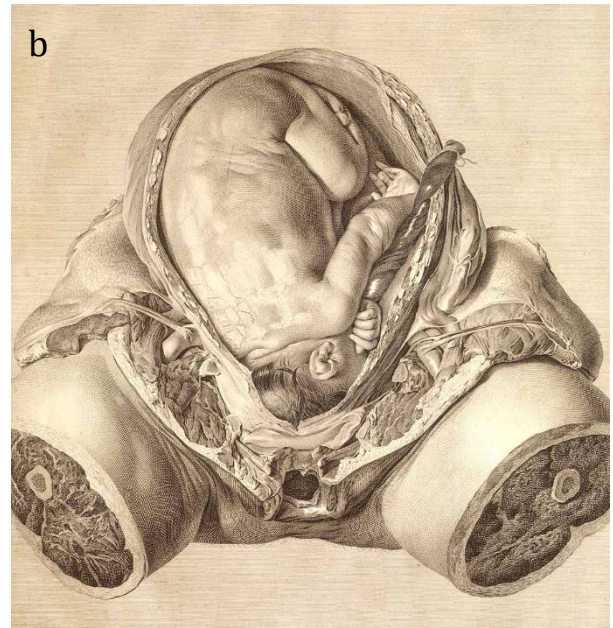
Figure 8b, In Utero Foetus by Jan Van Riemsdyke, here the body parts seem to float in the air in front of a plain background
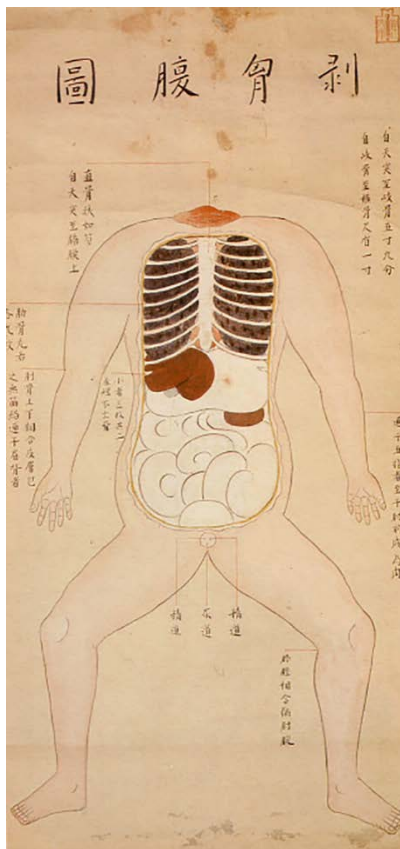
Figure 9, An Illustration from Zōzu by Tōyō Yamawaki, documenting the first human dissection to take place in Japan

The first human dissection to take place in Japan was documented in the 1754 book *Zōzu* by Tōyō Yamawaki (Figure 9). Although human dissection had previously been prohibited in Japan, authorities granted Yamawaki permission to cut up the body of an executed criminal in the name of science (Pink-Tentacle, 2010). The crude style of these images is closer to that seen in the 13th and 14th Century images, with a distinct linear outline to the body.

During the 19th Century mass printing of medical and anatomical texts became more commonplace. Colour tinting and printing also became more frequent and although it was still the more expensive option, it was within reach for the great textbooks of the time. The

first edition of *Gray's Anatomy*, was published 1858: it consisted of 750 pages and 363 illustrations. Gray collaborated with his friend Dr. H.V. Vandyke Carter on the new manual of anatomy for students. Carter, a skilled draughtsman, made the 363 illustrations for the first edition of *Gray's Anatomy* (Figure 10). Much of the initial success of the text is attributed to these detailed illustrations (Rifkin et al., 2011).
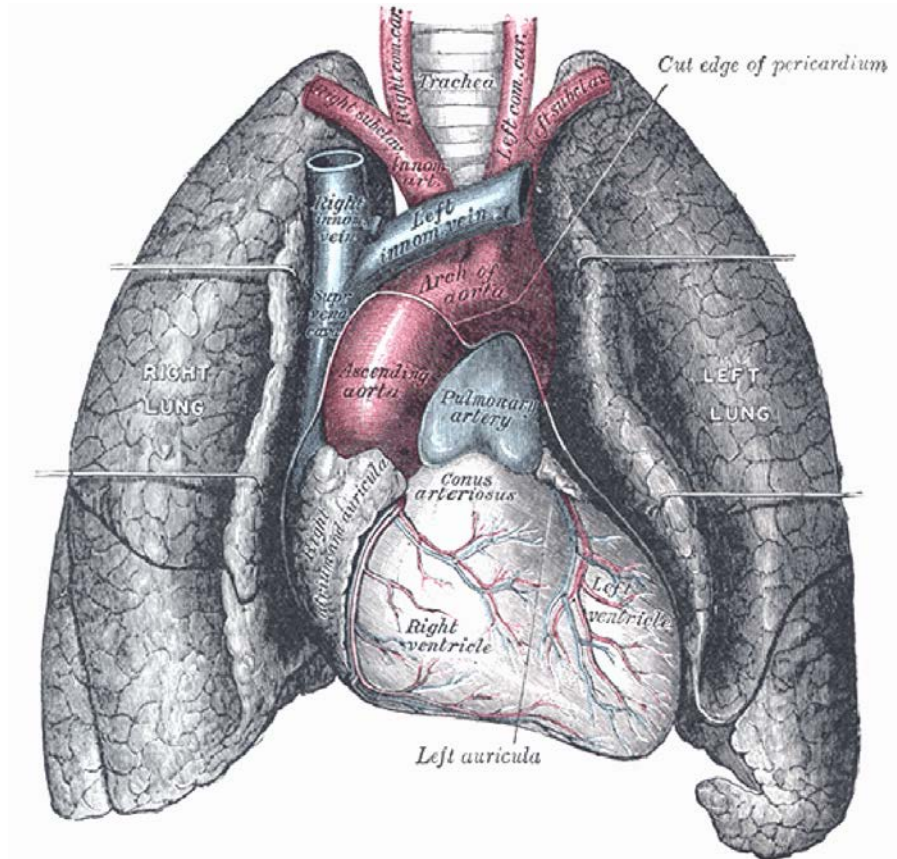
Figure 10, Illustration of the heart and lungs from the first edition of Gray's Anatomy. Much of the texts initial success is attributed to these detailed illustrations.

The 20th Century saw the founding of several professional bodies for medical artists and illustrators. The most prominent of these were the Association of Medical Illustrators founded in America in 1945, closely followed by the British Medical Artists Association in 1949 and more recently the European Association of Medical and Scientific Illustrators in 1986 (Association Européenne des Illustrateurs Médicaux et Scientifiques). Changes in technology continue to have an impact on medical illustration. Radiography was invented in 1895 and photography was becoming much more common. Both of these

technologies altered the way artists viewed the human body and had a significant impact on the development of medical illustration as a profession.

Table 1, Timeline of technologies relating to anatomical imaging (National-Library-of-Medicine, 2002)

Timeline: Technologies of Anatomical Imaging	
1300s	Woodcut printing brought from China to Europe, used to print textiles
1400s	Paper becomes available in Western Europe
1423	Earliest known European woodcut print on paper
1452	Copperplate engraving invented
1450s	Moveable type invented; Gutenberg Bible printed (1455)
1491	First illustrated printed medical book published in Venice, Johannes de Ketham, *Fasciculus Medicinae*
1543	First profusely illustrated anatomy, Vesalius, *De Humani Corporis Fabrica*
1620s	First multi-colour printed illustrations
1630s	Etching invented
1642	Mezzotint invented by Ludwig von Siegen, a German army colonel
1740s	Mezzotint colour printing method perfected
1780s	Thomas Bewick develops modern technique of wood engraving
1798	Lithography invented in Solnhofen, Germany by Alois Senefelder
1837	Daguerre invents first practical photographic method
1895	Roentgen demonstrates x-ray imaging

Modern medical illustration is often said to have begun with the work of Max Brodel, who in 1911 founded and subsequently directed the first medical illustration program in the world, at the Johns Hopkins Hospital in Maryland (Rifkin et al., 2011). Brodel began working at the hospital in 1894. He observed thousands of surgeries and autopsies which he rendered using carbon dust on chalk coated board. With his breathtakingly

realistic drawings he was able to do something the camera could not. That was to select exactly what it was that he wanted to show, without the excessive blood and gore that is captured in a photograph (Hajar, 2011). Another of the most influential figures in medical illustration of the 20th Century was the artist and surgeon Frank Netter. Several generations of medical students have studied human anatomy and pathology using his illustrations (Rifkin et al., 2011). Following medical school Netter trained as a surgeon and briefly practiced in Manhattan before committing his professional life to medical illustration. His images can be appreciated both for their aesthetic qualities as well as their intellectual content. In several illustrations he would combine radiographic images with his illustrations in order to help practitioners better relate one to the other (Rifkin et al., 2011).

Contemporary medical art is built upon this strong foundation. In addition to producing two dimensional images for text books, modern medical artists work across a range of media including 3D digital modelling for virtual anatomy atlases and patient information.

2.4 STEREOSCOPY AND VIRTUAL REALITY

Stereoscopy

Stereoscopy is a technique for creating 3D depth perception by showing two slightly different views of a scene to the left and right eye of the viewer. There are numerous ways to accomplish this, some of which require the user to wear special glasses (these can either be 'active' or 'passive', with active referring to glasses with electronic components and passive to those without) and others, known as 'autostereoscopy' which do not. The main advantage of using stereoscopic imaging over other forms of technology (computer models, photographs or drawings) is reported to be the depth cues generated from binocular vision (Henn et al., 2002). Depth cues such as

Convergence (only effective on short distances (less than 10 metres), is when our eyes point slightly inwards) and Binocular Parallax (referring to the slightly different images seen by the left and right eyes) help in the understanding of the complex relationships between structures, which cannot be obtained through monocular vision alone (Henn et al., 2002).

It should be noted that stereoscopic viewers are not new. From the mid nineteenth Century 'stereoscopes' (Figure 11) were used in medical education to depict anatomy and medical conditions. Doctors published stereo-cards with text to accompany the images. Such devices appear to have fallen out of use sometime after the 1920's, perhaps due to the increasing availability of cadavers, 3D plastic models, and eventually to video and computers (Lohr and Mages, 2015).

Figure 11, A stereoscope, late 19th c, with a collection of dermatological stereo cards

More recently a number of authors have investigated the benefit of 'true 3D vision' using stereoscopy over presenting a 3D model on a 2D screen. Stereoscopy has been used to enhance surgical telemanipulator performance (Falk et al., 2001). Three different

viewing conditions were compared; 2D and 3D National Television Standard Committee (NTSC) screens and a 2D high-definition television (2D-HDTV). The results showed that 3D vision enhances telemanipulator performance compared with a 2D system at the same or higher level of resolution, as it allows for faster and more precise movement. The surgeons involved in the study also tended to favour the 3D system despite their familiarity with 2D systems in their own practice.

Luursema et al. (2006) investigated the benefits of interactivity *and* stereopsis on learning. Participants studied human anatomy (specifically the abdominal organs) through 3D reconstructions; with either stereoscopic vision (through the aid of shutter glasses) including the ability to interact with the model by changing the viewpoint, or through biocular (where both eyes see the same image) study alone. The acquired knowledge was tested in two ways: 1) an identification task, in which anatomical structures had to be identified from a 2D cross-section, and 2) a localisation task, in which a 2D frontal cross-section had to be properly located and placed. The results showed that the stereoscopic/interactive group performed significantly better on both tasks with individuals of low visuo-spatial ability benefitting the most.

In a later study, Luursema et al. (2008) studied stereopsis in isolation from interactivity in individuals of differing visuo-spatial abilities (the ability to form, retrieve and manipulate mental representations of a visuo-spatial nature). Visuo-spatial ability was assessed using Vandenberg and Kuse's mental rotation test (Vandenberg and Kuse, 1978) Two groups with a similar distribution of visuo-spatial ability studied a 3D digital model of human abdominal anatomy; group one with stereopsis and group two with biocular vision. The groups were tested by identification and localisation tasks in the same way as previously. The results showed no difference between the groups for the identification test; however, there was a slight increase in performance for the stereoscopic group in the localisation test. The results also confirmed earlier research

that having a higher visuo-spatial ability predicts improved anatomical learning (Garg et al., 1999, Garg et al., 2002). Luursema et al (2008) concludes that judgment be postponed on the advisability of implementing stereopsis enabling hardware in medical study settings and suggests that further research is undertaken into the role of interaction/dynamic exploration in isolation.

Perry et al. (2007) discuss the value of using stereoscopic 3D images for dissection education. They point out that learning real (3D) anatomy for the first time can be daunting to many students and that 2D illustrations and plastic models tend to over-simplify the complexity of anatomy. In their study, undergraduate students studying the anatomy and physiology of the speech mechanism were given access to stereoscopic 3D images of the process of cadaver dissection in addition to time in the dissection room. The paired stereoscopic images were presented over the Internet and students were provided with a stereoscope to aid personal viewing. Student feedback was obtained through a questionnaire with 96% stating that the project was "helpful" or "very helpful." Several students elaborated by listing reasons for its usefulness with the three most common being: 1) the images represented real anatomy, 2) the stereoscopic images were better than 2D images in books, and 3) the images increased the amount of time available for viewing the specimen.

Google cardboard is the most recent and accessible stereoscopic viewer and can be used with 3D still images, film and even 3D interactive models via sites such as sketchfab.com.

Virtual Reality

The term 'Virtual Reality' (VR) as it is used here, refers to the interaction with an artificial object or environment through computer software using an immersive head mounted display. A virtual environment at its most basic can consist of a simple 3D image which can be interactively explored via the computers interface (usually) of mouse and/or keyboard and monitor. Viewing a virtual environment in this way means the user is

interacting with a 3D object/s viewed on a 2D monitor. Fully immersive VR experiences require the use of head mounted displays (HMD) such as the Oculus Rift and HTC Vive headsets (https://www.oculus.com/en-us/ & https://www.vive.com/uk/) to create fully immersive experiences.

In *Understanding Virtual Reality* (Sherman and Craig, 2002) four key elements to the VR experience are described:

1. The Virtual World

i. An imaginary space often manifested through a medium.

ii. A description of a collection of objects in a space and the rules and relationships governing those objects.

2. Immersion

The sensation of being in an environment; can be purely a mental state or can be accomplished through physical means: physical immersion is a defining characteristic of virtual reality; mental immersion is probably the goal of most media creators.

3. Sensory Feedback

The VR system provides direct sensory feedback to the participants based on their physical position. In most cases, it is the visual sense that receives feedback, although VR environments do exist that display exclusively haptic (touch) experiences. Achieving immediate feedback requires the use of a high-speed computer as a mediating device.

4. Interactivity

For VR to seem authentic, it should respond to the user actions. Interactivity comes more readily with the addition of a computer. The ability to affect a computer-based world describes one form of interactivity. Another form is the ability to change one's viewpoint within a world.

Considering the above, Sherman and Craig (2002) provide the following definition of VR:

Virtual Reality a medium composed of interactive computer simulations that sense the participant's position and actions and replace or augment the feedback to one or more senses, giving the feeling of being mentally immersed or present in the simulation (a virtual world) (Sherman and Craig, 2002, p13).

Virtual reality represents one of the most recent steps in humankind's continuing attempts to communicate more effectively with one another. From the first cave art to the invention of the Internet this process has developed hand-in-hand with technological advancement. Whether it is the creation of pigment for painting or the mass media of print, television, computer games or the Internet, technology has allowed humankind to reach more people in more ways than ever before. However, what VR offers is the opportunity to communicate through *multiple* senses; visual, auditory, and tactile. As such, it advances ever closer to conveying accurately the thoughts and intention of one person to another. As the late philosopher Terrence McKenna (1991) stated:

When we are in the act of seeing what is meant, the communicator and the one communicated with become as one. In other words, the visible languages possible in VR will overcome the subject/object dualism as well as the self/other dualism (McKenna, 1991, p232).

And also:

Indeed, the non-destructive nature of VR means that the talent of many artists, designers and engineers can be absorbed into VR projects with no impact whatsoever on ordinary reality. Finally, virtual reality, with its capacity for virtual replay of constructions of the imagination, may hold the key to accessing and mapping of the imagination. The dream of artists, to be able to show the fabric of their dreams and visions, may be fast approaching virtual reality (McKenna, 1991, p234).

2016: The Year of Virtual Reality

2016 is being described by many as 'the year of virtual reality' (http://www.bbc.co.uk/news/technology-35205783). While google cardboard (which mounts user's smartphones in a low cost viewer) has been around since 2014, 2016 sees the first general release of more advanced VR headsets. Such headsets allow users to interact with their environments via handheld controllers and advanced movement trackers. While most content currently available for such systems focusses on entertainment and gaming, specialist uses including in the fields of medicine and anatomy are already being developed (Cha et al., 2016, Messier et al., 2016). For example Headleand et al (2016) used the Oculus Rift headset to create training activities in VR for new wheelchair users. To achieve their goal the authors employed a degree of 'gamification', which abstracted the core skills required of a new powered-wheelchair. Users had to navigate through a virtual environment featuring a multi-story building complete with an elevator and different scenarios on each floor. There were a total of four floors with scenarios becoming incrementally more challenging. 'Wheelchair-Rift' as it was known was evaluated by a panel of three experts from a local Posture and Mobility Service. Each panel member used the simulator for between 15 and 20 minutes after which qualitative feedback was sought. Feedback indicated that overall, the simulation was accurate in terms of operation, with the immersion, interaction and environment being cited as particularly strong points. A number of areas were identified for change however, such as the turning and braking speeds.

Wheelchair-Rift was developed using the Unity gaming engine (Unity Technologies, San Francisco, CA). Unity can be used to create applications across a number of platforms including PC, Mac and mobile devices. It is most commonly used for games but can equally be used to create learning and teaching applications such as medical simulators

or 'serious games'[v]. There are a number of plugins available for Unity including one for haptics developed by the Glasgow School of Art (Poyade et al, 2014[a]). Poyade et al (2014[b]) used this plugin in the creation of a bespoke VR haptic training system for the administration of local anaesthesia injection for dental students. A detailed digital 3D model of the anatomy of the head and neck was first created. This could be used as an application its own right to first study the anatomy of the region. When used in conjunction with an Xbox game controller and motion capture technology the users point of view can be tracked, this combined with a stereoscopic projection allows for an immersive experience enabling users to fully explore the head and neck anatomy in stereoscopic 3D. In addition, the haptic dental injection simulator allows the user to practice the administration of local anaesthesia to the aforementioned model using a haptic force feedback interface. As of 2014 no formal assessment of the system had taken place.

VR and haptics have been successfully combined for a number of different applications including within the ceramics industry (where sculptors for Wedgwood and Royal Doulton have used the Freeform Modelling software to create sculptures which are subsequently displayed in virtual showrooms and domestic settings), the aerospace industry (for example in a VR maintenance demonstrator), and even training in land mine clearance (where an immersive VR land mine detection training system has been developed for the French Army) (Stone, 2001).

The Role of the Artist in Virtual Reality

Many technologies have impacted upon the visual arts, including the invention of photography and more recently computer graphics packages. Artists have, for the most

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[v] A 'serious game' is a game primarily designed for a purpose other than pure entertainment such as educations, health care etc.

part, been both familiar with operating technology as well as using it to convey their message. However, as technology continues to advance, this may not always be the case. The programming of VR worlds and objects is one such area where a team effort is often required:

Often, advancement of a medium occurs when two forces approach each other from different viewpoints – from an artistic viewpoint and an engineering viewpoint, for instance. Technologists (engineers) often provide the basis for the (carrier) medium and push to improve the medium itself. Artists approach a medium as a way to express their ideas or simply as a place to explore the representation of ideas. Artists drive the content forward by making it more interesting to an audience. (Sherman and Craig, 2002, p68).

The use of technology by the artist highlights an important distinction which must be made between the tool maker and the tool user. To help clarify the position taken in this thesis, an analogy set out by Harvey (2009) describes the distinction as follows:

A carpenter may occasionally make her own chisels and a chisel maker may sometimes build his own cupboard; but the criteria for good chisels are different from criteria for good cupboards, and the division of labour allows people to focus on what they are most interested in, and perhaps on what they are best at (Harvey, 2009, 313).

In this instance, the tool maker would be the computer programmer and the tool user would be the artist who uses these virtual tools (the software programme) to create their art form. A third party must also be considered; in the case of virtual reality teaching packages this is the end-user, or learners.

It is hypothesised that as well as being two different roles (the division of labour) they may also require two different mind-sets and therefore, frequently, two or more individuals.

2.5 HAPTIC AND MULTI-MODAL INTERFACES

Dissection is a multisensory discipline which combines the sense of touch with a highly visual experience. Haptic technologies allow for the sense of touch to be present in virtual environments. Together with advances in stereoscopy and autostereoscopy they are allowing virtual anatomy to be viewed in 'true' 3D vision (Ji et al., 2006, Perry et al., 2007).
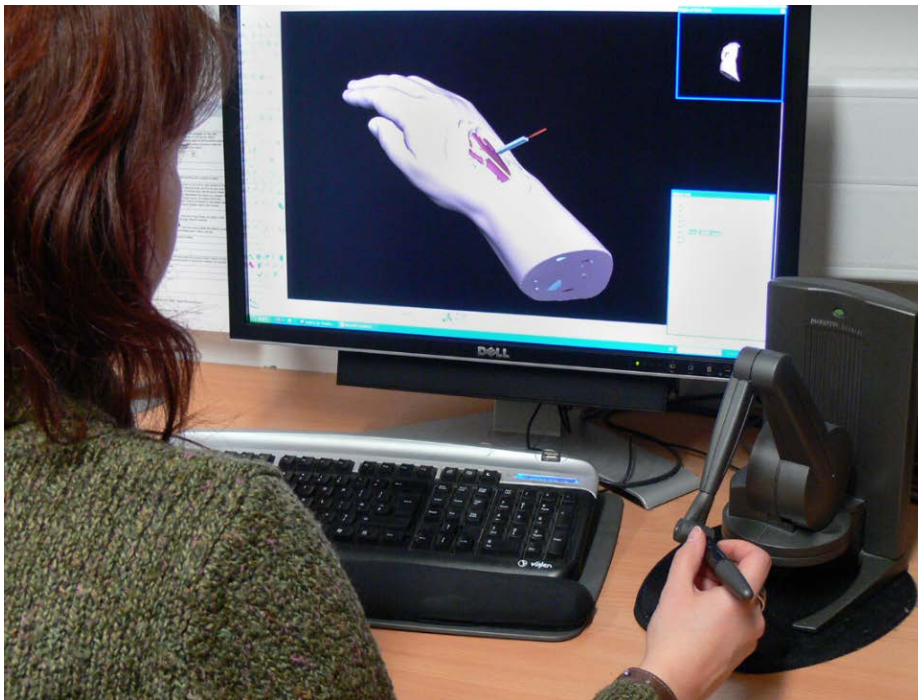
Figure 12, The author using a 'Sensable Phantom' haptic device to virtually dissect the hand and wrist models created for this study

Research into the relationship between visual and haptic interfaces has been conducted by a number of groups (Ernst and Banks, 2002, Jones et al., 2005, Chen et al., 2011). The relationship appears to be complex with no simple answers relating to which modality dominates the other. Rather, the wider context and factors such as whether or not visual and haptic cues reinforce or contradict one another, appear to play a large role. The following example of this in an anatomical modelling situation demonstrates

that altering the visual cues can trick the brain into believing the degree of haptic feedback has also changed:

"This finding suggests that, for example, organ A will be perceived to be softer than organ B if it's graphical display deforms more than organ B, even though they both reflect the same forces in magnitude to the user for a unit displacement of the indenting probe held in the hand" (Basdogan et al., 2004, p62).

An important finding in relation to education is that the addition of haptic to visual feedback appears to increase student interest in the exploration of virtual objects (Jones et al., 2002). Students spent more time examining the objects as well as expressing a greater interest when questioned. In a later study Jones et al. (2005) found that students who used a haptic or haptic and visual interface to explore virtual objects, spent considerably more time exploring the 'back' of the objects when compared to those using a visual interface only. This is particularly relevant to anatomy education, where both the anterior and posterior of structures are of equal importance.

Stull et al. (2009) suggest that students who have active control (using the IntertiaCube2 3-degrees of freedom interface developed by InterSense, Inc) over a 3D object compared with passive observation show more efficient recognition of the object after practice. This is perhaps in contrast to earlier research (Garg et al., 1999, Garg et al., 2002) which concluded there was no advantage of a fully rotatable model (of the wrist) over one allowing certain key or canonical viewpoints (such as anterior and posterior) only. Garg and colleagues concluded that key or canonical viewpoints of an object are critically important for spatial learning and that learner control of multiple orientations provided no particular advantage. However Stull et al. (2009) suggested that this research failed to consider situations where learners need to develop spatial associations between areas that are not easily visible in key views, such as is common in anatomy education.

Fager and Wowern (2005) describe the role of haptics in many medical applications including laparoscopic and other surgical simulators, procedure training, clinical practice and anatomy education. They conclude that while the use of VR with haptics is still in its infancy, it offers the promise to speed up procedures, make them more efficient and cheaper, as well as improve patient safety. They also speculate that the Internet will play an important future role, eventually allowing haptic interaction to take place over the web. A more recent study by Coles et al (2011) looked at combining and collocating haptic and force feedback with visual cues. Using augmented reality (AR) to replicate femoral palpation and needle insertion they created a simulation named PalpSim. A monitor combined a virtual scene with live video footage of the user's hands and needle so that they appeared to interact with the virtual patient. This was combined with force and tactile feedback to create the illusion of touching and injecting the virtual patient. When asked to rate the simulation, experts reported that it closely reproduced the fine tactile cues of a real life palpation.

Multi-modal and multi-sensory interfaces are likely to become much more commonplace in the near future. Roberts et al (2014) describe us as being 'on the cusp of a revolution in information visualization research'. Where all of our senses; vision, touch, sound, even smell and taste, will play a role in manipulating and communicating data and information.

2.6 SIMULATION

Simulation is a growing field within medicine and allows for both clinical and surgical trainees to hone their practical skills before encountering real patients. Simulation can take the form of 'part-task trainers' which allow for key elements of a procedure or skill to learned, such as taking blood from an arm, to fully simulated patients and wards. The

Clinical Skills Centre at the University of Dundee for examples has a fully simulated ward and offers a Postgraduate Ward Simulation Exercise (PgWSE) for medical trainees who have performance concerns within their clinical practice. The PgWSE takes around 90 minutes to complete and allows for the performance of trainees to be directly observed in a simulated environment by the assessors. The PgWSE has become a useful tool in the management of trainee doctors in Scotland and has been shown to have a positive impact by providing a detailed assessment and feedback thus improving their clinical skills (Stirling et all, 2012).

As well as clinical skills, simulators are also increasingly used to practice a variety of surgeries. These simulators may use physical or virtual models and can be either high or low fidelity depending on the skill being taught. For the purposes of this study, it is virtual surgical simulators which will be discussed.

Virtual Surgical Simulators

Virtual surgical simulators are increasingly being used to augment traditional teaching methods. The advantages of simulators include: a structured learning experience, practice without endangering patients, teaching rare or unusual cases, and providing objective skills assessment (Liu et al., 2003).

Liu et al. (2003) surveyed current work in the field, broadly classifying simulators in terms of their complexity: needle-based, minimally invasive, and open surgery. Needle-based simulators are usually simplistic and contain minimal visual and haptic realism. They are useful for teaching straightforward and commonplace procedures at low cost. Minimally invasive simulators, such as those for laparoscopy and endoscopy are more advanced, with the anatomy usually being of sufficient detail and realism for educational purposes. There are many commercially available laparoscopic trainers for teaching basic skills such as: camera navigation, grasping, suturing and knot tying, and cauterization. Seymour et al. (2002) demonstrated that skills are transferable from VR

haptic laparoscopic simulators to the operating room (OR). Results showed that gallbladder dissection was 29% faster for VR trained residents, while non-VR trained residents were nine times more likely to (temporarily) fail to make progress and five times more likely to injure the gallbladder or burn non-target tissue. The standard training group made six times as many errors as the VR group. Seymour et al. (2002) concluded that VR surgical simulation significantly improved the OR performance of residents during laparoscopic cholecystectomy. Basdogan et al. (2004) looked at the role of haptics in minimally invasive surgery (MIS) and concluded that because MIS procedures involve palpating and manipulating the organs through instruments, the integration of haptics into MIS simulators seems essential and that the development of haptics-integrated systems will require close collaboration between medical personnel and technologists.

Open surgery is the most difficult to simulate with the visual field, range of haptic feedback, and freedom of motion being considerably increased. Early attempts at open surgery simulation struggled at attaining realistic visuals and haptics. Bro-Nielsen et al. (1998) described a prototype abdominal trauma simulator for training in the removal of a shattered kidney concluding that it (the simulator) could not be considered completely realistic and that current technology did not allow for fully life-like simulators for open surgery. Such early tests did however allow researchers to study the interaction of the many technologies required for creating such complex simulators. Bielser and Gross (2002) made progress in this field with their research into open surgery procedures by improving; collision detection, the haptic frame rate, as well as creating a flexible way of modelling complex surgical tools out of basic components thus allowing for actions such as cutting and clamping (Figure 13a and b).

Another category of surgical simulator not described by Liu et al. (2003) is virtual (sometimes haptic) temporal bone dissection. Temporal bone dissection/surgery usually

requires many years of training due to the complex anatomy of the region. Conventional training is through cadaveric dissection, however, in recent years there have been a number studies into *virtual* temporal bone dissectors (Bryan, 2001, Pflesser et al., 2002, Agus et al., 2003, Wiet et al., 2005). Agus et al. (2003) used patient specific CT and MRI data to create volumetric object models for use in a haptic and visual simulated training system for temporal bone surgery. This prototype system was trialled by specialist surgeons and their feedback used to tune the parameters controlling haptic force feedback. The overall realism of the simulator was considered sufficient for training purposes.
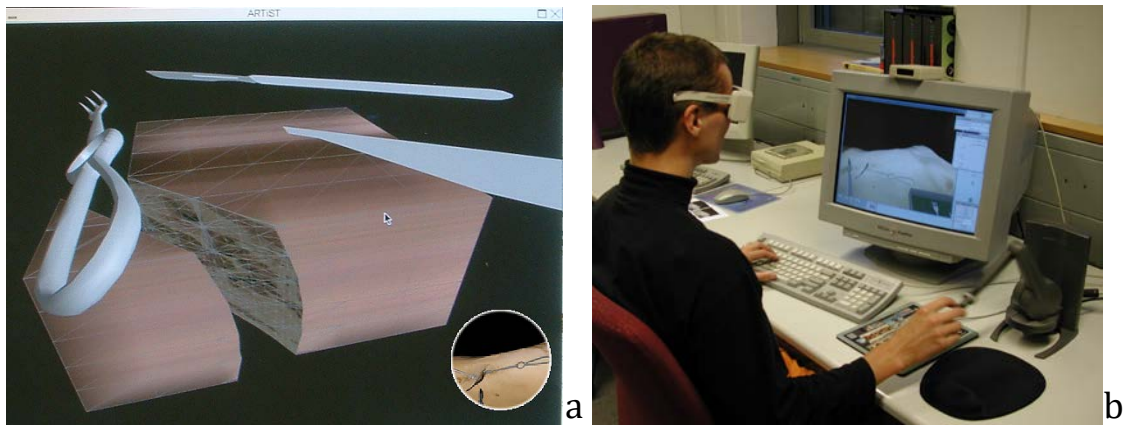
Figure 13a, Bielser and Gross's open surgery simulation allows for cutting and collision detection

Figure 13b, Bielser and Gross open surgery simulation in use with a haptic interface

Tissue Properties and Cutting

Interaction with virtual anatomical models through tissue deformations and cutting remains a fundamental challenge in the field of virtual reality (Vafai and Payandeh, 2009). Vafai and Payandeh (2009) state that *'the complex nature of deformable bodies still lacks acceptable solutions particularly where real-time performance is concerned'* (p85). Nealen et al. (2005) described it as an inherently interdisciplinary field which *'combines Newtonian dynamics, continuum mechanics, numerical computation, differential geometry, vector calculus, approximation theory and Computer Graphics'*

(p809). While research into this area is relevant to the topic of this study, it is not an area of expertise for the researcher and as such does not form a part of the study.

There have been many approaches and solutions created depending on the specific requirements. These can be broadly divided into two categories; surface and volume based models. Surface models model only the visible surface on an object as a thin plane, while volume based models actually contain an internal mass. A number of groups (Gibson, 1997, Delingette, 1998, Pflesser et al., 1998, Agus et al., 2003, Jerabkova et al., 2004) have suggested that there may be benefits to using volume models for virtual cutting rather than surface models. Delingette (1998) explained that the choice between surface and volume based models comes down to two main factors, computer efficiency and physical accuracy. In terms of computational speed, surface models contain fewer vertices than volumetric models thus making them faster to load and manipulate. However, for modelling anatomical structures, physical accuracy is of utmost importance. Surface models are more likely to generate physically invalid deformations, such as self-intersections, especially where the model is thin. Volumetric models may also be better suited to the simulation of cutting as it results in changes to the geometrical and physical properties of the model. Meier et al. (2005) provided an excellent overview of real-time deformable models for surgery simulation comparing the different models that have been developed and presented the advantages and disadvantages of each. Each model was scored on a variety of factors in relation to biomechanical realism, topology and computation. Their results are summarised in Figure 14.
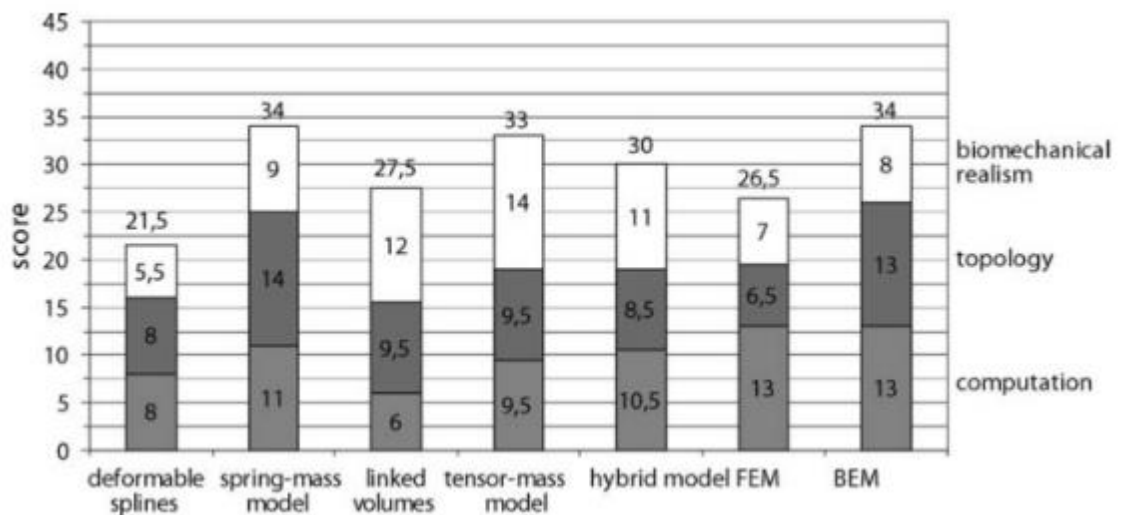
Figure 14, Graphic comparison between deformable models, from Meier et al., 2005. Definitions of each term can be found in the glossary

Meier et al. (2005) concluded that while no single method appeared to be overwhelmingly better than the others, there were three different approaches which yielded comparable results, each of which might be preferable depending on use. The Boundary Element Method (BEM) was the only non-iterative approach, being computationally quicker and more robust than the others. The spring-mass model offered the highest topological flexibility and simplicity for rendering. And finally, the only approach that combined both good volumetric performance and realism of large deformations was the tensor-mass model. Definitions of each of these terms can be found in the glossary.

Many researchers have created variations and hybrid combinations of the above methods. For example, Mensmann et al. (2008) introduced a technique for interactively creating deformations of volumetric data by exploiting the 3D ChainMail algorithm in combination with a GPU-based ray-casting renderer in order to perform deformations. This process allows for complex, interactive deformations without pre-processing. Dewaele and Cani (2004) developed a virtual clay model using a deformation algorithm that bore a striking resemblance to that of the ChainMail algorithm, with the deformation spreading clay to neighbouring cells until the deformation is absorbed.

In the majority of instances, where tissue deformation and cutting is required for a piece of software, it has to be developed from scratch or built upon the libraries and routines found in Application Programming Interfaces (APIs). However, what would be of more use in this current study is a 'tool' for adding such properties to an existing model.

Such a code has been written for virtual deformations and cutting for others to use (Faeth et al., 2008, Faeth, 2009). Named 'M4' it is described as a 'multi-modal mesh manipulation system', which allows for cutting, deforming, and painting of manipulations for 3D interaction. A cutting algorithm is presented for planning cuts on a triangle mesh along with a deformation algorithm for non-homogeneous meshes. Two haptic feedback devices were used which allowed for the second hand to assist the manipulation of the object by 'holding' the mesh while the first hand manipulated it. This approach has much in common with real-time haptic virtual clay modelling discussed below. The system was envisaged to be of use to 3D artists, designers, landscape architects and other users of spatial geoscience data. Its primary function would be in the creation of 3D objects and spaces for such things as product design, character animation, and geo-scientific manipulation. M4 is not commercially available. In addition, it is not developed for medical applications and its cutting algorithm is suited to situations where the user wants to plan a precise cut rather than simulate contact with a cutting tool.

There are a number of haptic virtual clay modelling systems commercially available (Multistation, Geomagic). Sensable Technologies® developed the current market leader FreeForm® Modelling™, shortly after they were founded in 1993. Now owned by Geomagic, FreeForm® (and also FreeForm® Modelling Plus™ and ClayTools®) allows for '*touch-enabled solutions for fast 3D modelling of complex, highly-detailed, organic shapes for manufacturing*' (http://www.geomagic.com/en/products-landing-pages/3d-design/). FreeForm® uses the PHANTOM® Desktop™ (Massie and Salisbury, 1994) and PHANTOM® Omni™ high fidelity haptic devices, 3D interfaces with force feedback which

allow modellers to use their sense of touch to model with virtual clay (Sener et al., 2003). FreeForm® (from version 8 onwards) features 'Multi-representational Geometry Technology' which allows it to combine both voxels (volumetric pixels) and NURBS (Non-Uniform Rational B-Splines, are a mathematical representations of 3D geometry) for speed and precision modelling. FreeForm® is used in a number of applications including product design (Chen et al., 2011), fine art, gaming, facial reconstruction and medical and dental modelling.

2.7 REVIEW OF EXISTING SOFTWARE

As well as reviewing the important research and literature relating to this field, the existing software which is commercially available must also be considered. The reason for reviewing this separately is that it is usually released with no more supporting documentation than system requirements, product information and possibly some quotes from academic institutions/lecturers, who have purchased the software. Unlike academic research, these software packages do not aim to answer research questions relating to how students can best learn anatomy but simply to sell their product. Where a piece of software has been created as a result of academic research it is discussed under section 2.1 *3D Virtual Models for Anatomy Education.*

The following are brief summaries/reviews of some of the software currently available. Where possible, a free trial was downloaded for review.

Visible Body[vi]

Argosy's Visible Body software is described on their webpage as being 'the best human anatomy visualization tool available today' and the 'most sophisticated and complete 3D

[vi] http://www.visiblebody.com/start.

model of the human body available'. It is free to download for undergraduate and graduate level anatomy instructors (Figure 15).

Interestingly it claims to be created by a team consisting not only of computer programmers but also pedagogic experts and an 'extensively trained team with decades of experience in medical illustration and biomedical visualization', although this does not guarantee anatomical accuracy. Discussion on the internet seems very positive with numerous anatomy students describing how useful it is to their studies.
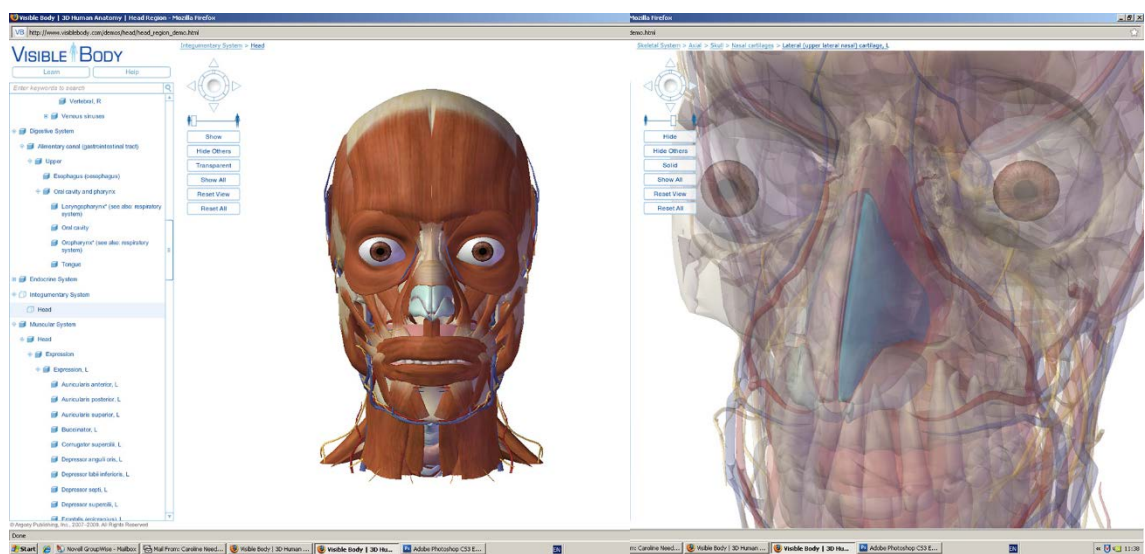
Figure 15, A screen shot from Argosy's visible body software

A free trial of the head and neck region was downloaded and tested. The software is intuitive to use and responds quickly. It is delivered fully over the internet and designed for display on a standard 2D monitor. It does not replicate the actual act of dissection but individual structures can be selected and either hidden or made transparent. A structure can either be selected by clicking on it or searched for by typing or clicking on its name. Interaction is through a keyboard mouse interface. The visuals appear rather simplistic. There are problems with some of the musculoskeletal anatomy with muscles depicted either as being too large (for example auricularis anterior) or with incorrect attachment sites.

Primal Pictures[vii]

Primal pictures '3D Human Anatomy Software' is described by Primal on theor webpage as being 'the most complete, detailed and accurate 3D model of human anatomy'. It is available both online as well as on CD. Costs (as of 2014) vary for the various editions, from £180 for '3D Head and Neck Anatomy for Dentistry' up to £610 for the full '3D Human Anatomy, Regional Edition'.
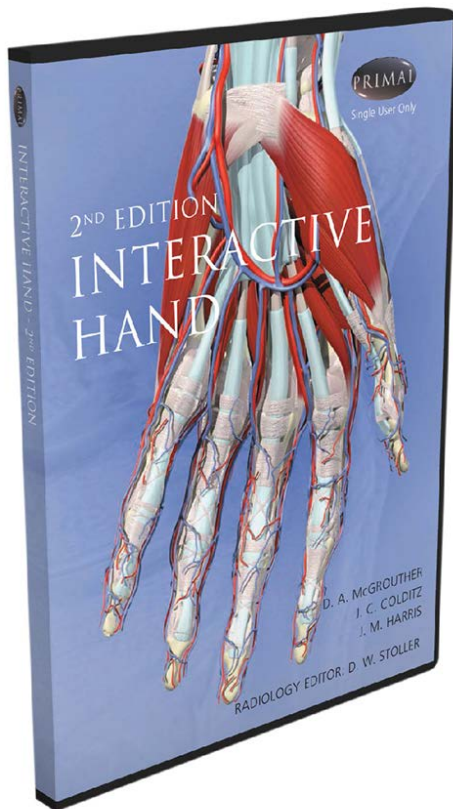
Figure 16, Primal Pictures Interactive Hand software

The models are created from medical (MRI) scan data which is described as being, 'interpreted by a team of Primal anatomists and then translated into three-dimensional images by an expert team of graphics specialists'. The website goes on to say:

"Used for patient, practitioner and student education in over 20 countries and in over 600 universities and colleges, this award winning software will be used by over 500,000 students learning anatomy in 2010 and by many thousands of practitioners in all specialties".

From the above statement it is suggested that this software has been integrated into many anatomy departments. There are quotes and case studies on the web page from numerous universities including: Bath University, Bristol University, The University of

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[vii] http://www.primalpictures.com/

North Dakota, Jefferson Medical College, Peninsula Medical School and the Royal College of Surgeons, England. While these endorsements sound good it is not the same as having the usefulness (or otherwise) of the software backed up by research.

A free trial of the 'Interactive Hand' (Figure 16) is available for educational evaluation. The software is downloaded from the internet and is designed for display on a standard 2D monitor. The display window is disappointingly small, only taking up around a quarter of the monitor, making it very difficult to see the fine anatomical detail.

In a similar way to the 'Visible Body', it is possible to make muscle/anatomical layers invisible. However, it is not possible to make *individual* muscles or structures invisible or to make them transparent. Overall the models look to be of a higher quality than those seen in the Visible Body. The image quality however, in terms of resolution and image size is disappointing. There do not appear to be any major anatomical inaccuracies that this author could identify, although the structures often appear a little over simplified.

Primal Pictures: Real Time 3D

Primal Pictures have released an updated version of their earlier software, available from the third quarter of 2010. The real time 3D software appears to answer some of the earlier versions failings. The models now exist as full 3D rotatable models and can be viewed at any angle. Anatomical features can now be selected individually and either made invisible or semi-transparent. One of the features highlighted in the webcast is the ability to take custom 2D images from the model to use in PowerPoint presentations.

VH Dissector (Visible Human Dissector)[viii]

Touch of Life's VH Dissector (Figure 17) is based upon both the male and female Visible Human Project (http://www.nlm.nih.gov/research/visible/visible_human.html) data sets. It comprises of 3D anatomical models of the individual structures which can be both 'dissected' from the superficial structures to the deep, or built up from the deep to the superficial. As it is based upon the Visible Human Project data set, and it also allows for comparison of the 3D models with the 2D cross sections of CT and MRI slice data. Additional information (such as attachment and origin of muscles) is also provided when a structure is selected.
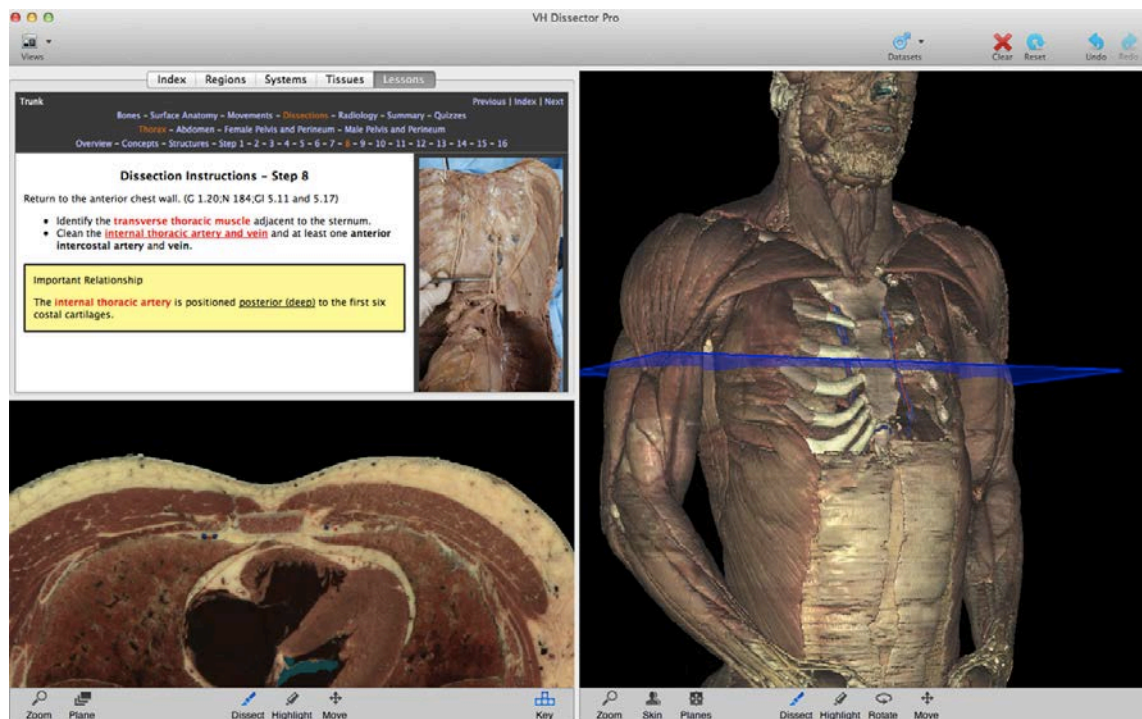
Figure 17, A screen shot from Touch of Life's Visible Human Dissector demonstrating the relationship between the cross-sectional and 3D views

Three versions of the software are available to purchase; Lite, Pro, and Stereo. The resolution of the images and models gets higher with the more expensive versions. The

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[viii] http://www.toltech.net/

most expensive version is the 'Stereo', which allows for stereoscopic viewing when used in conjunction with appropriate hardware. The standard prices for the three editions are:

Lite: $200, **Pro:** $1000, **Stereo:** $3000 (As of 2014)

Overall the software looks to have been created to a high standard. The anatomical models appear accurate and realistic. It claims to offer 'a virtual cadaver experience' and certainly seems to come the closest of the software discussed here. The virtual dissection on offer however, still relies on using a mouse to deselect anatomical structures rather than making any attempt to mimic the act of actual dissection.

Interact-Elsevier (Powered by CyberAnatomy)[ix]

The large science and health publishers Elsevier have developed their own virtual anatomy software, Interact-Elsevier, for 'learning, reviewing and teaching anatomy' (Figure 18). It is advertised to either complement or even replace full body dissection. The website describes the software as follows:

"Using state-of-the-art software and advanced gaming technology, the Interact-Elsevier series is anatomy education like you've never seen it before. Bringing the human body to life with 3D virtual reality, both faculty and students are immersed in a realistic environment for virtual dissection and complete exploration of human anatomy. Cross-referenced to gold standards, Gray's and Netter's atlases."

The software is available with two texture options, one being rendered from original Frank Netter paintings and the other with 'computer graphic realism'. Both options share the same 'detailed and clinically accurate base'. Artwork plates from Netter's and Gray's anatomy atlases (Drake et al., 2014, Netter, 2014) have also been added and correlated to the models as have CT and MRI data.

[ix] http://www.interactelsevier.com/
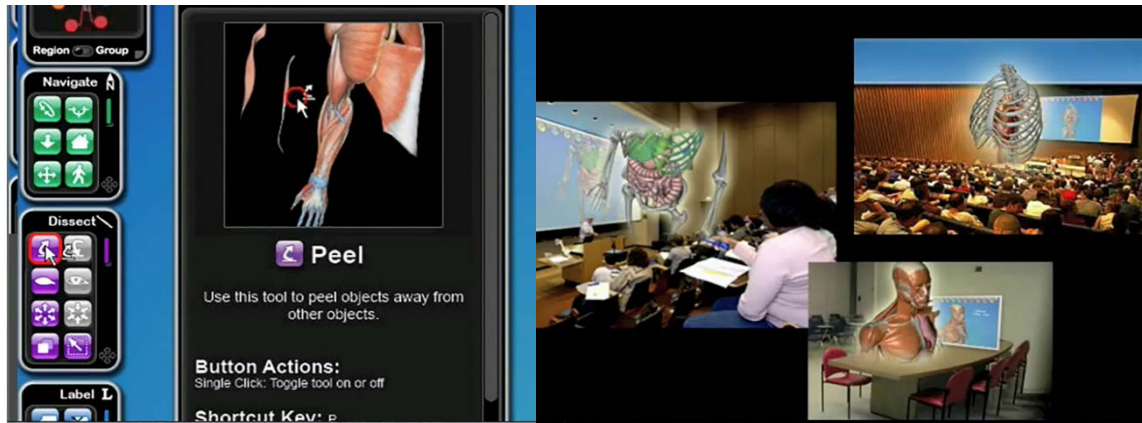
Figure 18a, A screen shot from the Interact-Elsevier virtual anatomy software

Figure 18b, An artist impression of Interact-Elsevier in use, from their website

The software includes a 'dissect' navigation menu which allows the user to move muscles and/or make them invisible and transparent. The software also includes search functions, tutorials and quizzes. The software is accessible either online or in full stereoscopic 3D. The cost (as of 2014) for 12 months individual online access is $149.95. The price for full stereoscopic 3D is available on application.

VOXEL-MAN 3D-Navigator[x]

VOXEL-MAN has been developed by the University of Hamburg and a number of related products are now available (Figure 19). These include a haptic surgical simulator and '3D Navigator' packages of regional anatomy. The upper limb is the latest addition to the series of interactive atlases. The program is based on cross-sectional images from the Visible Human Project. It contains approximately 320 three-dimensional anatomical objects of the arm and the hand including bones, muscles, arteries, and nerves, as well as tendons and ligaments. A trial version of the software is not available. However from looking at videos, images and reviews the model looks to be of a high quality and the software appears to have some useful features such as the ability to compare 3D models with radiographs. 'True' dissection is not possible however. The interface consists of a

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[x] http://www.voxel-man.de/3d-navigator/upper_limb/

mouse and keyboard with the ability to hide anatomical structures. The VOXEL-MAN 3D Navigator: Upper Limb (Arm and Hand) can be purchased for £72 (as of 2014).
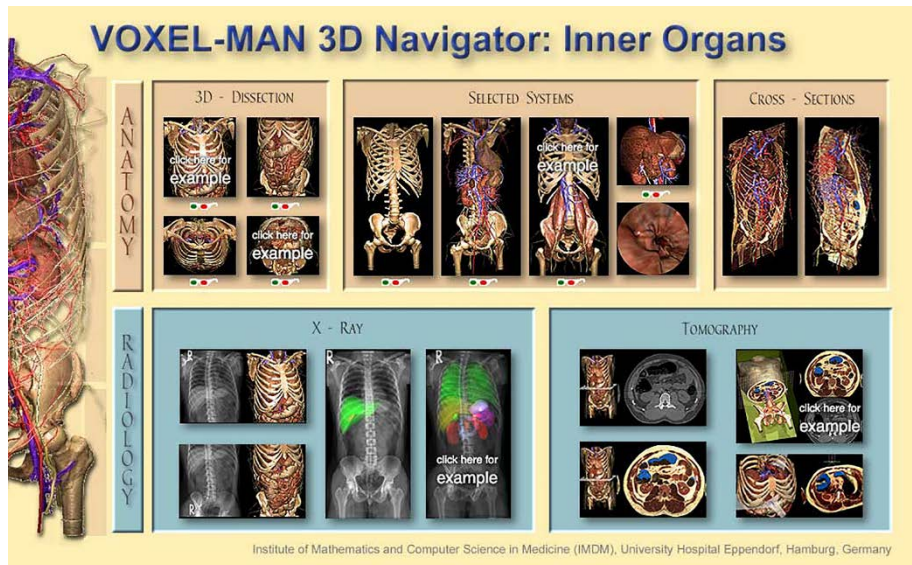
Figure 19, Images from 'Voxel-Man 3D Navigator' created by the University of Hamburg

Anatomage Table[xi]

Anatomage offer what is described as 'a unique, life-size interactive anatomy visualization table for the medical community', which the developers advise using to complement cadaver based dissection (Figure 20). The table allows students to manipulate a 3D life-size human body through a touch screen interface. Students can zoom and rotate structures, remove organs and even virtually slice, layer, and segment the anatomy. It is also possible to add annotations to identify anatomical structures, which in turn aids institutions in creating programs, quizzes, and other novel methods of study that were previously not possible. It is possible to project the Anatomage Table to a screen, however it is not currently available on tablet such as the iPad.

[xi] http://www.anatomage.com/

Anatomage loaned the system to Stanford University's School of Medicine to test in an undergraduate anatomy course for bioengineers (Ravindran, 2011). Chief of the division of clinical anatomy, Sakti Srivastava, evaluated the effectiveness of the table as a teaching tool, stating "it's not a replacement for a cadaver, but it's a nice complement." The table can also display data from MRI and CT scans of patients. Paul Brown, Consulting Associate Professor in the Division of Anatomy at Stanford, hopes to develop a library of anatomical images to use on the table, giving students access to a larger number of cadavers of different genders, BMI and ethnicities (Ravindran, 2011)." Srivastava is working with engineers to develop feedback devices for the table to allow users to touch and feel the virtual bodies.

Figure 20, An image of the Anatomage table from their website

2.8 CHAPTER SUMMARY

This chapter has looked at a range of topics relating to the present study. Current approaches to anatomy education have been explored, encompassing both the more traditional methods such as dissection as well as the use of virtual anatomy. This was followed by a discussion on learning styles and theories, particularly in relation to anatomy as a subject matter. Next, a brief history of art and its long relationship with anatomy and medicine was outlined, leading to the present day where stereoscopic imaging a virtual reality (VR) are becoming more readily available. 2016 has been seen as the year of VR, and a review of the current state of the art was provided. This led in to a discussion on haptic and multi-modal interfaces, with particular attention being paid to how they can benefit three dimensional anatomical learning. Simulators, both traditional and digital, for medicine and surgery were also discussed along with the simulation of tissue properties and cutting of digital models. Finally a review of the existing digital anatomy software that is commercially available was provided.

Chapter 3: 'Materials and Methods', will describe the creation of the model and the interface, along giving an overview of the research design. Chapter 4: 'Results and Discussion', details the results from each phase of the study and discusses how they relate to the hypothesis. Finally, chapter 5: 'Conclusions and Future Work' summarises the findings and relates these to suggestions for future work.

3: MATERIALS AND METHODS

This chapter will describe in detail the creation of the digital hand and wrist model used in the study. It will discuss the model's anatomical accuracy as well as the level of realism depicted. The design of the user interface will be outlined along with the creation of the dissection manuals and used guides. Feedback from a focus group was sought early in the project and their suggestions for improvements and alterations are outlined here. Finally the research design, participant tasks and proposed analysis of results are described.

3.1 CREATING THE MODEL

The region of the hand and wrist was chosen due both to its size (fitting on a computer screen at close to life size) and complexity (students could benefit from additional study). The data collection for this project come from two sources, the Visible Human Project Female (Spitzer, 1999) and CT scan data of the Scheuer Collection of Juvenile Remains housed at the University of Dundee. A number of different software and processes were undertaken by the author to create the final model. These are summarised in the process diagram in Figure 21, and described in more detail in the following sections.
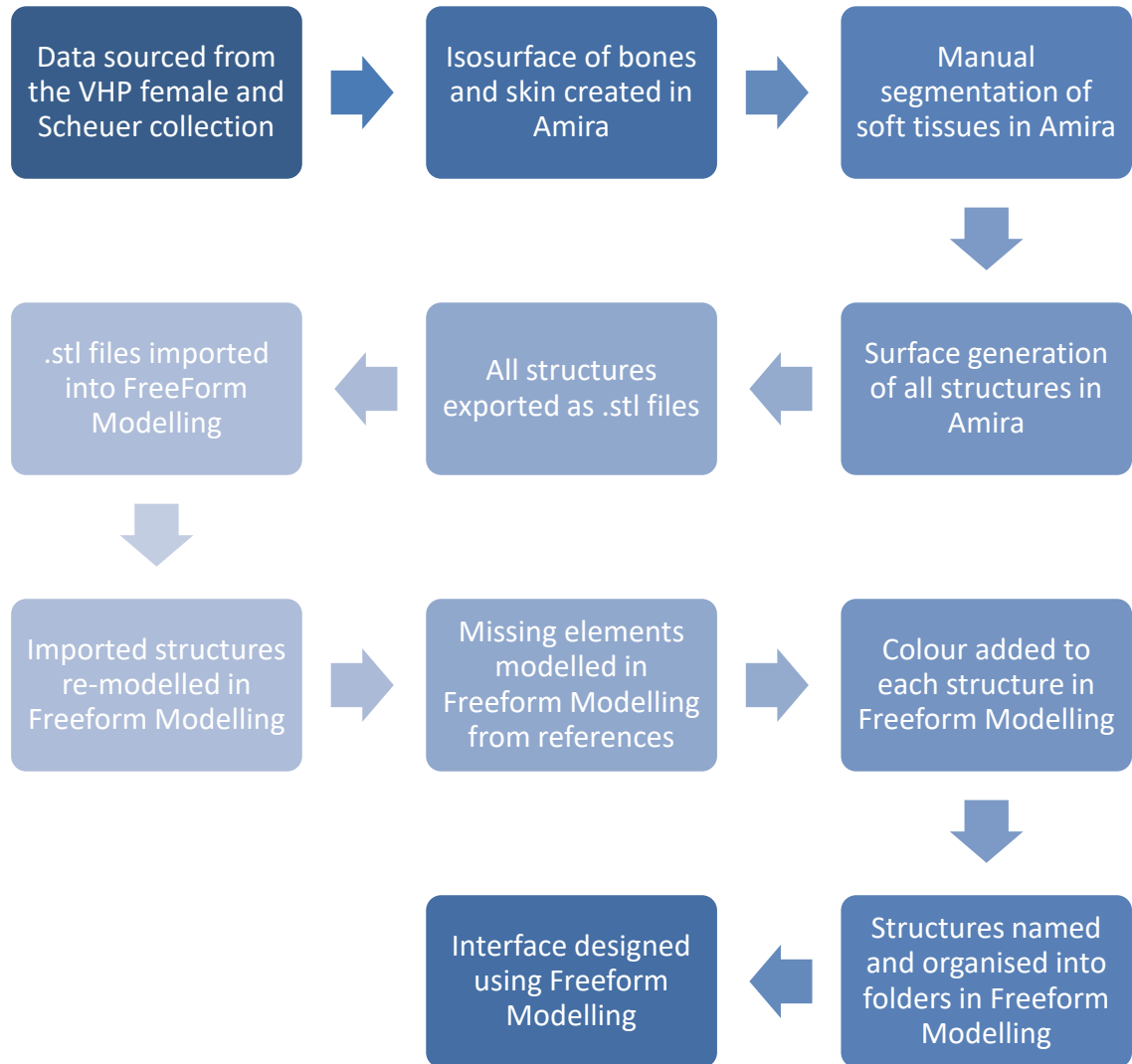
Figure 21, Process diagram outlining the steps taken and software used to create the model and interface

Segmentation and Modelling of the Bones

The VHP female CT data was used to provide a template for the bony skeleton of the hand. The CT data was imported into Amira® 5.2.2. Amira® can be used to convert the CT slice data into 3D objects. In this instance an 'isosurface' was created from the data at a threshold which preserved the hard tissues but deleted the soft tissues. Although this method provided a 3D model of the skeleton of the hand, the resolution was not as high as desired. For this reason, micro CT data of a 16 year old female from the Scheuer Collection was also used.

Both the CT and micro CT data were exported from Amira® as STL files. This allowed import into Sensable's® Freeform® Modelling™ software (V11, 64 bit, now Geomagic FreeForm) for further manipulation. Freeform® Modelling™ is a 'virtual sculpture' software which utilises haptic feedback to provide the artist with a more intuitive approach to modelling. The VHP female CT data was used as a 'template' for the accurate positioning of the micro CT data (Figure 22). The required changes to the shape and scale of the micro CT bones were made by the author using the 'tug' tool in Freeform® Modelling™ to obtain the most accurate fit to the VHP female data.
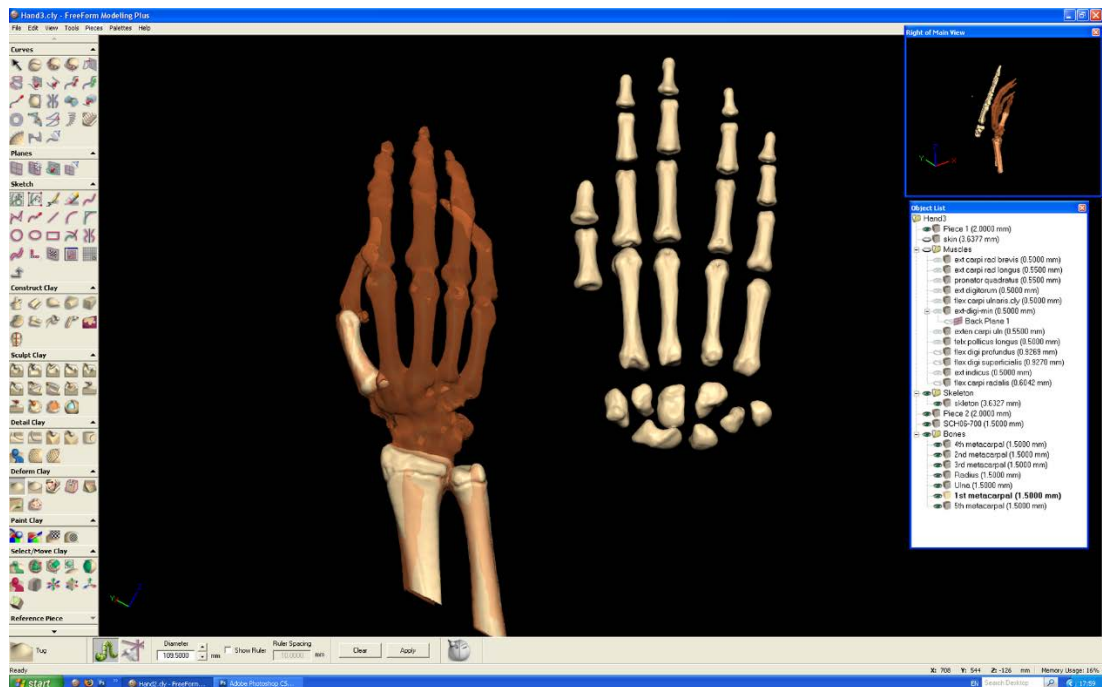
Figure 22, Using the VHP data as a template (red) the more detailed micro CT data (from the University of Dundee's Scheuer collection) was scaled and deformed to fit

Segmentation and Modelling of the Soft Tissues

Photographic cross sections of the VHP female are available taken at one-third of-a-millimetre intervals. Each image is 2048 pixels by 1216 pixels, with each pixel being .33mm in size, and defined by 24 bits of colour. The original data set consisted of 5189 photographic cross sections with a slice distance of .33mm (Figure 23). This distance was chosen to match the 0.33mm pixel sizing in the "X-Y" plane allowing for three-

dimensional reconstructions to be created with cubic voxels. From these slices, an image volume of 662 x 576 x 188 pixels was selected to show the region of the right hand.

The structures of the hand and wrist are too small and too similar, in terms of density and colour gradient, to easily create isosurfaces for each structure in the same way as for the CT Data. Each structure (every muscle, ligament, nerves, vessel, fat and skin) needed to be exported as a separate STL file to allow for individual manipulation in Freeform® Modelling™. In order to achieve this each structure was manually and individually 'segmented' in Amira®.

Figure 23, An example of the VHP female photographic slice data used to reconstruct the soft tissues

Manual segmentation was achieved using Amira's® *labelField* window. A total of 50 individual structures were created by manually 'painting' around them on each of the 188 slices and adding them to the materials list. Elsevier's Interactive Anatomy (Atlas of continuous cross-sections on CD-ROM & CDI) Volume 2-II, Upper Limb (http://www1.elsevier.com/homepage/sab/eia/v2d2/frame.html) was used to help to identify each structure in cross section (Figure 24).

Figure 24, Elsevier's interactive anatomy of the upper limb was used to aid structure identification in Amira®
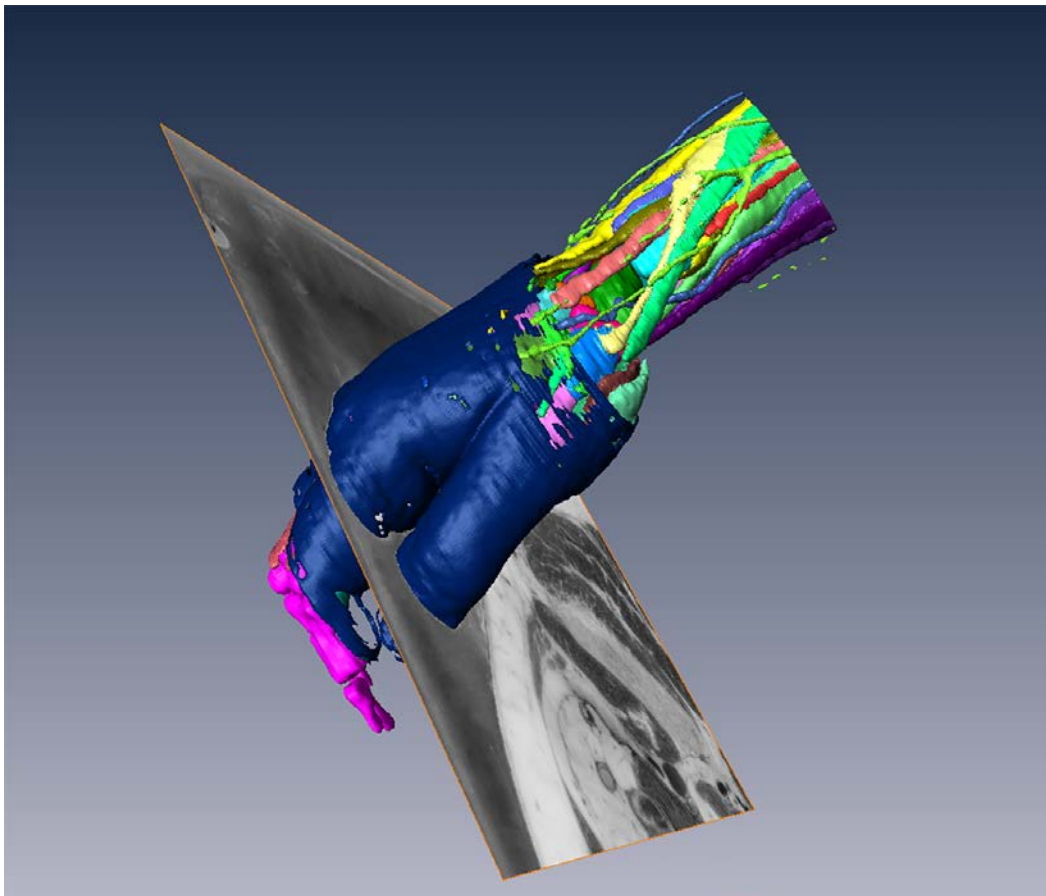
Figure 25, A screen shot from Amira® demonstrating the of 'surfaceview' for all segmented structures

Once segmentation was complete the individual structures were exported as STL files and imported into Sensable's® Freeform® Modelling™ software. This was achieved by first deleting all but the structure to be exported from the materials list. The *SurfaceGen* tab was applied followed by *SurfaceView* and finally *ExtractSurface* (Figure 25)*.*

The individual STL files where imported into Freeform® Modelling™. Each structure was exported from Amira® with location co-ordinates so that they retained their spatial relationships to one another once opened in Freeform® Modelling™. Once imported into Freeform®, the individual structures each required varying degrees of re-modelling where detail had been lost during the segmentation process. This involved both smoothing out jagged edges as well as re-modelling missing and partial elements. Having the 'template' model however made this process much quicker and accurate than modelling alone (Figure 26).
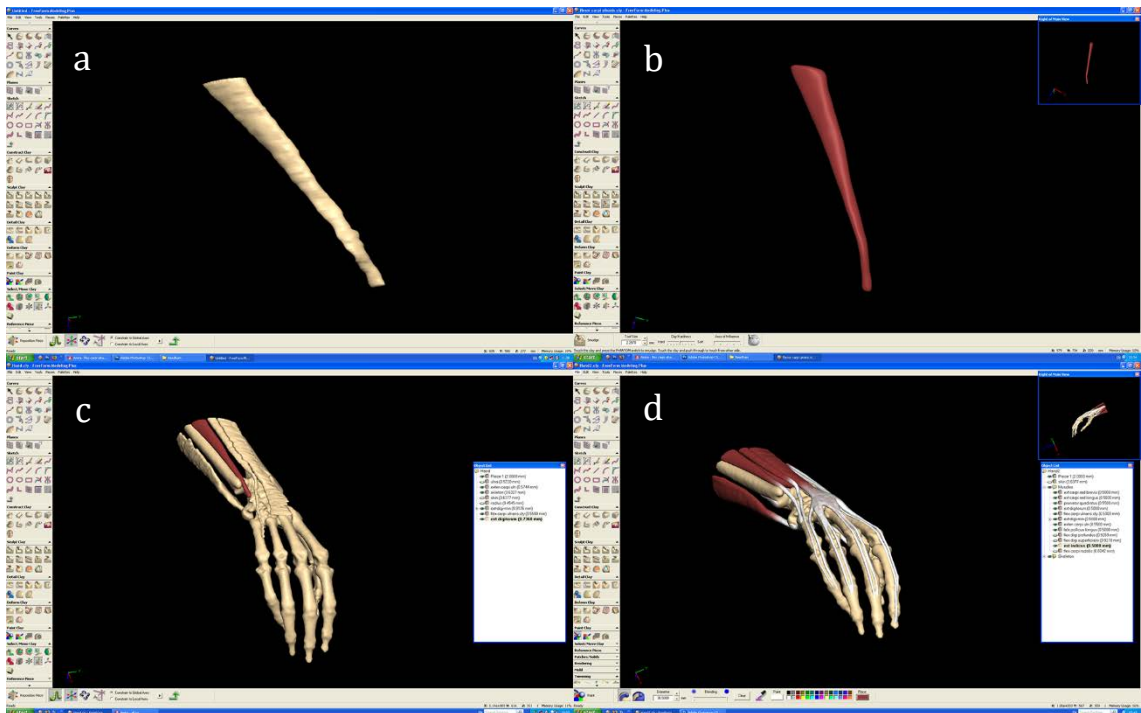
Figure 26a, An example of a muscle as it first appears when imported to FreeForm Modelling from Amira
Figure 26b, An examples of a muscles once it has been refined in FreeForm Modelling
Figure 26c, This image shows a comparison of a refined muscle with those newly imported from Amira
Figure 26d, In this image all of the muscles have been refined in FreeForm Modelling

Segmentation and Modelling of the Vessels, Nerves, Skin and Fat

The nerves, veins and arteries were difficult to observe and therefore segment on the cross-sectional images. Small elements were able to be segmented and exported and these acted as a guide for their otherwise freehand modelling. A limitation of this approach was that the exact pathway of each structure wasn't known and had to be interpreted from the elements that were exported along with using other references including text books, models and cadavers. However, creating the vessels and nerves in this way did ensure that they represented the most common pathways.

The skin was created from the VHP CT data as an isosurface and exported as a solid STL file which was later 'shelled' within Freeform®. The fat was created from a duplicate of the solid skin layer. It is possible within Freeform® to remove one area of virtual clay from another. The skin, muscles, nerves and vessels were therefore removed from the fat layer to leave material in only the voids between the other structures.

Accuracy of the Model

As the model was largely derived from the Visible Human Female data there was little room for error, especially for the larger structures. In addition, the accuracy of the model was checked by two anatomy lecturers (from within The Centre for Anatomy and Human Identification) and any suggested changes made prior to testing on any student groups.

Certain details and fine structures could not be visualised as they are presented in the cadaver due to the limitations of the modelling system. These included the very small branches of the nerves and vessels as well the fascia which surrounds the muscles and other structures. This could be seen as a drawback if the model were intended to replace cadaveric dissection. However, this was not case. Rather the model was intended to act as a 'stepping-stone' between the lecture theatre and dissection room.

In his book Understanding Comics, Scott McCloud described three approaches to creating art: Realism (reality), idealization (meaning) and abstraction (the Picture Plane) which together form the 'McCloud triangle' (McCloud, 1994). For example, a photograph or hyper-real image usually shares a close resemblance to the real thing, whereas a cartoon moves away from resemblance (simplifying and conceptualizing forms, exaggerating features, etc.) but is still capable of conveying the same meaning. This continuum from realistic to cartoon images represents increasing levels of iconic abstraction. When taken to its extreme, the result of this process is written language. Pure abstraction however, departs from both resemblance and meaning. Taken to its extreme, it leads to the picture plane of pure shape, colour, and line. Connecting these three vertices creates a map of every possible form of visual art and communication (McCloud, 2009).

The level of realism required of any model must be considered both in terms of its functional (conveying anatomical meaning to the student) as well as practical requirements, taking into consideration the limitations of the hardware and software. Currently, the majority of anatomy students' progress to dissection after receiving lectures and reading textbooks. The images they are exposed to during this time range from photographs of dissected specimens to diagrams of anatomical features, thus spanning a wide spectrum, particularly across the bottom axis (reality to meaning) of McCloud's triangle (Figure 27).

The model created for this study needed to strike a balance between 'reality', provided by the cadaver, and 'meaning' which is essential for student learning and was provided by illustrations and diagrams in anatomy text books as well as by teachers and lecturers. Pure abstraction was to be avoided as this would diverge from both realism and meaning. These considerations along with the practical limitations of the software and hardware guided the final appearance of the model (Figure 28).
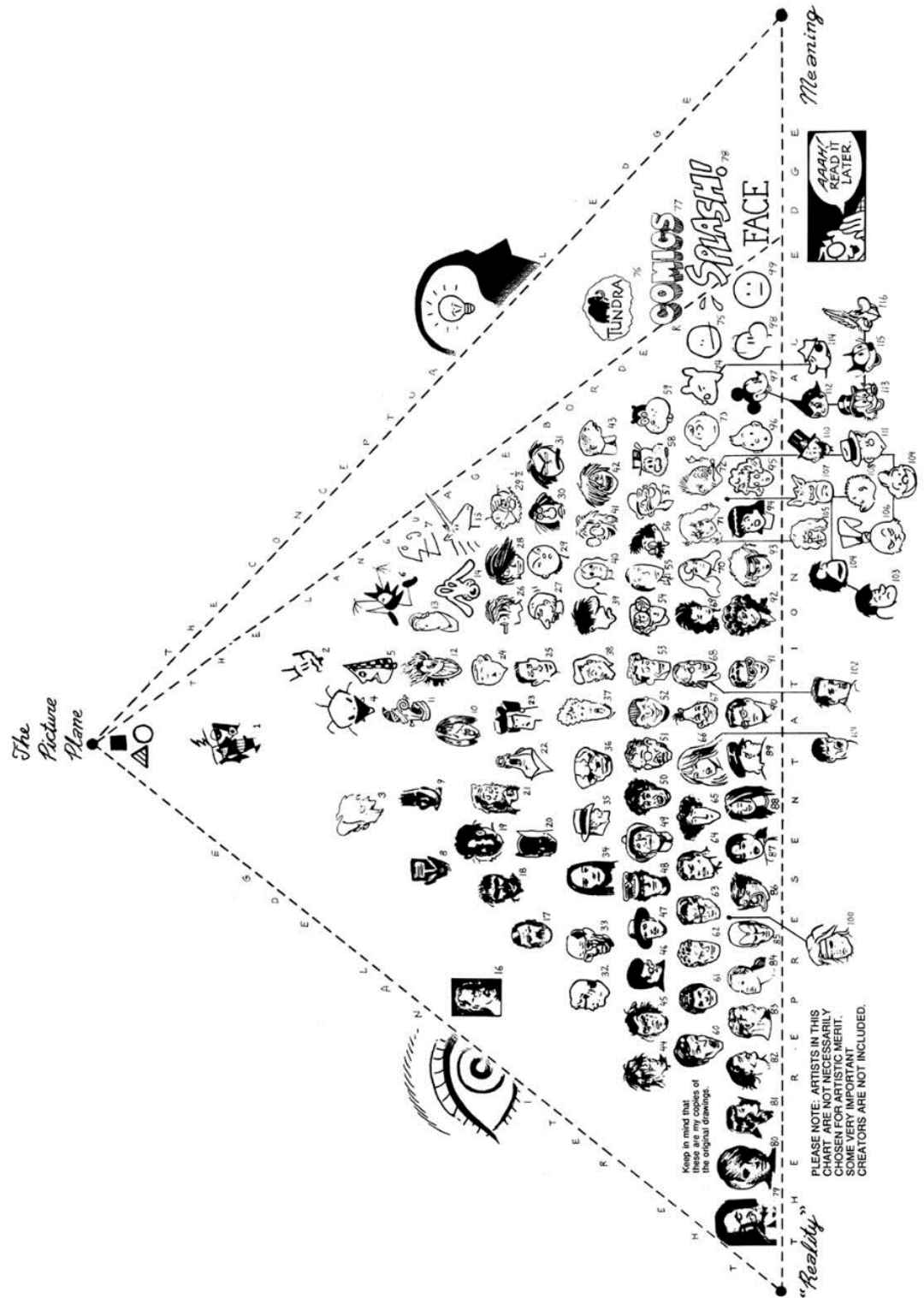
Figure 27, 'McCloud's Triangle' from Understanding Comics by Scott McCloud. The virtual hand and wrist model created for this study would fall half way across the lower continuum, between 'reality' and 'meaning'
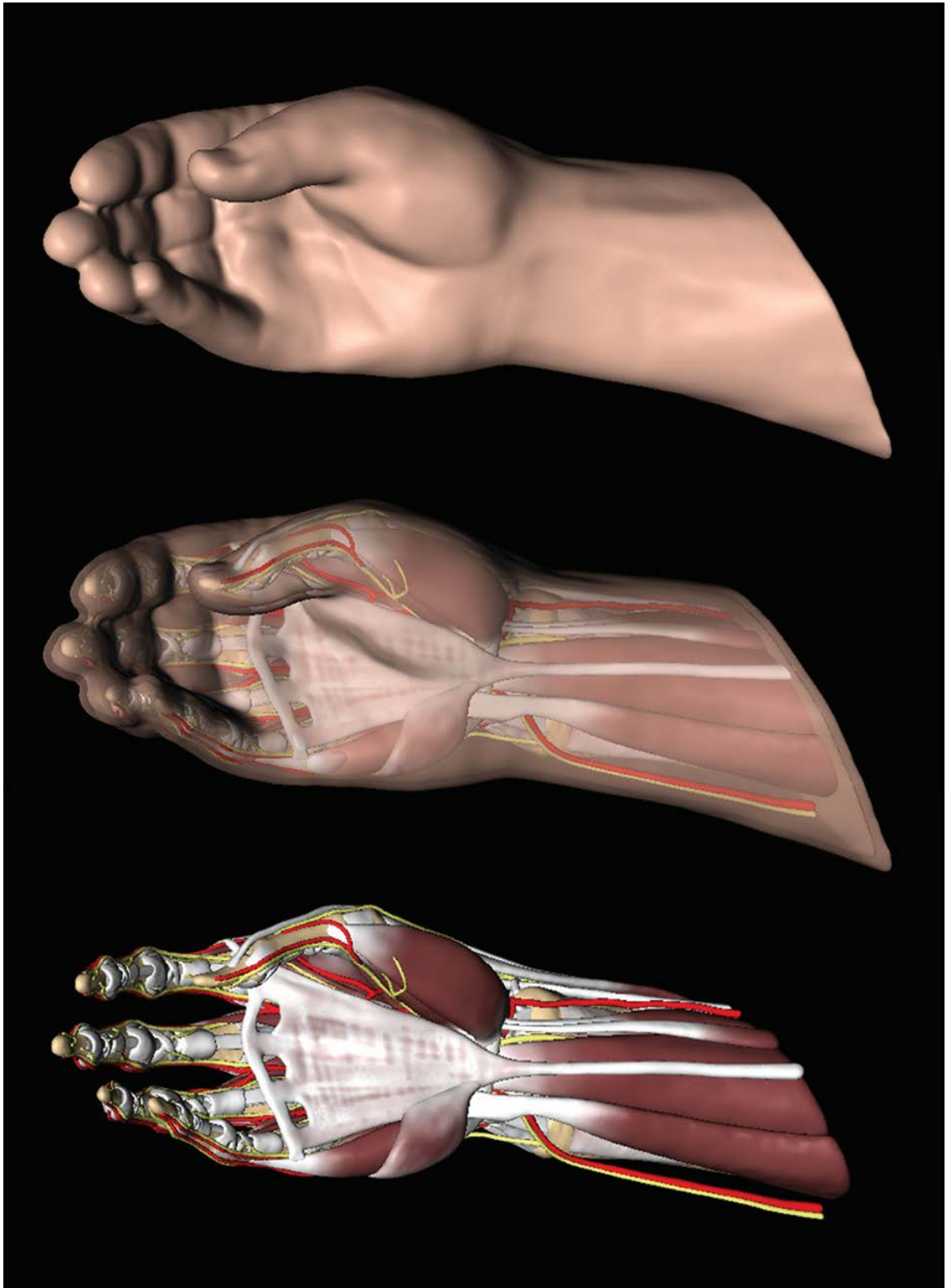
Figure 28, The final model in Freeform® showing: musculoskeletal system, nerves and arteries, and see-through skin layer

3.2 DESIGNING THE INTERFACE

To allow for adequate interaction with and dissection of the model, the user interface needed to meet the following minimum set of requirements:

- To freely rotate the model in 3D space and view it from any angle.

- To allow the user to revert to 'standard views' if they got lost using free rotation.

- To allow for a side view of the model (to help with depth perception on a 2D screen).

- To allow the user to identify structures either by highlighting them in a menu or by clicking on them.

- To allow for individual activation of each structure so that it may be highlighted, made transparent or made invisible.

- To allow the user to manually cut through each individual structure using the haptic device.

- To allow the user to slice through the model in standard anatomical planes.

The final interface for interacting with the virtual hand and wrist model was an adaptation (made by the author) of the Freeform® Modelling™ system used to create the model. This software allows alterations to be made to the desktop layout so that all unnecessary tools and windows can be hidden, leaving only those required for interaction with the model (Figure 29).

Interaction

Interaction with the model can be through either a traditional keyboard and mouse or a haptic interface. Use of a haptic interface not only adds the sense of touch but also alters the way in which the user interacts with and views the model. For example, the act of cutting through the layers of the model produces a 'window of view' similar to that

produced during traditional cadaveric dissection. While this happens as a result of the cutting process, rather than by design, it is potentially useful in that it forces the user to try and identify anatomical structures from limited information much in the same was as cadaveric dissection. Conversely, using a keyboard and mouse interface would limit users to viewing structures only in their entirety (with the option to make them either invisible or transparent) thus making them easier to identify.
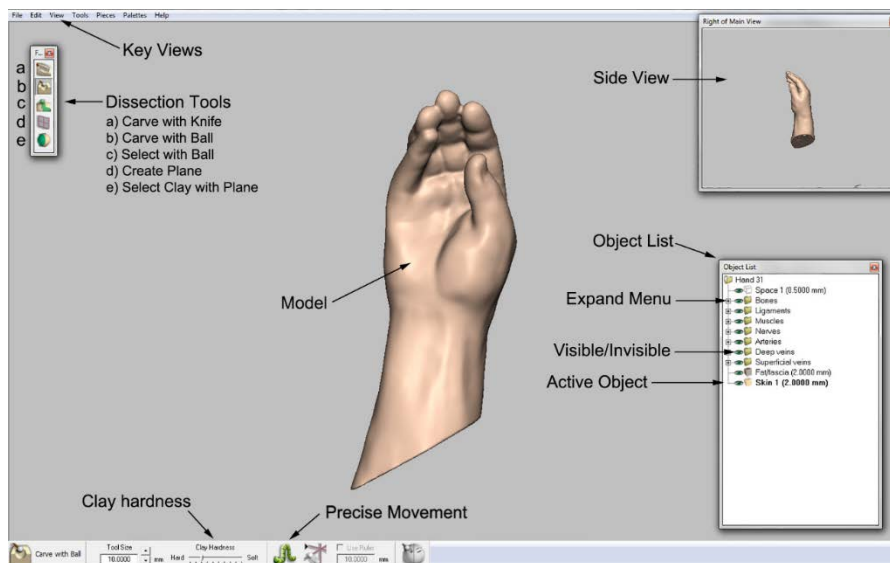
Figure 29, A labelled screen shot demonstrating the interface as adapted within FreeFrom Modelling

Navigation

Key views allows the model to be viewed from the front and back, left and right, top and bottom.

Side views can be activated by going to 'view' and 'side views'. This feature is useful for getting a better understanding of the 3D space.

Dissection tools consist of five tools used to interact with the model. From top to bottom they are: *Carve with knife, Carve with ball, Select with ball, Create Plane*, and *Select with Plane*.

Clay hardness can be altered to the users preference by moving the cursor from hard to soft.

The **Precise Movement** button allows for carving in slow motion, use for detailed dissection.

The **Object list** is activated by pressing 'O' on the keyboard. The individual anatomical structures can be activated from this list by right clicking on their name and selecting 'activate'. The structures were separated into the following folders; Bones, Ligaments, Muscles, Nerves, Arteries, Deep Veins, Superficial Veins, Fat/Fascia, Skin.

The **Expand menu** button (+) will reveal the anatomical structures within each folder.

The **Visible/invisible** (eye) button will toggle each folder or object between being visible and invisible.

Only the **Active object** can be dissected at any time. An object is activated by right clicking on its name and selecting 'activate'. The active object is highlighted in the object list.

It is possible to make an object **transparent** by clicking on the object name and selecting 'see through' and 'see through on'.

Identifying Structures

Structures can be identified in a number of ways:

1) Pressing the '?' key will take the user into Labelling Mode (Figure 20). Using the cursor to hover over any visible structure will cause its name to appear. This feature only works using the haptic stylus and not the mouse.

Figure 30, A screen shot demonstrating 'labelling Mode'

2) Using the search function at the bottom of the object list. This allows for any structure to be found quickly and easily.

3) Left clicking on the structure name in the object list will cause it to become highlighted in green (Figure 31a & b). It is generally easier to identify structures when the entire surface is visible (Fig 31a). However, it is more realistic and useful to be able to identify structures through a more limited 'window of view' (Figure 31b) created through the dissection process. Note – the active object cannot be highlighted. The object list is organised so that each structure, with the exception of the skin and fat/fascia, is grouped in a relevant folder as follows: Bones, Ligaments, Muscles, Nerves, Arteries, Deep Veins and Superficial Veins.
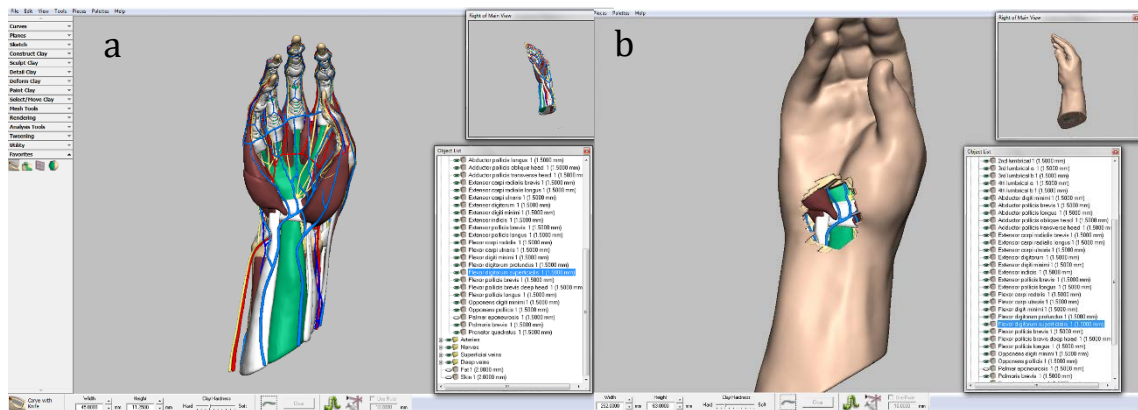
Figure 31a, Using the keyboard and mouse interface allows for identification and highlighting of structures with their entire surface visible

Figure 31b, Using the haptic interface allows for identification and highlighting of structures though a smaller 'window of view'

Moving the model

The model can be moved within six-degrees of freedom (forward/backward, up/down, left/right) and fully rotated within the 3D workspace. It is also possible to move the model without rotation and to zoom. 'Key views' can also be accessed from the 'view' menu at the top of the screen.

Dissecting the Model

Of the two modes of interaction, only the haptic-enabled version allows for virtual dissection. Using the keyboard and mouse interface, users can only hide structures from

view or make them semi-transparent, rather than cut through structures as with the haptic stylus.

Three methods of dissecting the model through a haptic interface are possible (Figure 32): 1) Using a the carve tool to cut through the selected layer; 2) using planes to cut the selected structure through standard anatomical planes and 3) using a selection paint-ball to first select and then delete the layer. The tools are:
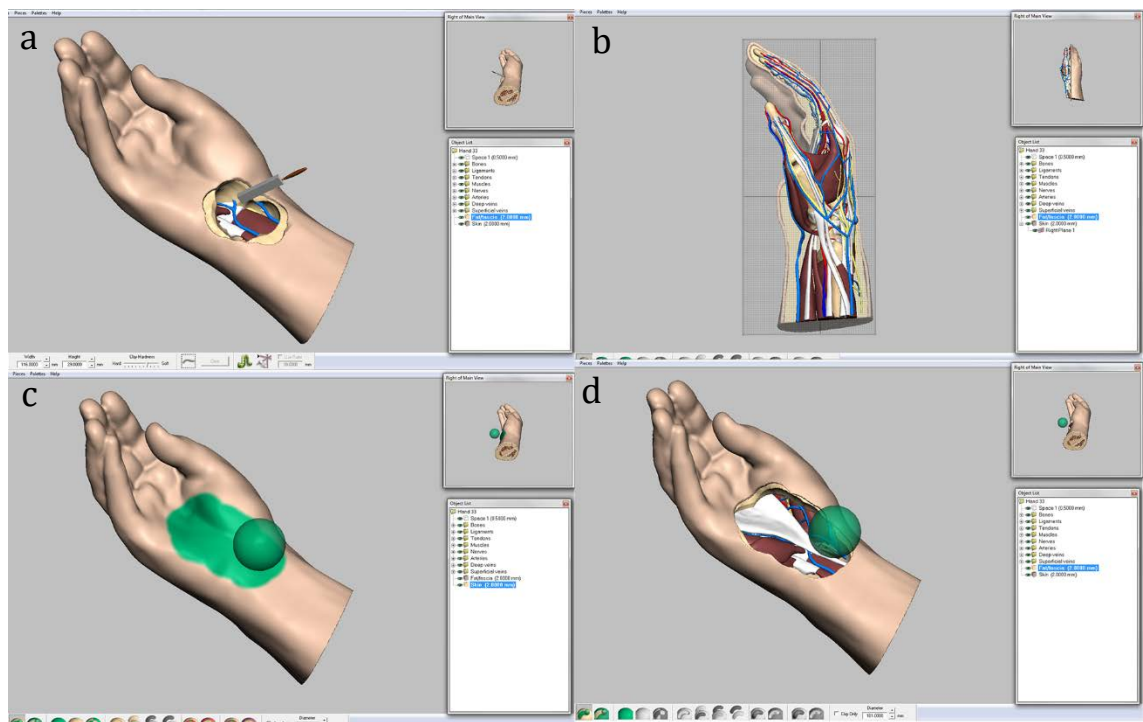
Figure 32, A series of screen shots demonstrating the different dissection methods; a: the carve tool, b: the cutting plane', c and d: selection with ball

Carve (with knife/ball): The Carve tool was chosen as it offers the most realistic way of dissecting the model and results in producing a 'window of view' through which the user must to try to identify structures. While the knife shaped version looks the most realistic (i.e. similar to a scalpel), the ball shape is actually easier to use, as such both were included. Both shapes of carve tool allow for the tissue to be cut/scraped away to reveal underlying structures.

Select with ball: The Select with Ball tool was chosen as it allows for quicker selection and removal of tissue than the Carve tool while still producing the same 'window of view'.

The area to be removed is first highlighted with the ball selection tool before being deleted.

Create Plane: The Create Plane tool was chosen as it allows the user to slice through structures in standard anatomical planes (sagittal, coronal or axial) or to freely rotate the plane to a bespoke position.

Select with Plane: The Select with Plane tool was chosen as it allows the user to bisect a structure in standard anatomical planes (sagittal, coronal or axial) deleting the selected side.

Haptic Behaviour of the Model

The final model of the hand and wrist exists as a Freeform® .cly file and can be 'dissected' using FreeForm® Modelling™ as the user interface. In order not to overwhelm the user with unnecessary tools and windows these can be minimized, leaving only a selection of required tools available for use. Each anatomical structure can be selected separately and virtually 'dissected' with the PHANTOM® Desktop™ haptic tool (Figure 33a). Three primary methods of interacting with the model have been identified: 1) Using a cutting tool to cut through the selected layer (Figure 33b); 2) using a selection paintball to first select and then delete the layer (Figure 33c); and 3) using planes to cut the selected structure through standard anatomical views (Figure 33d).

Using the haptic interface, it is possible to feel and cut through each structure. The haptic interface applies force feedback to the user's hand, providing resistance as the structure is cut. It was not possible (without programming skills that the author did not have) to apply different tissue properties to the various structures. As only one structure can be activated at a time this was not deemed to be important.   However in the future, if multiple structures were to be activated and felt simultaneously, having different tissue properties would become more important.
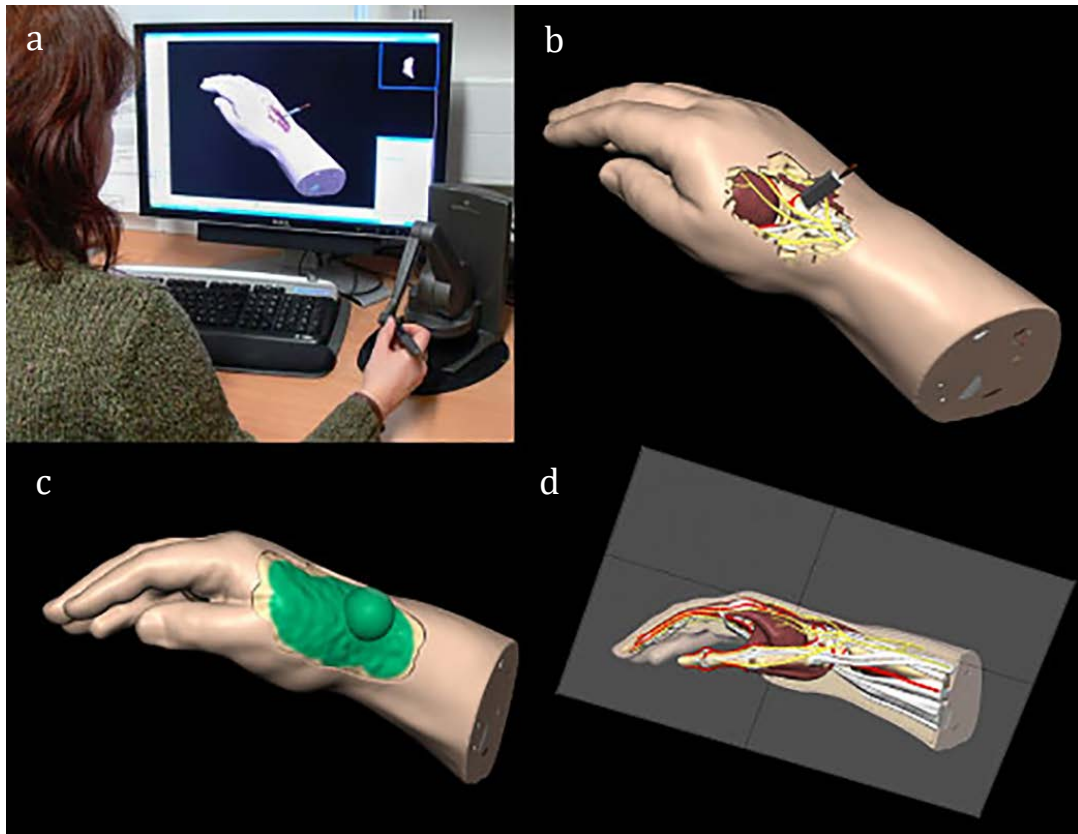
Figure 33a, The author using PHANTOM® Desktop™ & FreeForm® ModellingTM
Figure 33b, Using a cutting tool to cut through the selected layer
Figure 33c, Using a selection paintball to first select and then delete the layer
Figure 33d, Using planes to cut selected structure through standard anatomical views

3.3 DISSECTION MANUAL

Two dissection manuals were created to aid students in the use of the software, one for non-haptic use and one for haptic-enabled use. Both began with a software user guide that described how to navigate the software, move, manipulate and dissect the model. The non-haptic version only described how to use the keyboard and mouse to interact with the model, whereas the haptic-enabled version included information on both using the keyboard and mouse as well as the haptic interface to interact with the model. All dissection manuals followed the same overall format and were adapted from Grant's Dissector 12th Edition (Grant and Sauerland, 1999). The manuals described the dissection sequence and made suggestions in relation to which tool was best used for

each step (this is differed between manuals). Anatomical structures which should be identified and traced were also listed. The text was illustrated with screen shots of the software in use for each version (Figure 34a & b). The dissection manuals were shown to the students when they came to the first tutorial and were left next to the computers throughout the study (a digital copy was also available on the computers desktop). Both dissection manuals are presented in Appendix 13.
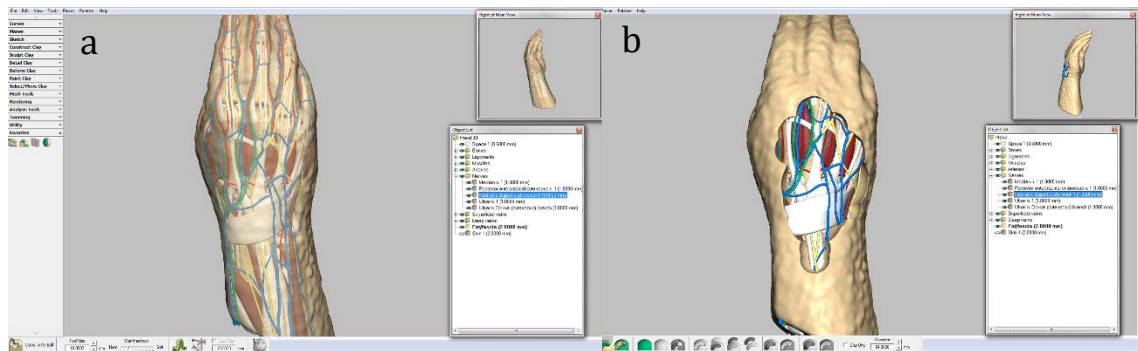
Figure 34a, An example screen shot from the non-haptic dissector
Figure 34b, An example screen shot from the haptic dissector

3.4 FOCUS GROUP FEEDBACK

After completing their role as control group (see section 3.5) students from year one of testing were invited to try the software as a 'focus group' to get their feedback and make any required alterations before it was used in year two. Other individuals who tried the software and gave feedback during this time included Anatomy lecturers, MSc Medical Art students and PhD students within the Centre for Anatomy and Human Identification. Everyone who took part in the focus group was given draft copies of both dissection manuals to go through and make notes on. Ten students gave feedback overall.

Suggestions and Alterations

Everyone who tried the software commented that overall they enjoyed using it and thought it would be a useful learning aid. Suggestions which resulted in significant changes being made to either the model and/or dissection manuals are detailed below, along with details of the resulting changes.

The most frequent request was for a 'pointer' tool which would cause the anatomical name to appear when pointing at a structure. This is a common style of interaction in many 3D anatomy packages. After contacting the software manufacturers (Sensable
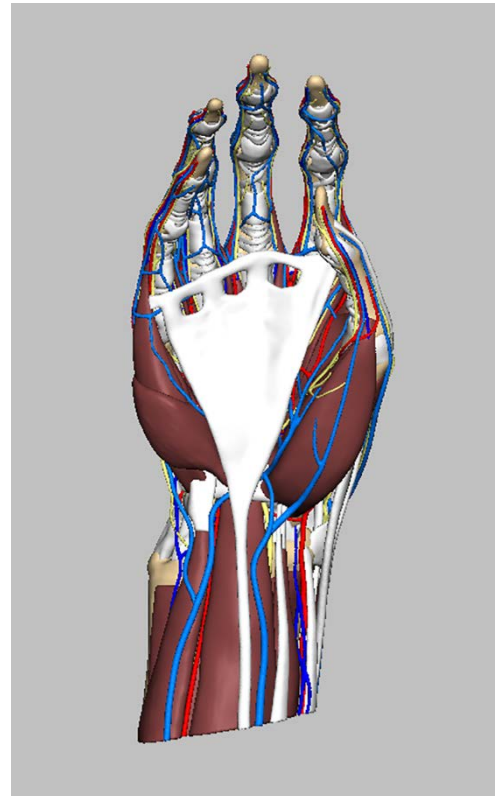
Figure 35, The model with muscles and tendons as separate pieces

Technologies) it was discovered that the "?" key could be used to access such a mode. Unfortunately this is only possible when using the haptic stylus and does not work with the mouse.

It was suggested that since each structure is a single colour (to save on computer memory, see section 4.7 for more information), some structures which were previously coloured and labelled as muscles might be more appropriate as tendons. Those structures which were predominantly tendinous (due to where the model ended at the wrist) therefore had their colour changed from red to white and added to a new folder for tendons. This had the added benefit of splitting structures between two folders, thus making them easier to locate. A number of structures contained both muscular and tendinous parts, these were therefore split into two pieces and coloured and labelled as such (Figure 35).

Information was added to the dissection manuals on the following: how to select multiple structures, use of the 'precise movement' button when carving and additional information on selection tools.

Minor alterations were made to the wording of the manuals to clarify points and rectify typographical errors.

The dissection manual was also checked by an anatomy lecturer to ensure it was consistent with cadaver dissection.

3.5 RESEARCH DESIGN

The potential benefit of the software as an aid to learning anatomy and to improving cadaver dissection was assessed by testing both the haptic-enabled version of the software (allowing for real-time cutting) and a non-haptic version, using instead a mouse and keyboard 'point and click' style interface. Both versions were tested on anatomy students including; BMSc and MSc Human Anatomy students, MSc Anatomy and Advanced Forensic Anthropology students, and BSc Anatomical Sciences and BSc Forensic Anthropology students, in relation to test results (which did not contribute to their grades), dissection quality and student experience. The software was made available in addition to normal tuition. All students undertook full body dissection. The University Non-Clinical Research Ethics Committee of the University of Dundee reviewed and approved this study (UREC 10034).

The study ran over five successive years and was split into three discreet phases. Phase one took place over four years (2011-2014) and compared the results of MSc/BMSc students across a control group (2011/12), non-haptic group (2013) and a haptic group (2014). Phase two took place over one year (2014) and compared the results of BSc students between a control group and a haptic group (2014). Phase three took place

over one year (2015) and compared the results of BSc students across a control group, a non-haptic group and a haptic group (Figure 36).

The effectiveness of the software was evaluated and assessed both quantitatively and qualitatively. The quantitative assessment consisted of comparing anatomy test results of the haptic-enabled groups with those of the non-haptic and control groups. The quality of the dissection was also qualitatively evaluated by an anatomist after student dissection classes.

After cadaveric dissection had taken place, those students who took part in the study were also asked to complete an optional questionnaire on the efficacy of the software.
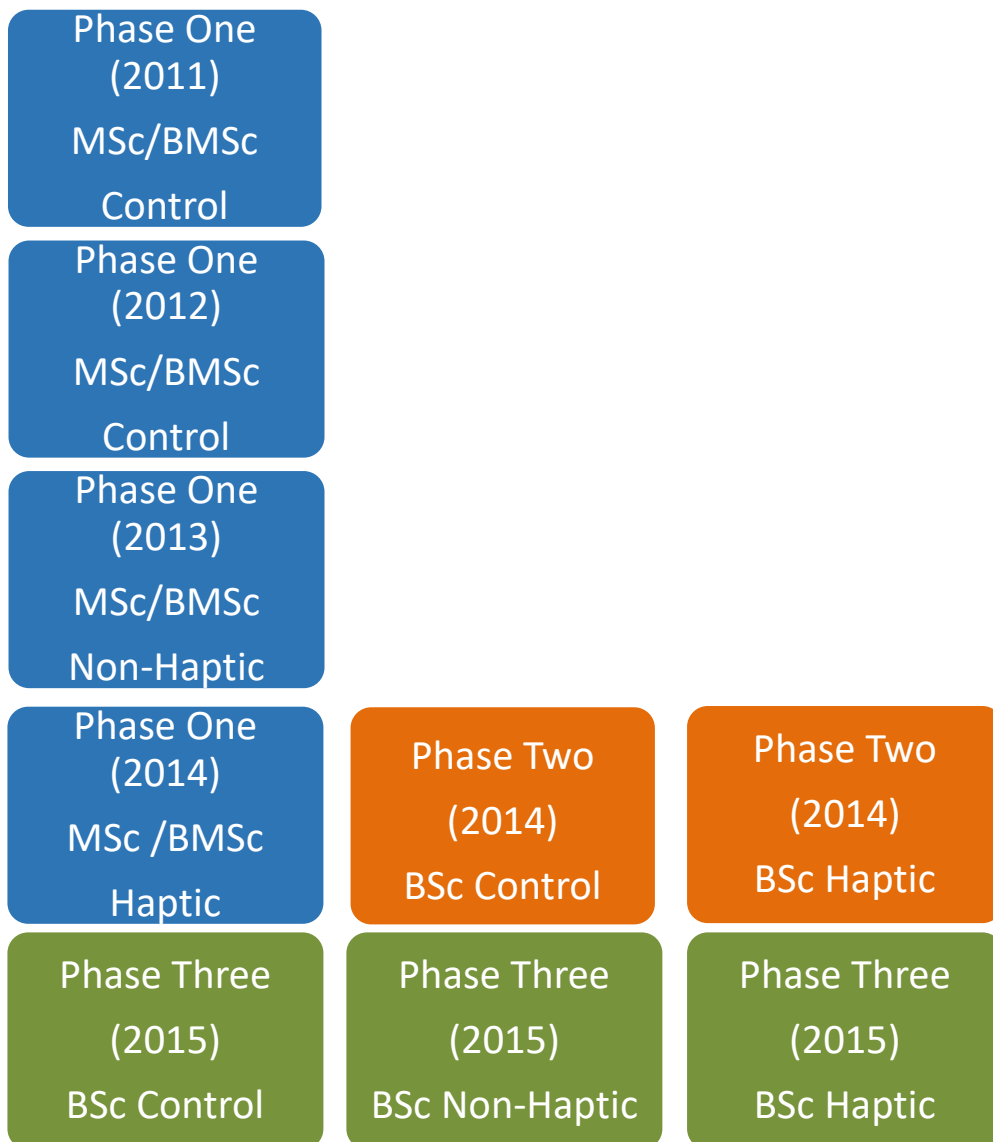
Figure 36, Diagram outlining the study phases over five years

Tracking Students

To link student knowledge while maintaining anonymity, each student was given a unique identification number. This identifier also made it possible to align students to cadavers and thus link the results from the anatomy test, feedback questionnaire and dissection evaluation (Tables 2 & 3).

Table 2, Example of the information gathered regarding how many students from the study dissected each cadaver

Cadaver number	Total in group	Total in study
Cadaver 1	4	4
Cadaver 2	4	2
Cadaver 3	4	1

Table 3, Example of ID number allocations, used to maintain anonymity of participants

Name	Course	Cadaver #	ID
Name 1	MSc Human Anatomy	1	P1 MScA 2013
Name 2	MSc Human Anatomy	1	P2 MScA 2013
Name 3	MSc Anatomy & Forensic Anthropology	2	P3 MScAFA 2013
Name 4	BMSc	3	P4 BMSc 2013

Study Phases

Initially the study planned to use MSc/BMSc students only. At the time the study began these were the only students with access to Thiel embalmed cadavers (the Centre was in the process of transitioning from formalin to Thiel embalming). As the groups were relatively small the study was staggered over four successive years, two gathering control data (2011/12) (the author was on maternity leave for the second), one gathering non-haptic data (2013) and one gathering haptic data (2014).

However, by 2014 the BSc students were also using Thiel embalmed cadavers. Phases two and three were added to the study to increase the number of participants and therefore make any findings more robust. Phase two took place during 2014 and gathered only haptic and control data. Phase three was added in 2015 and gathered both non-haptic and haptic data, as well as control data. Phase three was added both to again increase student numbers, but also to compare results within a discrete student population (a single year group, having had exactly the same learning experiences so far) (Figure 36).

All groups consisted of discreet student cohorts.

Phase One Student Groups

Three groups of students were used for the purposes of testing the software during phase one; the MSc Human Anatomy students, MSc Anatomy and Advanced Forensic Anthropology students and the BMSc Anatomy students. Although the students came from three different courses they all shared the same gross anatomy module and facilities.

MSc (Master of Science) Human Anatomy:

The MSc in Human Anatomy at the University of Dundee is a one year taught postgraduate programme for those who want to study for a higher degree in Anatomy

prior to for example, taking up an Anatomy teaching post or undertaking further research at PhD level.

MSc (Master of Science) Anatomy & Advanced Forensic Anthropology:

This one-year postgraduate degree is designed for students who already hold a first degree (BA or BSc) in Anthropology or a related subject, and is intended to provide advanced training in subject areas which are germaine to current professional requirements, but which are not available collectively at any other institution in the world.

BMSc (Bachelor of Medical Science) Anatomy:

This BMSc is only available to intercalating medical and dental students who have successfully completed the first three years of the MBChB programme or the first two years of the BDS programme. Students are expected to average at least a grade B in the year prior to undertaking the BMSc. Students enter the equivalent of the Level 4 programme (4th year honours) sharing classes with third year and honours students.

Phases Two and Three Student Groups

BSc (Bachelor of Science) Anatomical Sciences

Anatomical sciences are fundamental to many other aspects of the biological sciences. The Undergraduate BSc degree at the University of Dundee includes gross anatomy with whole body dissection hence there is a strong focus on practical, hands-on, experience.

This is a four years honours degree with dissection taking place during year three.

BSc (Bachelor of Science) Forensic Anthropology

Forensic anthropology serves the investigative and judicial communities by analysing human remains for medicolegal purposes. It has adopted a pivotal role in both UK and international investigations being core to issues of repatriation, mass disasters and war crimes.

This is a four years honours degree with dissection taking place during year three. The first three years of study are the same for both BSc's, with specialisation in year 4.

Consent and Participant Information

Students were informed of the research project before beginning dissection of the hand and wrist. The researcher generated interest by giving all students a short talk (at the end of one of their anatomy lectures) and providing participant information and consent to sheets those interested. This was followed up via email and the Virtual Learning Environment (VLE). The participant information sheets outlined the purpose of the research and the experimental design. Contact details of the researcher and project supervisors were also provided. Students who wished to participate in the study were asked to read and sign a consent form. Both the consent form and participant information sheet were approved by the University of Dundee Ethics Committee on 26/06/2010 and are shown in appendix 10. The full consent form and participant information sheets are shown in appendices 16 and 17.

3.6 PARTICIPANT TASKS

Those students who agreed to participate in the study were allocated to one of three of groups; Control, Non-Haptic or Haptic. Allocation of the non-haptic and haptic groups occurred when students came to the initial training session (described below). This was done to enable an approximate split between the two groups. Depending on their allocation, students were asked to perform the following tasks:

Control

1. Complete the module as normal with no interventions.

2. At the end of the module students were asked to complete a (non-assessed) knowledge tests on the anatomy of the hand and wrist.

Non-Haptic

1. Students were be asked to use the non-haptic version of the dissection software prior to dissecting the hand and wrist. They had access to the software for two weeks before cadaver dissection took place.

2. Students also had access to the software for one week after cadaver dissection took place and were also encouraged to use it for revision.

3. When using the software, students were encouraged to follow the dissection manuals provided.

4. Training sessions were provided at regular intervals during the time the software was available (3 tutorials, one per week). Students were asked to attend at least on training session.

5. At the end of the module students were asked to complete a (non-assessed) knowledge test on the anatomy of the hand and wrist.

6. At the end of the module students were asked to complete an optional and anonymous questionnaire on how useful or otherwise they felt the software to be.

Haptic

1. Students were be asked to use the haptic-enabled version of the dissection software prior to dissecting the hand and wrist. They had access to the software for two weeks before cadaver dissection took place.

2. Students also had access to the software for one week after cadaver dissection took place and were also encouraged to use it for revision.

3. When using the software, students were encouraged to follow the dissection manuals provided.

4. Training sessions were provided at regular intervals during the time the software was available (3 tutorials, one per week). Students were asked to attend at least on training session.

5. At the end of the module students were asked to complete a (non-assessed) knowledge test on the anatomy of the hand and wrist.

6. At the end of the module students were asked to complete an optional and anonymous questionnaire on how useful or otherwise they felt the software to be.

Tasks 1 and 2 for the non-haptic and haptic groups were chosen to encourage students to use the software both as a precursor to cadaver dissection and as a revision aid. Task 3 for the non-haptic and haptic groups aimed to give students structure and guidance in using the model. It was expected that students would follow the dissection manual and both identify and remove structures as the progressed.

Throughout the study, both versions of the software were available in the Forensic Anthropology Teaching Lab, within the Centre for Anatomy and Human Identification (CAHID) at The University of Dundee.

Phase One Control 1 (2011)

During the first year of phase one, MSc Human Anatomy students had no access to the software but were asked to complete a knowledge test and the condition of the cadaver was evaluated qualitatively by an anatomist after dissection.

In addition, after completing their role as control group, the students were invited to try out the software as a 'focus group' to get their feedback before it was used in year three. Their feedback and subsequent alterations are discussed in section 3.4.

Phase One Control 2 (2012)

During the second year of phase one, BMSc and MSc Human Anatomy students had no access to the software but were asked to complete a knowledge test and the quality of the dissection was evaluated qualitatively by an anatomist.

Phase One Non-Haptic (2013)

During the third year a non-haptic version of the software was made available to BMSc and MSc Human Anatomy students and MSc Anatomy and Advanced Forensic Anthropology students in addition to their normal tuition from two weeks before to one week after cadaveric dissection of the hand and wrist took place. Use of the software was optional and tuition was provided at regular intervals during the time the software was available (3 tutorials, one per week). Students were asked to complete an optional knowledge test as well as feedback questionnaire. The quality of the dissection was evaluated qualitatively by an anatomist.

Phase One Haptic (2014)

During the fourth year a haptic-enabled version of the software was made available to BMSc and MSc Human Anatomy students and MSc Anatomy and Advanced Forensic Anthropology students in addition to their normal tuition from two weeks before to one week after cadaveric dissection of the hand and wrist took place. Use of the software was optional and tuition was provided at regular intervals during the time the software was available (3 tutorials, one per week). Students were asked to complete an optional knowledge test as well as feedback questionnaire. The quality of the dissection was evaluated qualitatively by an anatomist.

Phase Two (2014)

During the fourth year a haptic-enabled version of the software was also made available to 3rd year BSc (Hons) students in Anatomical Sciences, and Forensic Anthropology in

addition to their normal tuition from two weeks before to one week after cadaveric dissection of the hand and wrist took place. Use of the software was optional and tuition was provided at regular intervals during the time the software was available (3 tutorials, one per week). Students were asked to complete an optional knowledge test as well as feedback questionnaire. The quality of the dissection was evaluated qualitatively by an anatomist.

To create a control group, the returning 4th years were invited to complete the anatomy test, after being given a week to revise if they wished.

Phase Three (2015)

During the fifth year both non-haptic and haptic-enabled versions of the software were made available to 3rd year BSc (Hons) students in Anatomical Sciences, and Forensic Anthropology in addition to their normal tuition from two weeks before to one week after cadaveric dissection of the hand and wrist took place. One group had access to the non-haptic version, the other to the haptic-enabled version. Use of the software was optional and tuition was provided at regular intervals during the time the software was available (3 tutorials, one per week). Students were asked to complete an optional knowledge test as well as feedback questionnaire. The quality of the dissection was evaluated qualitatively by an anatomist.

To create a control group, the returning 4th years were invited to complete the anatomy test, after being given a week to revise if they wished.

Anatomy Test, Feedback Questionnaire and Dissection Evaluation form

The anatomy knowledge test consisted of eight question; three 'spot tests' (multiple answer) and five multiple choice (single correct answer) on the anatomy of the hand and wrist. Questions one and two used photographs of Thiel embalmed hand dissections taken by the author. Question three used an image of a formalin embalmed hand provided by the MSc Human Anatomy lecturer. This image was already labelled 1 – 13. However, as the image has been cropped for the purposes of this study numbers 3, 4 and 7 are missing.

The anatomy test was given to students within one week of them completing the dissection and took place in the Anatomy Museum at CAHID. While the author was in the same room as the students, they were able to sit some distance away and it was not possible for the author to see their answers as they wrote. This was consistent across all groups with the exception of the control groups from phases two and three. For phases two and three the control groups came from the returning 4th years who had dissected the previous year (and were given a week to revise if they wished).

The feedback questionnaire consisted of 14 questions; nine using a five-point Likert scale, three asking 'open' questions, such as 'what improvements would you like to see made to the software?' and two asking 'closed' questions, such as 'how many training sessions did you attend – 1, 2, 3, 4 or 5+?' In addition there was a space for 'any other comments'. This was given to students to complete at the same time and place as the anatomy test above. Although the author was in the same room as the students, they were able to sit some distance away and it was not possible for the author to see their answers as they wrote. While the author is lecturer within CAHID, she does not teach on any of the courses involved in study and is not involved in grading the students work.

The dissection evaluation form consisted of 13 questions asking 'how well' different aspects of the dissection had been performed and were scored using a five-point Likert scale, where 1= 'not at all', 3= 'moderately' and 5= 'extremely'. For these questions therefore a higher score is preferable. One exception to this format was question 8, which asked, 'How much damage to the structure is there?' In this instance a lower score would be preferable. The evaluation was carried out by a qualified anatomist, being constant across all years of the study.

The anatomy test, feedback questionnaire and dissection evaluation form were each approved by the University of Dundee Ethics Committee. The full test, questionnaire and dissection evaluation forms are shown in appendices 11 through 13.

3.7 PROPOSED ANALYSIS OF RESULTS

The proposed analysis of results was as follows:

Anatomy Test

It was anticipated that the anatomy test results would be compared using either a t-test (if the sample showed a normal distribution and was large enough, >20) or a Mann-Whitney U test, using SPSS.

Dissection Evaluation

It was anticipated that the dissection evaluation results would be compared using a Mann-Whitney U test, using SPSS. As the data was derived from a Likert style questionnaire it would not be appropriate to use a parametric test such as a t-test.

Feedback Questionnaire

It was anticipated that the feedback questionnaire results would be compared using a Mann-Whitney U test, using SPSS. As the data was derived from a Likert style questionnaire it would not be appropriate to use a parametric test such as a t-test.

Correlations

It was anticipated that correlations would be explored between answers on the feedback questionnaire and the anatomy test results.

3.8 CHAPTER SUMMARY

This chapter described in detail how the 3D digital model of the hand and wrist used in this study was created by the author using a range of data and digital software. The model's anatomical accuracy and level of realism was discussed along with the influencing factors. Next, the design of the user interface was outlined along with that of the dissection manuals and user guides. Suggestions for improvements and alterations to the model, interface and dissection manuals from a focus group enlisted early in the study were then discussed. This was followed by a description of the research design and participant tasks for each group, including a description of the quantitative and qualitative data that would be collected. Finally the proposed analysis of results was described.

Chapter 4: 'Results and Discussion', details the results from each phase of the study and discusses how they relate to the hypothesis. Finally, chapter 5: 'Conclusions and Future Work' summarises the findings and relates these to suggestions for future work.

4: RESULTS AND DISCUSSION

This chapter will first look at the results of the anatomy knowledge test. It will describe, interpret and discuss the results for each phase of the study in turn. The dissection evaluation results will then be looked at for all phases together, followed by the feedback questionnaire results, again for all phases. Finally, limitations and suggestions for improvements will be outlined.

4.1 COMPARISON OF PHASE ONE RESULTS

The first set of results was from the MSc and BMSc students collected between 2011 and 2014. The first two years acted as controls (the author was on maternity leave for 2012) and the data combined. Year three (2013) saw the testing of the non-haptic version of the model, while year four (2014) saw the testing of the haptic version. The control group consisted of thirteen students, the non-haptic group of seven and the haptic group of nine. Two students were omitted from the haptic results however as they left over 40% of the questions unanswered. For individual results see appendices 2 through 6.

Anatomy Test: Comparison of Results for Phase One Students

Questions one to three were anatomy 'spotter tests' where the student had to identify the labelled structures. Questions four to eight were multiple choice style questions. Figures 38, 40, 42 and 44 compare the scores for each question from the anatomy test. Statistical analysis was performed using the Mann-Whitney U test in SPSS (version 23). The results of the control and non-haptic groups were compared, followed by the control and haptic groups. The results from individual students were used for the statistical analysis.

Question One

Q1 a) Abductor pollicis brevis b) Flexor pollicis brevis (superficial head) c) Flexor pollicis brevis (deep head) d) Flexor digitorum superficialis tendon e) Flexor digitorum profundus tendon f) Pronator quadratus g) Common palmar digital aa. h) Adductor pollicis (transverse head) i) Adductor pollicis (oblique head)

Sample Characteristics

A Shapiro-Wilk test (p>.05) (Shapiro and Wilk, 1965, Razali and Wah, 2011) and a visual inspection of their histograms, normal Q-Q plots and box plots (Figure 37) showed that the test scores were not consistently normally distributed across the three groups, for question one.

Figure 37, Box plots for phase one results for question 1 (the results for the Non-haptic group appear as a flat line due to all the individuals scoring the same with the exception of the two outliers)

Summary of Results

Question one was a spot test consisting of nine elements. Figure 38 shows the scores for each group for all nine elements.   The non-haptic group scored highest with a mean of 74.6%, followed by the control group with a mean of 63.2%, and finally the haptic group with a mean of 60.3%.
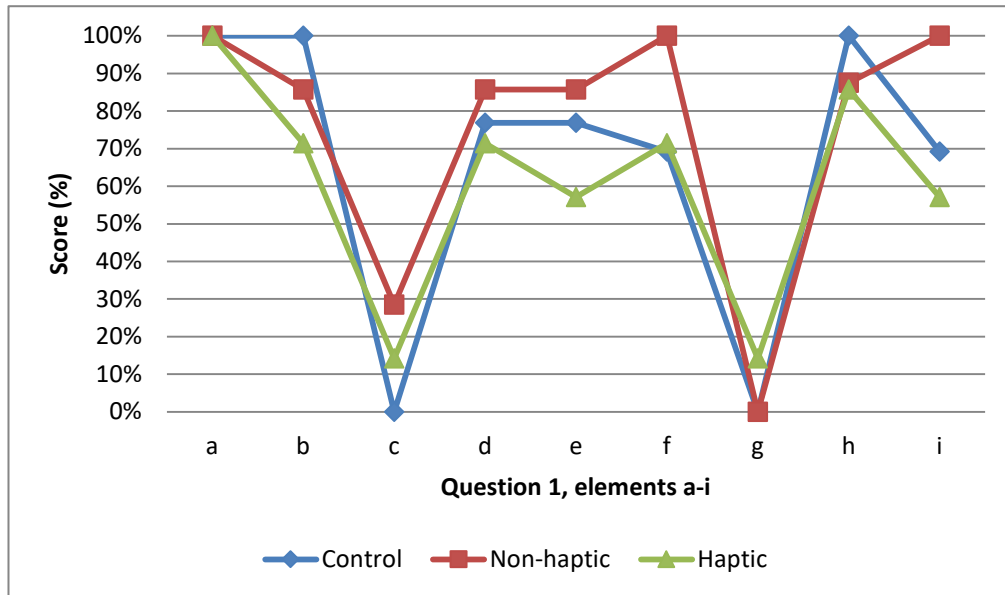
Figure 38, Graph of phase one results for question 1

Mann-Whitney U Test Results

Due to the small group sizes and largely non-normal distribution two Mann-Whitney U tests were performed. The first Mann-Whitney U test showed that the non-haptic group did not score significantly higher than the control group. The second Mann-Whitney U test showed that the haptic group did not score significantly higher than the control group.

The medians were also calculated for each group. Both the control and the non-haptic groups scored 77.7%, while the haptic group scored 55.5%.

Question Two

Q2 a) Abductor digiti minimi b) Dorsal interosseus (4th) c) 2nd
metacarpal d) Dorsal interosseus (1st) e) Extensor digitorum tendon f)
Abductor pollicis longus

Sample Characteristics

A Shapiro-Wilk test (p>.05) (Shapiro and Wilk, 1965, Razali and Wah, 2011) and a visual inspection of their histograms, normal Q-Q plots and box plots (Figure 39) showed that the test scores were not consistently normally distributed across the three groups, for question two.

Figure 39, Box plots for phase one results for question 2

Summary of Results

Question two was a spot test consisting of six elements. Figure 40 shows the scores for each group for all six elements. The non-haptic group scored highest with a mean of 80.9%, followed by the haptic group with 73.8%, and finally the control group with 52.5%.

Figure 40, Graph of phase one results for question 2

Mann-Whitney U Test Results

Due to the small group sizes and largely non-normal distribution two Mann-Whitney U tests were performed. The first Mann-Whitney U test showed that the non-haptic group scored significantly higher than the control group, scoring p-values of 0.003. The second Mann-Whitney U test showed that the haptic group scored significantly higher than the control group, scoring a p-value of 0.030.

The medians were also calculated for each group. The control group scored 66.6% while both the non-haptic and haptic groups scored 83.3%.

Question Three

Q3 1) Abductor digiti minimi 2) Abductor pollicis longus 5) Extensor carpi radalis brevis 6) Extensor carpi radalis longus 8) Extensor digiti minimi 9) Extensor digitorum 10) Extensor indicis 11) Extensor pollicis brevis 12) Extensor pollisis longus 13) Extensor retinaculum

Sample Characteristics

A Shapiro-Wilk test (p>.05) (Shapiro and Wilk, 1965, Razali and Wah, 2011) and a visual inspection of their histograms, normal Q-Q plots and box plots (Figure 41) showed that the test scores were largely normally distributed across the three groups, for question three.
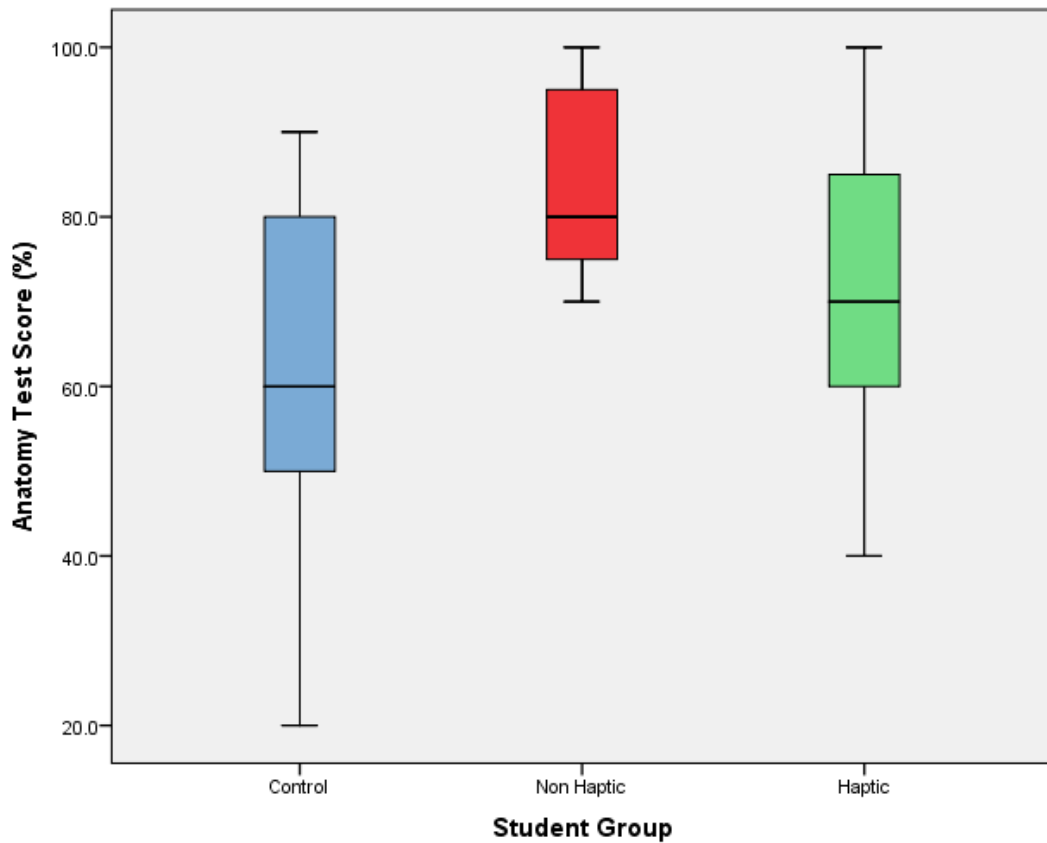
Figure 41, Box plots for phase one results for question 3

Summary of Results

Question three was a spot test consisting of ten elements. Figure 42 shows the scores for each group for all ten elements. The non-haptic group scored highest with a mean of 84.2%, followed by the haptic group with 71.4%, and finally the control group with 41.6%.
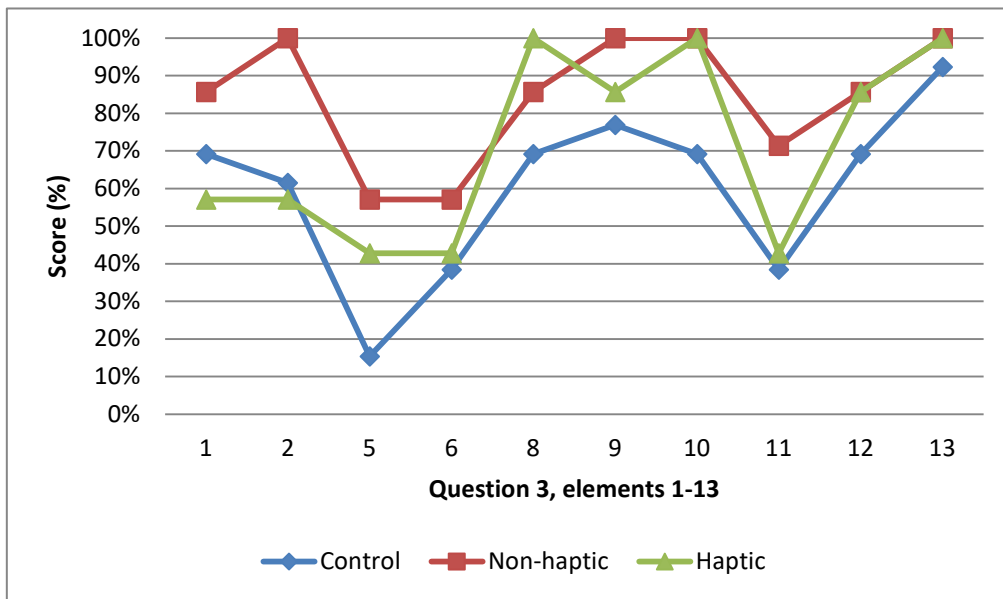
Figure 42, Graph of phase one results for question 3

Mann-Whitney U Test Results

Although the results for question three appear to be close to normal, for consistence along with the small group sizes two Mann-Whitney U tests were performed. The first Mann-Whitney U test showed that the non-haptic group scored significantly higher than the control group, scoring a p-value of 0.030. The second Mann-Whitney U test showed that the haptic group did not score significantly higher than the control group.

The medians were also calculated for each group. The control group scored 60%, the non-haptic group scored 80%, and the haptic group scored 70%.

Questions Four - Eight

Q4, Which muscle is deeper?

    a) Abductor pollicis brevis
    b) *Opponens pollicis**

Q5, What muscle lies directly lateral of flexor digitorum profundus?

    a) Palmaris longus
    b) *Flexor pollicis longus**
    c) Flexor carpi ulnaris
    d) Flexor carpi radialis

Q6, Which head of adductor pollicis is the largest?

    a) *Transverse head**
    b) Oblique head

Q7, What nerve innervates abductor digit minimi?

    a) *Ulnar n.**
    b) Radial n.
    c) Median n.

Q8, What nerve innervates the 1st and 2nd lumbricals?

    a) Ulnar n.
    b) Radial n.
    c) *Median n.**

* Correct answers in italics

Sample Characteristics

A Shapiro-Wilk test (p>.05) (Shapiro and Wilk, 1965, Razali and Wah, 2011) and a visual inspection of their histograms, normal Q-Q plots and box plots (Figure 43) showed that the test scores were not consistently normally distributed across the three groups, for questions four to eight.
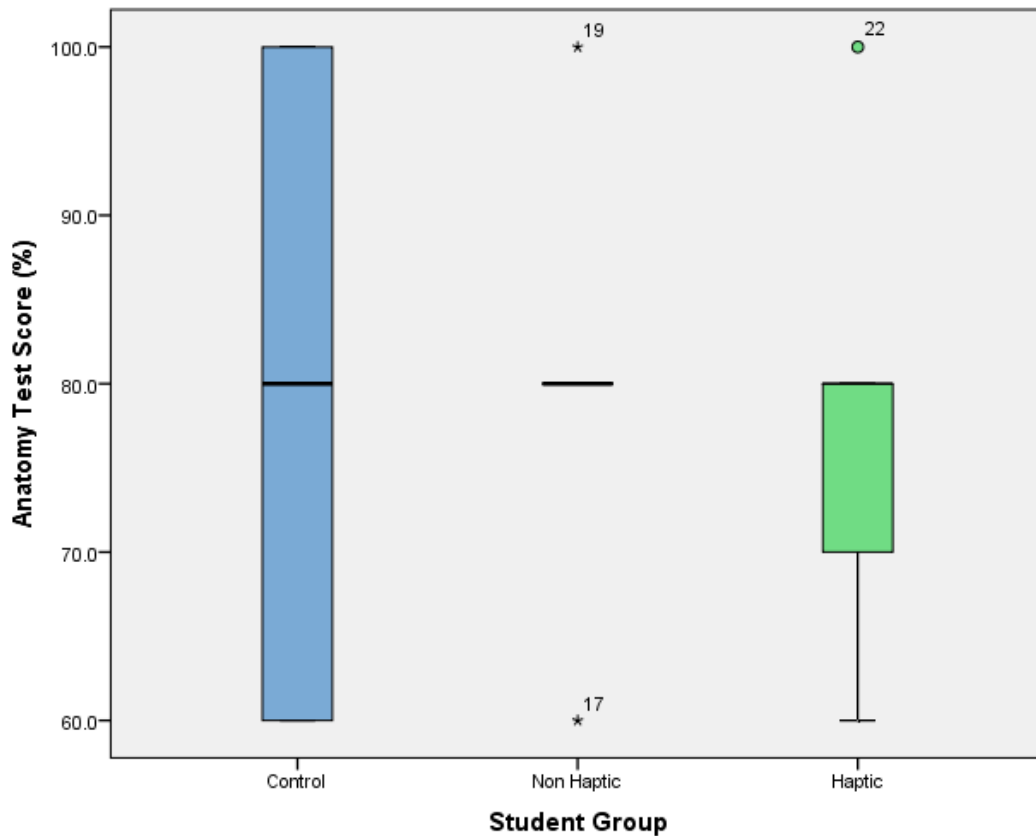
Figure 43, Box plots for phase one results for questions 4-8 (the results for the Non-haptic group appear as a flat line due to all the individuals scoring the same with the exception of the two outliers)

Summary of Results

Questions 4 to 8 were multiple-choice. Figure 44 shows the scores for each group for all four questions. The non-haptic group and the control group scored a mean (for all four questions combined) of 80% each, followed by the haptic group with 77.1%.
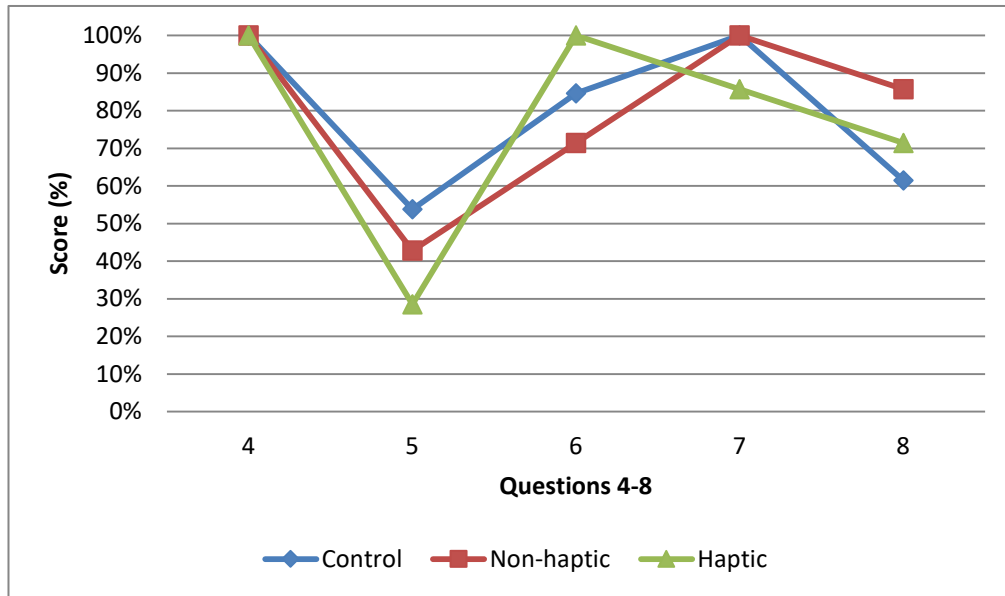
Figure 44, Graph of phase one results for questions 4-8

Mann-Whitney U Test Results

Due to the small group sizes and largely non-normal distribution a Mann-Whitney U test was performed. The first Mann-Whitney U test showed that the non-haptic group did not score significantly higher than the control group. The second Mann-Whitney U test showed that the haptic group did not score significantly higher than the control group. The medians were also calculated for each group. All groups scored the same median of 80%.

Summary of Anatomy Test Results

The means for all four question groups were combined. The non-haptic group scored highest with 80%, followed by the haptic group with 69.5%, and finally the control group with 62.8%. The means for the three spot tests were also combined with the non-haptic group scoring highest with 80%, followed by the haptic group with 68%, and finally the control group with 59.3% (Table 4). Figure 45 shows the overall means of each group per question for the anatomy test; while Figure 46 compares the means of each group overall with those for the spot tests and multiple choice questions alone. Finally Table 5 summarises the p-values for all questions in the phase one anatomy test.

Table 4, Final anatomy test results for phase one

Anatomy Test	Control	Non-haptic	Haptic
Overall Mean (Q's 1-8)	62.8%	80%	69.5%
Spot Test Mean (Q's 1-3)	59.3%	80%	68%
Multiple choice Mean (Q's 4-8)	80%	80%	77.1%
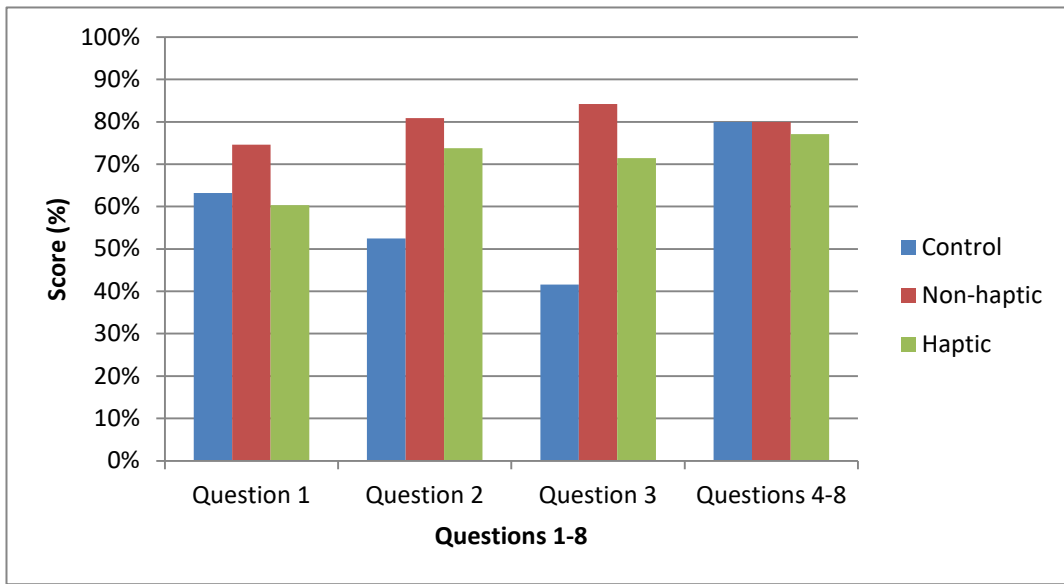
Figure 45, The overall means for each group per question of the anatomy test (phase one)
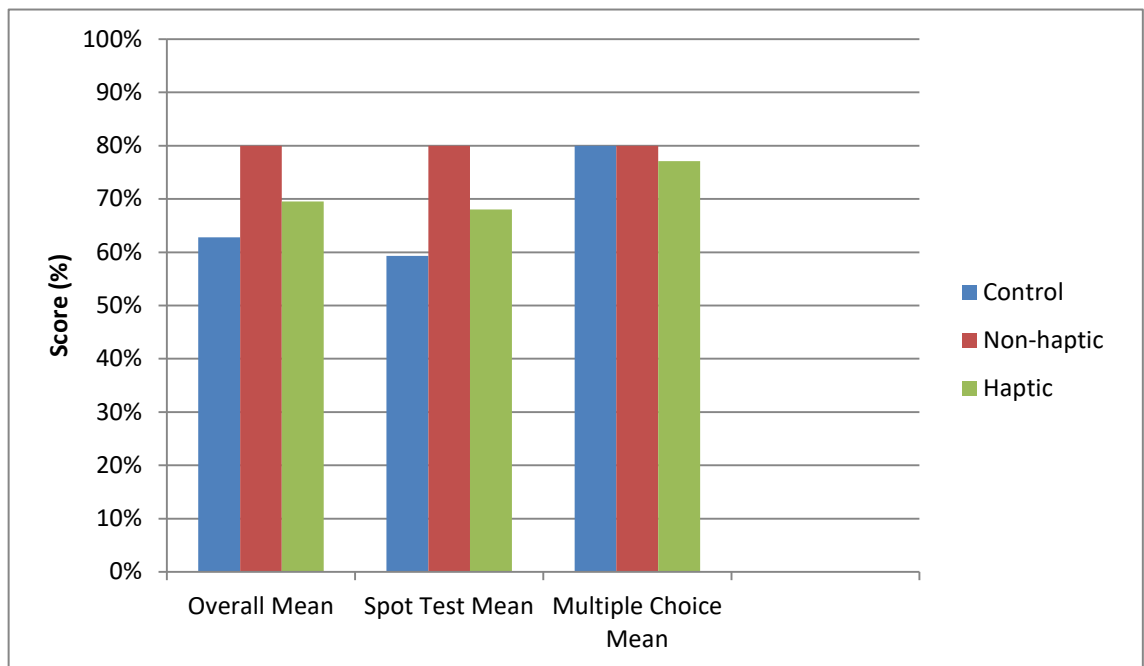
Figure 46, The means of each group overall, compared with the spot test and multiple choice style questions (phase one)

Table 5, Summary of p-values for all questions in the phase one anatomy test

Q1	Control/Non-Haptic	Control/Haptic
	0.211	0.485
Q2	Control/Non-Haptic	Control/Haptic
	0.003	0.030
Q3	Control/Non-Haptic	Control/Haptic
	0.030	0.393
Q4-8	Control/Non-Haptic	Control/Haptic
	1.000	0.757

Discussion of Anatomy Test Results

The results for each group follow a similar pattern across most of the questions as demonstrated by Figures 38, 40, 42 and 44. This indicates that some questions (discussed below) were consistently more challenging than others. Question 1C received few correct scores across all three groups receiving no correct answers from the control group. All but four of the incorrect answers were the same, 'opponens pollicis' (the correct answer being flexor pollicis brevis [deep head]). Opponens pollisis is a similar sized muscle in the same general vicinity as flexor pollicis brevis so it is possible to see how a student could get these two structures confused.

Questions 1G received no correct answers from either the control or non-haptic groups. While a range of (incorrect) answers were given, the majority opted for either 'median nerve' or 'lumbrical' (the correct answer being common palmar digital artery.). The median nerve is a similarly sized structure in the same general vicinity as the common palmer digital artery, so it is possible to see how these two structures could be confused.

There are four lumbrical muscle in the hand, with the third and fourth (which are bipennate) occurring in this region. However, the appearance of these muscles should be quite distinct to that of an artery so confusion is unlikely. Looking at the photograph used in the anatomy test it is possible that these students thought the letter 'g' was above a different structure, as the fourth lumbrical is only a couple of millimetres away.

These questions and their responses were discussed with an anatomy lecturer (Lamb, personal communication) to understand the reasons behind the poor results. It was suggested that students may be struggling to identify these structure as in each case they are quite small and difficult to identify from visual inspection of the surrounding structures alone. It is possible to achieve the correct the answer however, especially if students follow the structure to its insertion. The habit of relying on surrounding structures for identification rather than taking the time to trace the path of the structure is something that has also been observed in practical anatomy spotter exams (Lamb, personal communication).

Question 2C received consistently low scores for the control groups, while the haptic and non-haptic groups scored higher. While there were a range of (incorrect) answers given, the majority opted for the tendon of extensor indices. The correct answer is the 2nd metacarpal and on re-assessment of the image it can be seen how this could be quite unclear. The tendon of extensor indices passes along the 2nd metacarpal and due to the light reflected in this image in could be unclear as to whether it is bone or tendon being depicted.

Question 3.5 also received consistently low scores for the control groups, while the haptic and non-haptic groups scored higher. There was a wide range of (incorrect) answers given, with extensor carpi radialis longus and extensor carpi ulnaris being the most frequent. Extensor carpi radialis longus is a similarly sized muscle next to the correct

answer of extensor carpi radalis brevis, so it is possible to see how these two muscles could be confused. However extensor carpi ulnaris is on the opposite side of the wrist and is more difficult to explain. Discussing these results with an anatomy lecturer (Lamb, personal communication) it was suggested that confusion may have arisen due to this particular image not containing a thumb or the fifth digit (it is a close up photograph) thus making it difficult to orientate structures.

Questions one and two used photographs taken by the author of a dissection. Question three used an image provided by the MSc Human Anatomy lecturer. This image was already labelled 1 – 13. However, the image was cropped for the purposes of this study resulting in numbers 3, 4 and 7 being omitted. With hindsight it may have been preferable not to have cropped this image as this may have led to some confusion regarding its orientation as useful landmarks such as the thumb were missing. Alternatively the medial and lateral side of the image could have been labelled. It would also have been preferable to keep the labelling consistent, using either letters or numbers rather than both, to avoid any additional confusion.

As described above, a small number of issues became apparent for some of the questions after the first cohort of students took the test. Although the test had not been piloted prior to its use for the phase one control groups, it had been checked by two anatomy staff for its accuracy. The spot test questions (1-3) were chosen to test the student's ability to correctly identify a variety of anatomical structures, all of which were included in the model. The multiple choice style questions (4-8) were included to test how well students could recall the spatial relationships of structures. As a number of the issues described above relate to the quality of the images it may have been better to use actual prosections rather than photographs. However, once the test had been used on the first group it was not possible to make any changes as this would have impacted the ability to make comparisons across the groups. As the test results did not contribute to the

student's grade this was not considered to be a significant issue as it would affect all groups equally.

As the groups consisted of small numbers of students (between seven and thirteen in each) from different years, there remains the possibility that the differences seen are due to differences in individual ability. To explore this further the results were compared with the average grades for each group in the Gross Anatomy (GA) one module. The control years combined (2011/2012) scored an A3, the non-haptic year (2013) scored an A2, and finally the haptic group (2014) scored an A3. An A2 grade is equivalent to 80-89% while an A3 is equivalent to 70-79%. There is therefore a difference of approximately 10% between these two grades. The percent differences for the three significant results were as follows:

Question 2: Control/Non-haptic – 28.4%

Question 3: Control/Non-haptic – 42.6%

Question 2: Control/Haptic – 21.3%

This comparison indicates that while the non-haptic group (2013) did score slightly higher than the other groups for GA1 the difference is not as large as that seen for these results.

The non-haptic group scored significantly higher than the control for two out of the four question groups, while the haptic group only scored significantly higher once. This is in contradiction to the initial hypothesis which suggested that the haptic group would score highest, followed by the non-haptic group and finally the control. Some insight as to why this might be is given is the feedback comments where a number of students suggested that while the haptic feedback device was interesting to use, it might actually be a barrier to learning. One student commented:

"I found the haptic device difficult to use, the tool kept getting stuck inside the hand and the resistance made me tire quickly and my wrist sore. After a short time with the device I resorted to using the mouse and keyboard and clicking through the layers."

Another said:

"I used the mouse and keyboard when I was having difficulties with the haptic interface. This therefore improved my experience and made using the software easier."

Cognitive Load Theory (CLT) could go some way to explaining why the haptic interface may have been a barrier to learning rather than enhancing it. As discussed in the introduction CLT describes three types of cognitive load, intrinsic, extraneous and germane. While the educator can do little to impact the intrinsic load (with the exception of segmenting learning into discreet packages) they should be aiming to reduce the extraneous and promote the germane loads (Verhoeven et al., 2009). In this instance, learning to first use an additional piece of novel hardware (i.e. the haptic device) in order to learn anatomy from a 3D digital model could be considered extraneous load.

In addition, the 'split-attention' effect may also have impacted the students learning. As described in the introduction this can occur when the learner's attention is split between two or more sources of visual information that must to be combined for full understanding (and cannot be understood in isolation). This is often the case when learning to use a new piece of software and/or hardware. The mental integration required in learning to operate a technical device (such as a haptic feedback device) from a spatially separated paper manual, while simultaneously looking at the computer screen could certainly impose a considerable cognitive load on working memory (Schnotz and Kürschner, 2007). This effect could likely be reduced if users first spent time learning only how to use the haptic hardware thus making this a part of their prior knowledge base before using the system to learn anatomy.

In this study all students used the software for less than 5 hours. From personal observation this appeared to be a combination of learning to use the haptic device, navigating the software interface, and dissecting and learning from the model simultaneously. The cognitive load may have been further reduced had the software interface been a bespoke design to better integrate with the model and dissection task. As it was, the interface was essentially that of the modelling software, Geomagic Freeform, albeit with as many extraneous windows and tools minimised as possible.

Despite this there were also a number of positive comments regarding the haptic interface:

"It was odd to get used to the resistance and being able to feel the surfaces, but it helped to make (me) realise that it was 3D and the thumb structures would be more anteriorly placed."

"The haptic interface took some getting used to, but was quite helpful. You can 'feel' the tissue."

"I like the haptic interface. Good for learning dissection experience."

"It was useful to be able to feel what was being dissected. Also felt more like using the dissection tools."

Traditional dual-coding theory relates to the visual and verbal (auditory) channels, with each having a maximum load that it can process. When they are paired however (for example animation and narration) not only does this prevent too much load in the visual channel, but it also allows the brain to process and synthesize information from two different sources (Mayer and Mureno, 2002).

Until recently, the combination of visual and haptic modalities had not been explored. It had been suggested that they were both processed through the visual channel, and that

haptic information may therefore compete with visual information for the same memory resources (Kerzel, 2001). However, research by Seaborn et al (Seaborn et al., 2010) has shown no such bottleneck between visual and haptic processing for simple tasks such as pattern-matching. While their research showed no significant difference between the visual and visual+haptic modes, the results did indicate a strong user preference for the coupling of visual and haptic modalities. This suggests that working memory is not hampered by using both visual and haptic channels, and that recall may be strengthened by dual-coding both visual and haptic modes.

There are a number of more recent studies looking at the combination of haptic and visual or auditory modalities to enhance human computer interaction (HCI) (Israr et al, 2012 and 2014, Yannier, 2015). Israr et al (2014) for example explore the combination of haptic 'feel effects' with storytelling (in movies, games, rides etc). They define a feel effect as 'an explicit pairing between a meaningful linguistic phrase and a rendered haptic pattern'. They have designed a vocabulary of haptic effects that have been shown to produce the anticipated sensation for the majority of test users.

This is promising for many areas where the use of a haptic modality is particularly appropriate to the subject matter, such as 3D virtual anatomy and dissection. For future studies or integration into teaching it may be advantageous to encourage participants/students to spend longer learning how to use the hardware and software prior to its use for learning anatomy.

4.2 COMPARISON OF PHASE TWO RESULTS

The second set of results was from BSc students. This data was collected during 2014 only. The 4th year students acted as a control group (they had dissected the hand and wrist the previous year and been given a week for revision prior to the test) and the 3rd years had access to the haptic-enabled version for two weeks prior and one week after dissection. The control group consisted of seven students while the haptic group consisted of fourteen students. In order to maximise group size there was no non-haptic group in this phase. For individual results see appendix 7.

Anatomy Test: Comparison of Results for Phase Two Students

Questions one to three were anatomy 'spotter tests' where the student had to identify the labelled structures. Questions four to eight were multiple choice style questions. The anatomy test was the same as that used for phase one. Figures 48, 50, 52 and 54 compare the scores for each question from the anatomy test. Statistical analysis was subsequently performed using the Mann-Whitney U test. The results of the control and haptic groups were compared. The results from individual students were used for the statistical analysis.

Question One

Sample Characteristics

A Shapiro-Wilk test (p>.05) (Shapiro and Wilk, 1965, Razali and Wah, 2011) and a visual inspection of their histograms, normal Q-Q plots and box plots (Figure 47) showed that the test scores were broadly normally distributed across the two groups, for question one.

Figure 47, Box plots for phase two results for question 1

Summary of Results

Question one was a spot test consisting of nine elements. Figure 48 shows the scores for each group for all nine elements. The haptic group scored highest with a mean of 52.3%, followed by the control group with a mean of 39.7%.

Figure 48, Graph of phase two results for question 1

Mann-Whitney U Test Results

Although the results for question one appear to be close to normal, for consistency along with the small group sizes a Mann-Whitney U test was performed. The test showed that the haptic group did not score significantly higher than the control group.

The medians were also calculated for each group. The control scored 44.4%, while the haptic group scored 55.5%.

Question Two

Sample Characteristics

A Shapiro-Wilk test (p>.05) (Shapiro and Wilk, 1965, Razali and Wah, 2011) and a visual inspection of their histograms, normal Q-Q plots and box plots (Figure 49) showed that the test scores were not consistently normally distributed across the two groups, for question two.
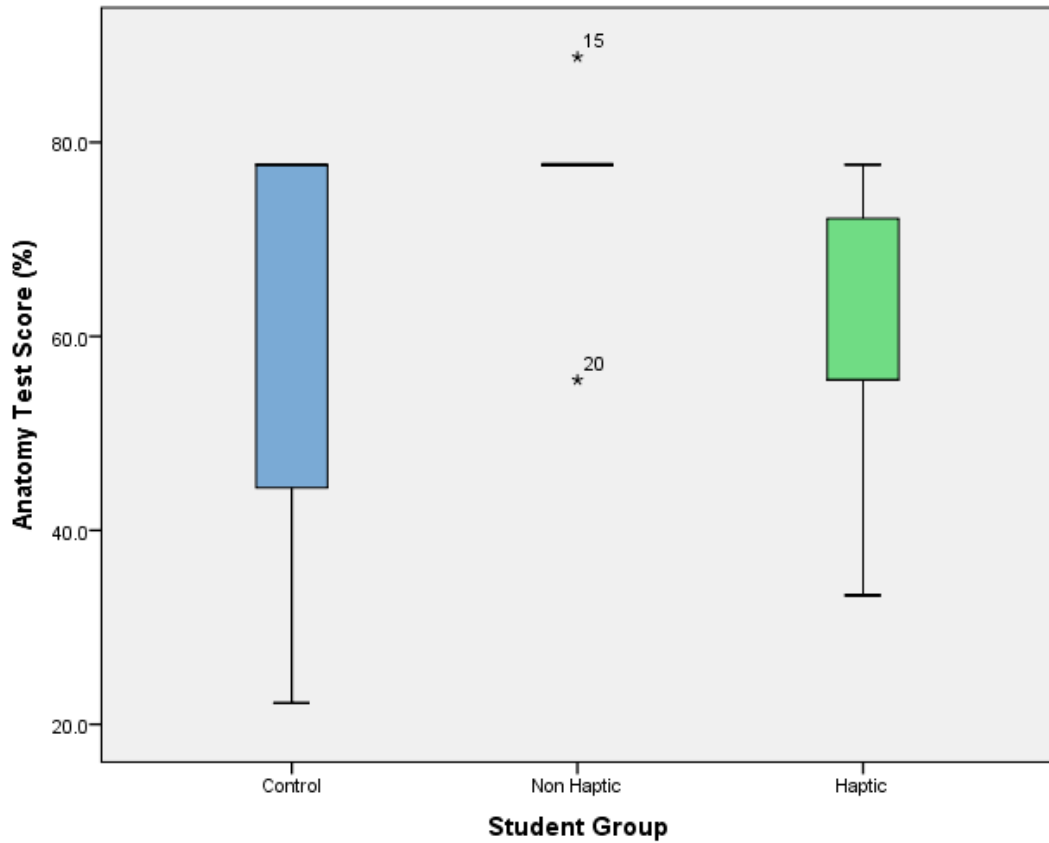

Figure 49, Box plots for phase two results for question 2 (the results for the Control group appear as a flat line due to all the individuals scoring the same with the exception of the one outlier)

Summary of Results

Question two was a spot test consisting of six elements. Figure 50 shows the scores for each group for all six elements. The haptic group scored highest with a mean of 54.7%, followed by the control group with 19%.

Figure 50, Graph of phase two results for question 2

Mann-Whitney U Test Results

Due to the small group sizes and largely non-normal distribution a Mann-Whitney U test was performed. The test showed that the haptic group scored significantly higher than the control group, scoring a p-value of 0.004.

The medians were also calculated for each group. The control scored 16.6%, while the haptic group scored 58.3%.

Question Three

Sample Characteristics

A Shapiro-Wilk test (p>.05) (Shapiro and Wilk, 1965, Razali and Wah, 2011) and a visual inspection of their histograms, normal Q-Q plots and box plots (Figure 51) showed that the test scores were broadly normally distributed across the two groups, for question three.

Figure 51, Box plots for phase results for question 3

Summary of Results

Question three was a spot test consisting of ten elements. Figure 52 shows the scores for each group for all ten elements. The haptic group scored highest with a mean of 45.7%, followed by the control group with 38.5%.
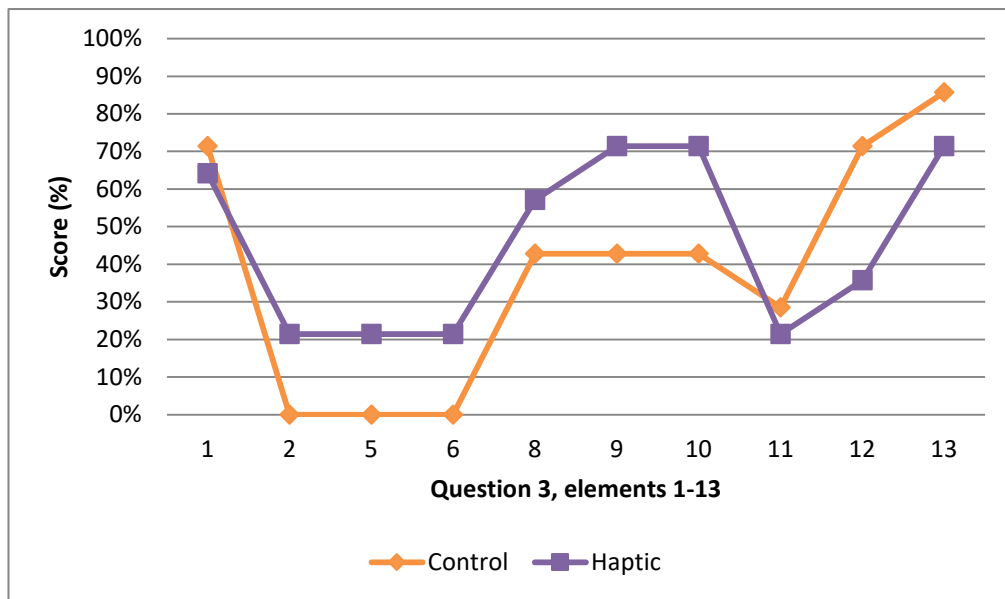
Figure 52, Graph of phase results for question 3

Mann-Whitney U Test Results

Although the results for question three appear to be close to normal, for consistency along with the small group sizes a Mann-Whitney U test was performed. The test showed that the haptic group did not score significantly higher than the control group.

The medians were also calculated for each group. Both groups scored 50%.

Questions Four - Eight

Sample Characteristics

A Shapiro-Wilk test (p>.05) (Shapiro and Wilk, 1965, Razali and Wah, 2011) and a visual inspection of their histograms, normal Q-Q plots and box plots (Figure 53) showed that the test scores were not consistently normally distributed across the two groups, for questions four to eight.
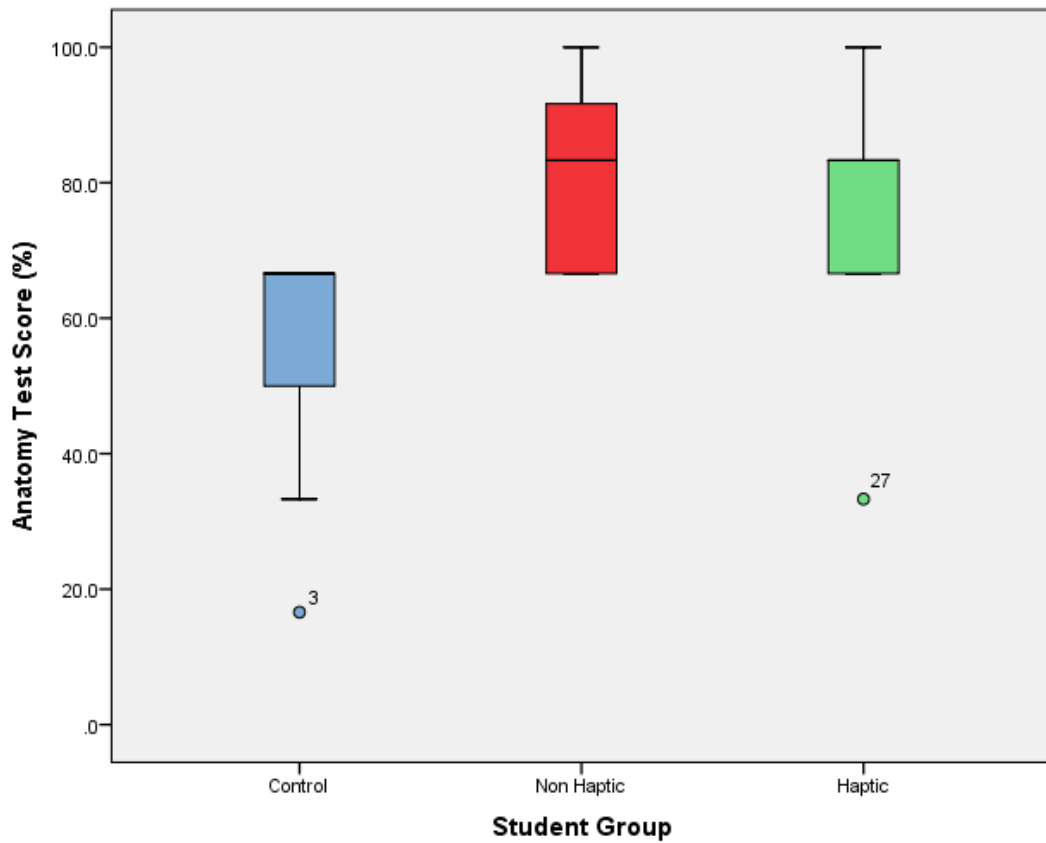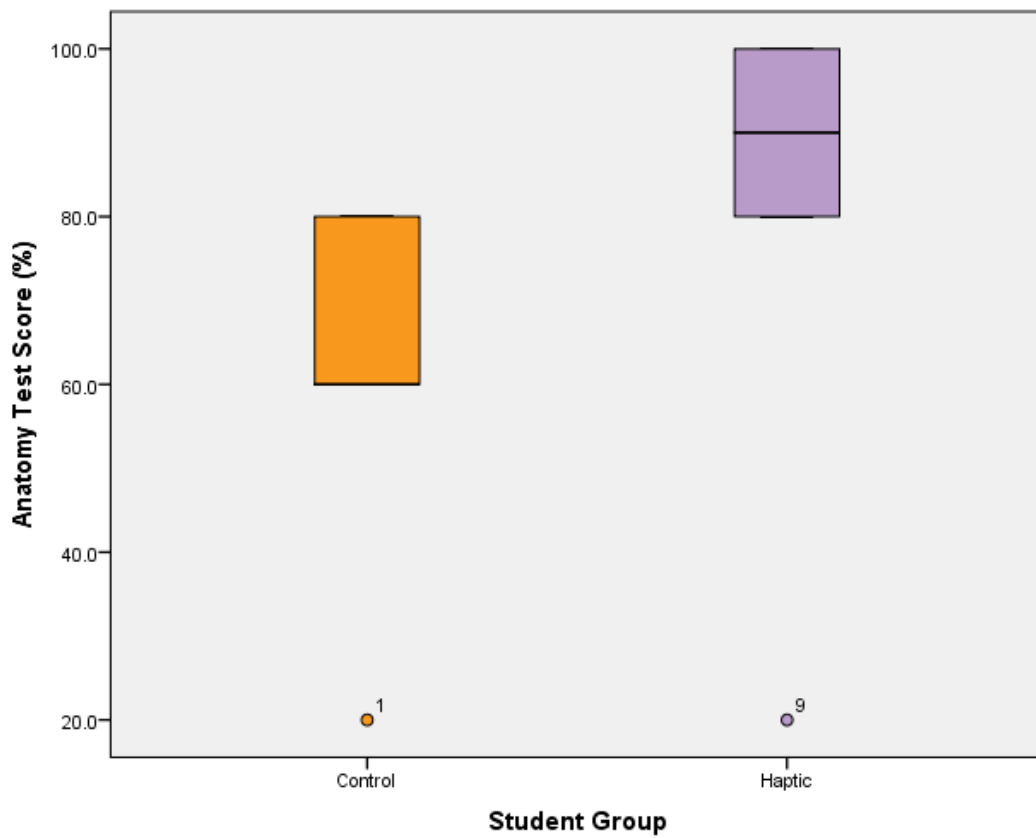

Figure 53, Box plots for phase results for questions 4-8

Summary of Results

Questions 4 through 8 were multiple-choice. Figure 54 shows the scores for each group for all four questions. The haptic group scored highest with a mean (for all four questions combined) of 82.8%, followed by the control group with 62.8%.
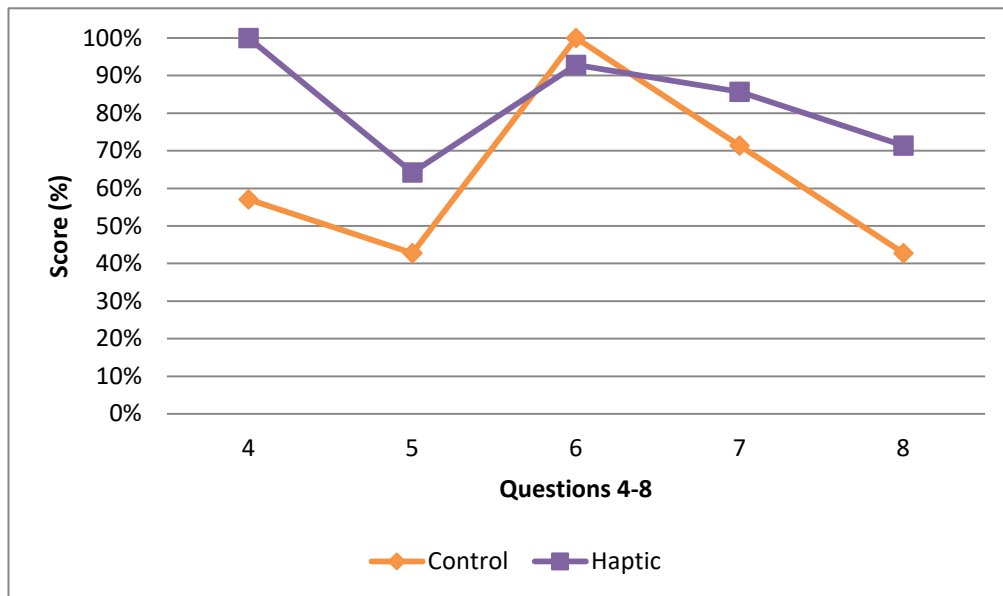
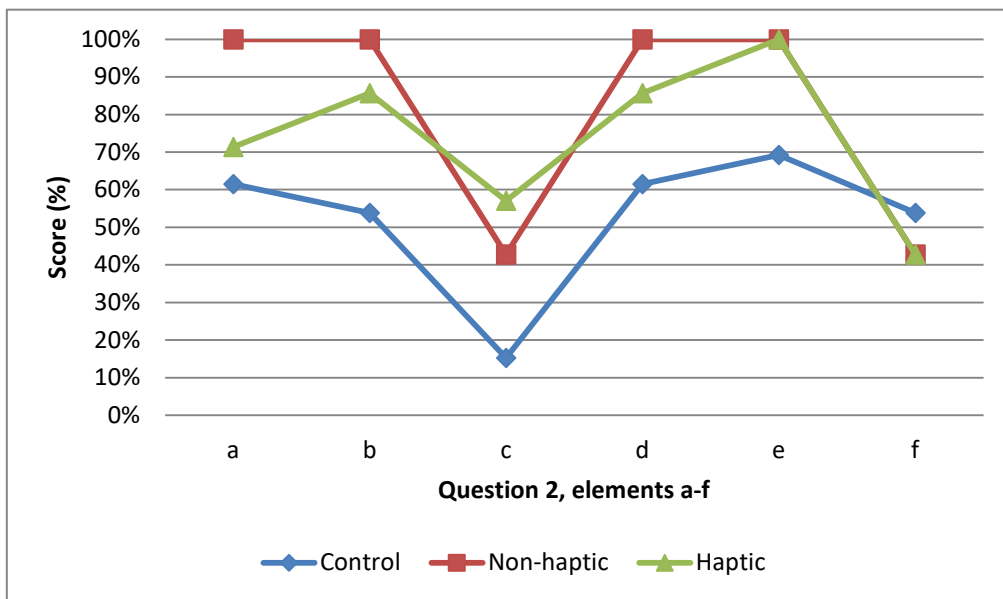**Figure 54,** Graph of phase results for question 4

Mann-Whitney U Test Results

Due to the small group sizes and largely non-normal distribution a Mann-Whitney U test was performed. The test showed that the haptic group scored significantly higher than the control group, scoring a p-value of 0.010.

The medians were also calculated for each group. The control scored 60%, while the haptic group scored 90%.

Summary of Anatomy Test Results

The means for all four question groups were combined. The haptic group scored highest with 55.7%, followed by the control group with 39%. The means for the three spot tests were also combined with the haptic group scoring highest with 50.2%, followed by the control group with 34.2% (Table 6). Figure 55 shows the overall means of each group per question for the anatomy test; while Figure 56 compares the means of each group overall with those for the spot tests and multiple choice questions alone. Finally Table 7 summarises the p-values for all questions in the phase two anatomy test.

Table 6, Final anatomy test results for phase two

Anatomy Test	Control	Haptic
Overall Mean (Q's 1-8)	39%	55.7%
Spot Test Mean (Q's 1-3)	34.2%	50.2%
Multiple choice Mean (Q's 4-8)	62.8%	82.8%
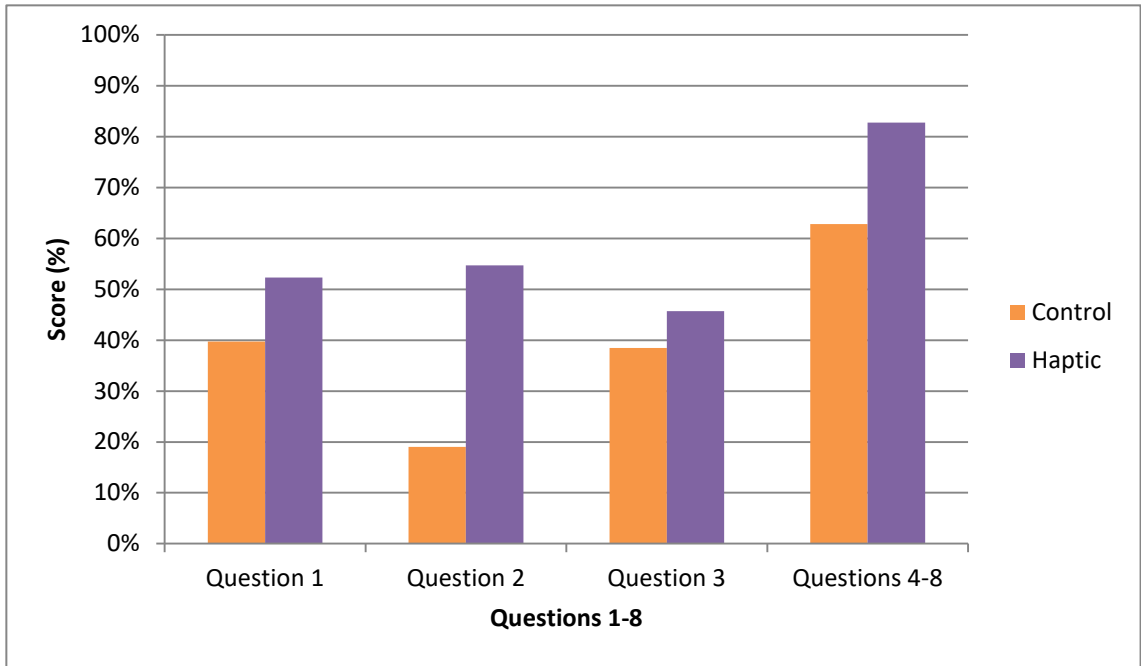
Figure 55, The overall means for each group per question of the anatomy test (phase two)

Figure 56, The means of each group overall, compared with the spot test and multiple choice style questions (phase two)

Table 7, Summary of p-values for all questions in the phase two anatomy test

Q1	Control/Haptic 0.149
Q2	Control/Haptic 0.004
Q3	Control/Haptic 0.689
Q4-8	Control/Haptic 0.010

Discussion of Anatomy Test Results

The results for both groups follow a similar pattern across most of the questions as demonstrated by Figures 48, 50, 52 and 54, with the haptic group scoring higher for each question total. This indicates that some questions (discussed below) were consistently more challenging than others. Question 1C scored consistently poorly across both groups receiving only one correct answer from the control group. All of the incorrect answers were the same, 'opponens pollicis' (the correct answer being flexor pollicis brevis [deep head]). This is same answer that was most frequently given by the students in phase one. Opponens pollicis is a similar sized muscle in the same general vicinity as flexor pollicis brevis so it is possible to see how a student could get these two structures confused.

Question 1D was answered incorrectly by the entire control group (while six (42.8%) out of fourteen of the haptic group answered correctly). The two most common (incorrect) answers were 'flexor digitorum longus' and 'flexor digitorum indicis' (the correct answer

being flexor digitorum superficialis'). Flexor digitorum longus was the answer most commonly given by the control group and actually refers to a muscle of the leg. The time between the control group having dissected the hand and taking the anatomy test may have resulted in them becoming confused between the similarly named structures of the upper and lower limbs. 'Flexor digitorum indicis' was the most frequent incorrect answer from the haptic group and is not a recognised muscle name. It appears to be a combination of other muscle names such as flexor digitorum superficialis and extensor indicis. As for the previous answer it appears that confusion surrounding the similar names of many muscles was a factor here.

Question 1E was answered incorrectly by all but one for the control group (while five (35.7%) out of fourteen of the haptic group answered correctly). The most frequent answer was 'flexor digitiorum brevis' (the correct answer being the tendon of flexor digitorum profundus) which is a muscle of the foot. As stated previously, the time between the control group having dissected the hand and taking the anatomy test may have resulted in them becoming confused between the similarly named structures of the hand and foot.

Question 1G was answered incorrectly by almost everyone (receiving no correct answers from the control or groups, and only three (21.4%) correct answers from the haptic group). While a range of (incorrect) answers were given, the majority opted for 'radial nerve' (the correct answer being common palmar digital artery). While the radial nerve is a similarly sized structure, it is located lateral to the common palmar digital artery, so these should not be confused.

Questions 2B, 2C, 2D, and 2F scored zero in all cases except 2B where there was one correct answer from the control group. The haptic group performed better with a minimum of five correct answers (35.7%) or higher for each. For question 2B the most

frequent (incorrect) answer was 'lumbrical' (the correct answer being dorsal interosseus (4th). While the lumbrical muscles are similarly sized and occur in the same general location as the dorsal interosseous muscles, they are visible on the palm of the hand rather than the dorsum. It may be that some students failed to consider the wider context of the image and surrounding structures which clearly indicate that this is the dorsum of the hand.

For question 2C there was a wide range of (incorrect) answers including; 'extensor indicis', 'extensor digitorum brevis', and 'fascia' (the correct answer being the 2nd metacarpal). As discussed for the phase one results, the tendon of extensor indices passes along the 2nd metacarpal and due to the light reflected in this image in could be unclear as to whether it is bone or tendon being depicted. Extensor digitorum brevis is a muscle of the foot. Again, the time between the control group having dissected the hand and taking the anatomy test may have resulted in them becoming confused between the similarly named structures of the hand and foot.

For question 2D there were a wide range of (incorrect) answers with the most common being 'extensor pollicis' and 'abductor pollicis', with two individuals also leaving it blank (the correct answer being the first dorsal interosseus). There are two extensor pollicis muscles, brevis and longus. While the tendons of both of these muscles do go close to the region of the image labelled 'd', they would usually appear more tendonous rather than the muscles depicted in the image. It is difficult to see how such a mistake could be made other than to suggest that the students were trying to remember the names of any structures in the vicinity. Abductor pollicis is a similarly sized (although a little larger) muscle in the same general region as the first dorsal interosseous muscle, so it is easier to understand how these could be confused. It should be possible to tell these muscles apart as their muscle fibres run in different directions. However on further investigation

of the image, it can be seen that the muscle fibres are not very clear which may have added to the confusion.

For question 2F there was again a wide range of (incorrect) answers including; 'abductor pollicis brevis', 'flexor pollicis longus', 'extensor pollicis longus', and 'extensor pollicis brevis' (the correct answer being abductor pollicis longus). Abductor pollicis brevis, while sharing a very similar name is a small muscle of the thenar eminence, whereas abductor pollicis longus is a larger muscle of the forearm, the tendon of which inserts on the first metacarpal. It seems likely therefore that this was a mistake between similar names rather than a mistake between structures. Flexor pollicis longus is a similarly sized muscle but on the opposite (posterior) side of the forearm. The tendon of extensor pollicis longus does run close to that of abductor pollicis longus, however it is sufficiently medial to avoid confusion in most cases. Finally, the tendon of extensor pollicis brevis does run extremely close to that of abductor pollicis longus and it is easy to understand how these two structures could be confused.

The control group also could not answer questions 3.2, 3.5 and 3.6 correctly. The haptic group only gave three correct answers (21.4%) for each. The most frequent (incorrect) answer for question 3.2 was 'extensor pollicis brevis' (the correct answer being abductor pollicis longus). As discussed for question 2F, the tendon of extensor pollicis brevis does run extremely close to that of abductor pollicis longus and it is easy to understand how these two structures could be confused.

The majority (71%) of the control group did not attempt question 3.5. The two answers that were given were 'flexor digitorum profundus' and 'flexor carpi radialis' (the correct answer being extensor carpi radialis brevis). Both flexor digitorum profundus and flexor carpi radialis are large muscles on the anterior of the forearm, whereas the tendon of

extensor carpi radialis brevis is on the dorsum of the hand. As discussed in the section 4.1, this is likely a result of the lack of orienting features such as the thumb or fifth digit.

Finally question 3.6 was left blank by all but one of the control group who answered 'flexor carpi radialis' (the correct answer being extensor carpi radialis longus). Both flexor carpi radialis and extensor carpi radialis longus are similarly sized muscles of the forearm. However, as with the previous question they occur on opposite sides of the forearm and therefore should not easily be confused. It is likely therefore that it was the close cropping of the image that was detrimental to this question.

As discussed in for phase one, a number of the issues described above relate to the quality of the images. This could have been addressed by using prosections rather than photographs. However, once the test had been used on the first group it was not possible to make any changes. As the results did not impact the student's grade this was not considered to be significant as it would affect all groups equally.

Discussing the results for question three with an anatomy lecturer (Lamb, personal communication) it was suggested that confusion may have arisen due to this particular image not containing a thumb or the fifth digit (it is a close up photograph) thus making it difficult to orientate structures. That said, it should still be possible to tell that is the dorsum of the hand from the available information. As discussed for phase one, with hindsight it may have been preferable not to have cropped this image as this may have led to some confusion regarding its orientation.

There were a small number of questions where the control group scored higher than the haptic group: Question 1H and 1I (adductor pollicis (transverse head) and adductor pollicis (oblique head)), question 2a (abductor digiti minimi), question 3.1 (abductor digiti minimi), 3.12 (extensor pollisis longus) and 3.13 (extensor retinaculum), and question 6 (Q: Which head of adductor pollicis is the largest? A: Transverse head). Why

this should be the case is unclear. There is nothing unusual about these particular questions and the structures are all clear on the images.

As the groups consisted of small numbers of students (between seven and fourteen in each) from different years, there remains the possibility that the differences seen are due to differences in individual ability. To explore this further the results collected here were compared with the average grades for each group in the Gross Anatomy (GA) one module. The control group (2014, 4th years) scored a B2, and the haptic group (2014, 3rd years) scored an A3. An A3 grade is equivalent to 70-79% while a B2 is equivalent to 63-65%. There is therefore a difference of 5-16% between these two grades (a mean of 10.5%). The percent differences for the two significant results were as follows:

Question 2: Control/Haptic – 35.7%

Question 4-8: Control/Haptic – 20%

This comparison indicates that while the haptic group (2014, 3rd years) did score slightly higher than the control group for GA1 the difference is not as large as that seen for these results.

These results support the hypothesis that the haptic group would perform better than the control. There was no non-haptic group in this phase. It was proposed in the discussion of the phase one results that the haptic device could potentially be 'getting in the way' of student learning by overloading their working memory (as per Cognitive Load Theory). Whether this was the case here is difficult to say with no non-haptic group for comparison. However feedback does suggest that this may have been the case for some students at least. Feedback comments included:

"Much more like dissection but a little confusing."

"I think it was more interesting to use, but when I was using it, one was not working perfectly and the other was not working at all, so it felt like the haptic interface was almost slowing everything down. However if everything was working smoothly I'm sure it would have been more useful than using just keyboard and mouse."

"I did try to use the haptic interface, but I feel I would need much more time with it in order to be quite confident using it."

"It took a long time to get used to the haptic device."

"The haptic interface was useful in terms of 3D structure of the model, however I found it very easy to go through the hand – making it more difficult to dissect. I definitely think that using the haptic tool improved the software though."

"Sometimes difficult to control the haptic device. Was interesting to feel the different movements at first but when I wanted to really study the structures I found it quite frustrating using the device and returned to the keyboard."

However there were also a large number of comments suggesting that for some the addition of the haptic device was helpful and engaging:

"Very hands on experience, probably more fun than keyboard."

"Instead of struggling with the keyboard you could just go and 'do' without having to think much."

"It was good to physically feel the difference and where you were 'cutting'."

"The haptic interface was very useful as you could literally feel as you were dissecting, and different layers felt differently. This aided real life dissection."

"It was bizarre, but made the dissection more lifelike."

"The haptic interface was useful in terms of 3D structure of the model, however I found it very easy to go through the hand – making it more difficult to dissect.   I definitely think that using the haptic tool improved the software though."

"It was good to be able to 'feel' the cadaver and it probably helped my dissection skills."

From the above comments, it appears that some students found the haptic device more intuitive and easy to use than others. This could be related to the individual's spatial ability as well as prior exposure to 3D computer models either via gaming, apps, or modelling software. This information was not recorded for this study but would be worth including in future research.

Previous studies (Rochford, 1985, Lufler et al., 2012) have found that anatomical knowledge involves spatial reasoning in three dimensions and that those students who perform worse in spatial exercises tend to score significantly lower in practical anatomy examinations and vice versa.   Studies have shown that this is the case both when learning from traditional static models (Rochford, 1985, Lufler et al., 2012) as well as from dynamic visualizations of 2D or 3D models (Garg et al., 1999, Huk, 2006, Luursema et al., 2008, Stull et al., 2009, Berney et al., 2015)

In relation to Cognitive Load Theory, Huk (2006) found that while students with a high spatial ability benefited from interactive 3D models, those with low spatial ability did not. When asked, the high spatial ability students reported their (perceived) cognitive load to be low whereas the opposite was true for low spatial ability students. This suggests that students with low spatial ability may have been cognitively overloaded by the presence of 3D interactive models, while the high spatial ability students benefited from them as their total cognitive load remained within working memory limits.

Comparison with Phase One Results

Overall, the MSc groups (phase one) scored higher than the BSc groups (phase two) (Figure 57). This is to be expected as they are studying at a higher level and have already completed an undergraduate program. It is interesting to note however, that the haptic BSc group scored better than the MSc control group for all question groups with the exception of question one. The haptic BSc group also scored the highest of all groups for multiple choice questions 4-8, although these differences do not appear to be significant.
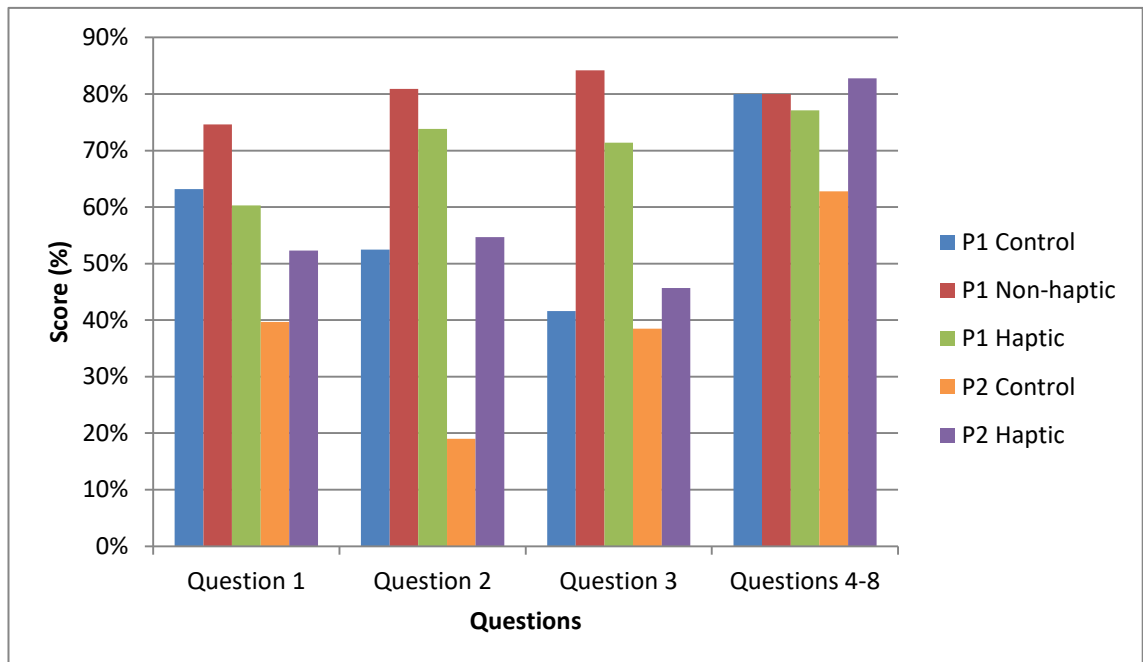
Figure 57, Graph comparing the anatomy test scores for questions 1-4 for phases one and two.

4.3 COMPARISON OF PHASE THREE RESULTS

The third set of results was from BSc students. This data was collected during 2015 only. The 4th year students acted as a control group. Only those who had not participated the previous year were invited to take part. The 3rd years were split into two groups at random. One group had access to the non-haptic version, the other to the haptic-enabled version for two weeks prior and one week after dissection. The control group consisted of twenty five students, while the non-haptic group consisted of six students, and haptic group of six students. Five students were omitted from the control results and one from the non-haptic results however as they left over 40% of the questions unanswered. For individual results see appendix 8.

Anatomy Test: Comparison of Results for Phase Three Students

Questions one to three were anatomy 'spotter tests' where the student had to identify the labelled structures. Questions four to eight were multiple choice style questions. The anatomy test was the same as that used for phases one and two. Figures 59, 61, 63 and 65 compare the scores for each question from the anatomy test. Statistical analysis was subsequently performed using the Mann-Whitney U test. The results of the control and haptic groups were compared. The results from individual students were used for the statistical analysis.

Question One

Sample Characteristics

A Shapiro-Wilk test (p>.05) (Shapiro and Wilk, 1965, Razali and Wah, 2011) and a visual inspection of their histograms, normal Q-Q plots and box plots (Figure 58) showed that the test scores were not consistently normally distributed across the three groups, for question one.
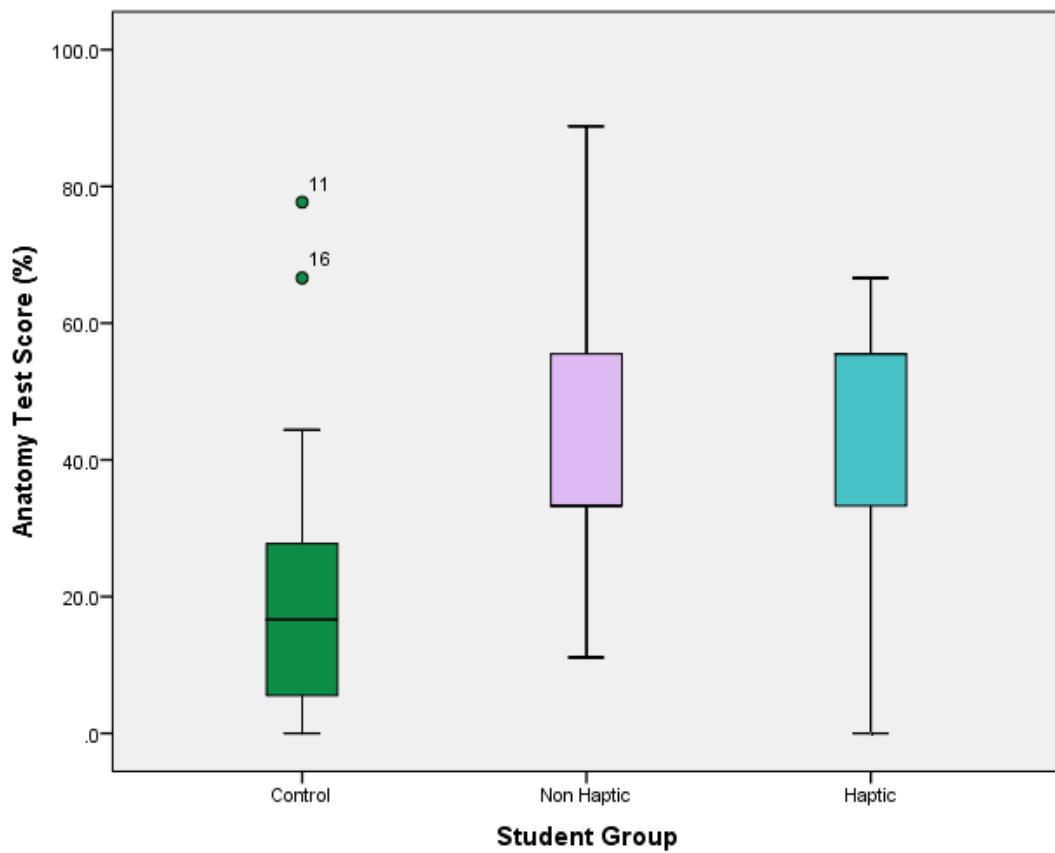
Figure 58, Box plots for phase three results for question 1

Summary of Results

Question one was a spot test consisting of nine elements. Figure 59 shows the scores for each group for all nine elements. The non-haptic group scored highest with a mean of 46.6%, followed by the haptic group with a mean of 44.4%, and finally the control group with a mean of 21.6%.
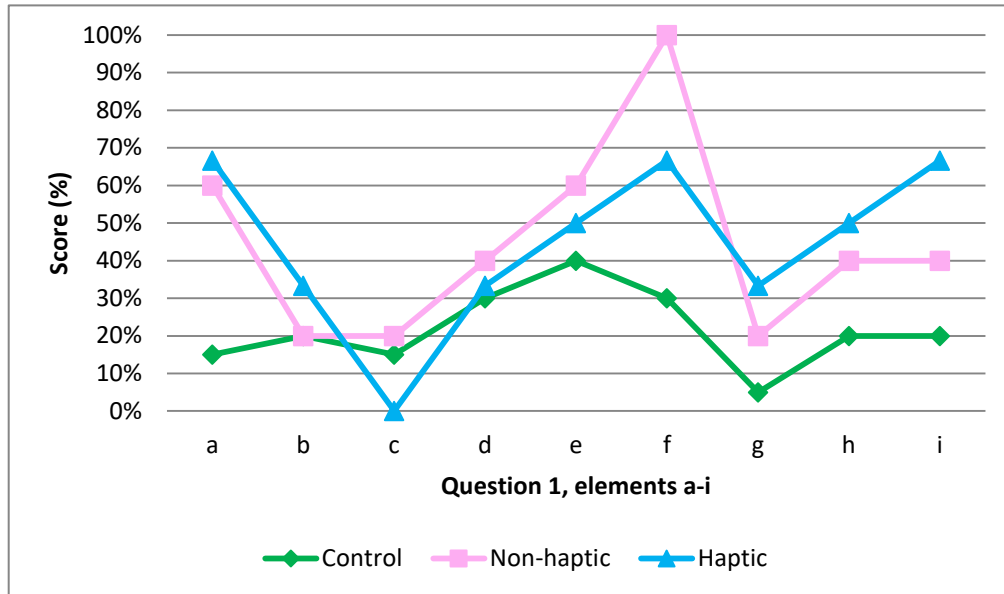
Figure 59, Graph of phase three results for question 1

Mann-Whitney U Test Results

Due to the small group sizes, partially non-normal distribution and to remain consistent with the previous phases, two Mann-Whitney U tests were performed. The first Mann-Whitney U test showed that the non-haptic group did not score significantly higher than the control group. The second Mann-Whitney U test showed that the haptic group did not score significantly higher than the control group.

The medians were also calculated for each group. The control group scored 16.6%, the non-haptic group 33.3% and the haptic group 55.5%.

Question Two

Sample Characteristics

A Shapiro-Wilk test (p>.05) (Shapiro and Wilk, 1965, Razali and Wah, 2011) and a visual inspection of their histograms, normal Q-Q plots and box plots (Figure 60) showed that the test scores were not consistently normally distributed across the three groups, for question two.
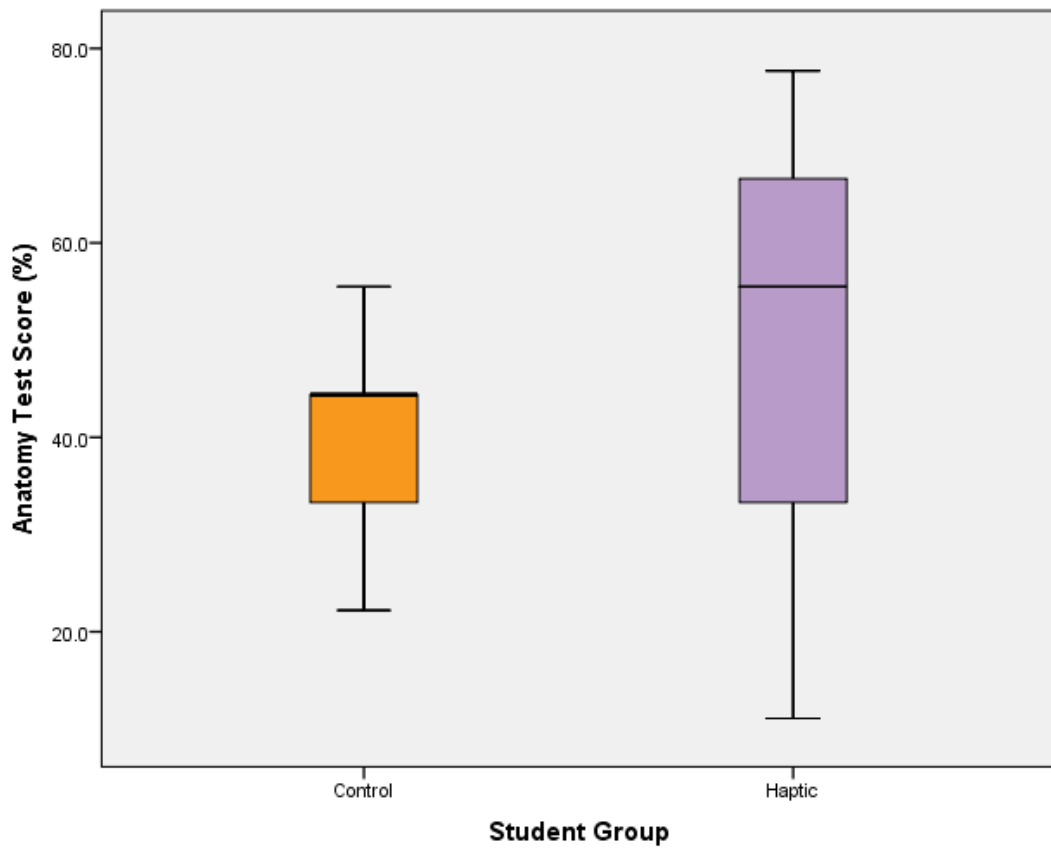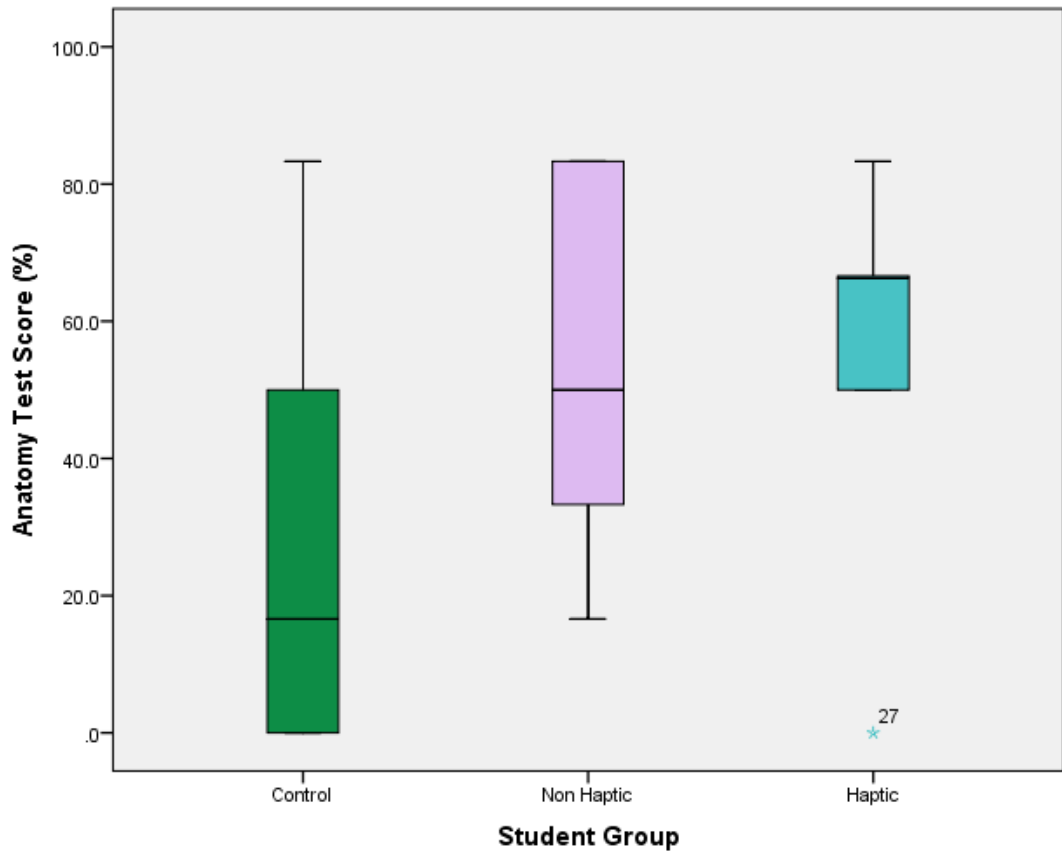

Figure 60, Box plots for phase three results for question 2

Summary of Results

Question two was a spot test consisting of six elements. Figure 61 shows the scores for each group for all six elements. The haptic group scored highest with a mean of 66.6%, followed by the non-haptic group with 53.3%, and finally the control group with 28.3%.
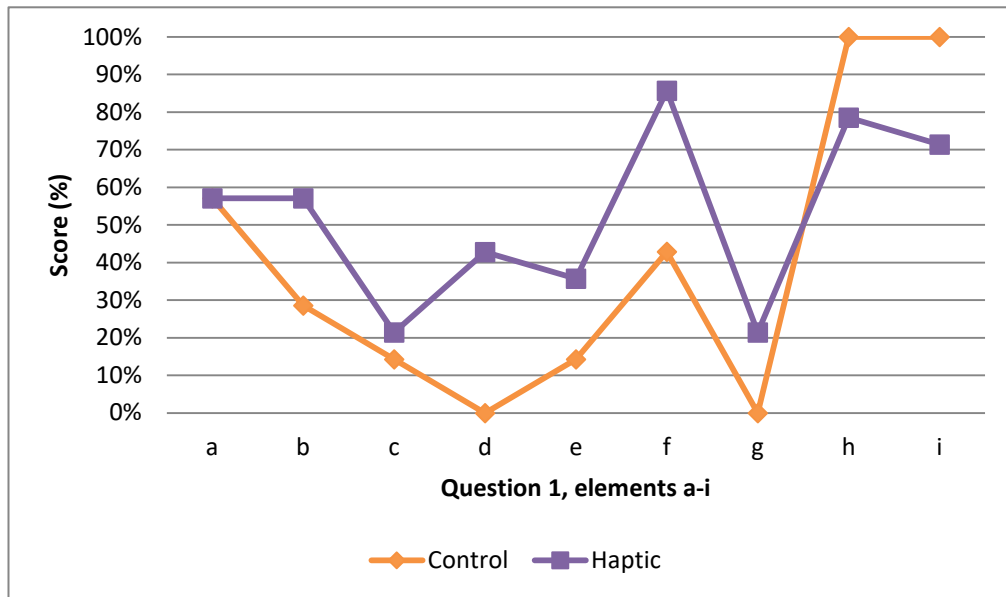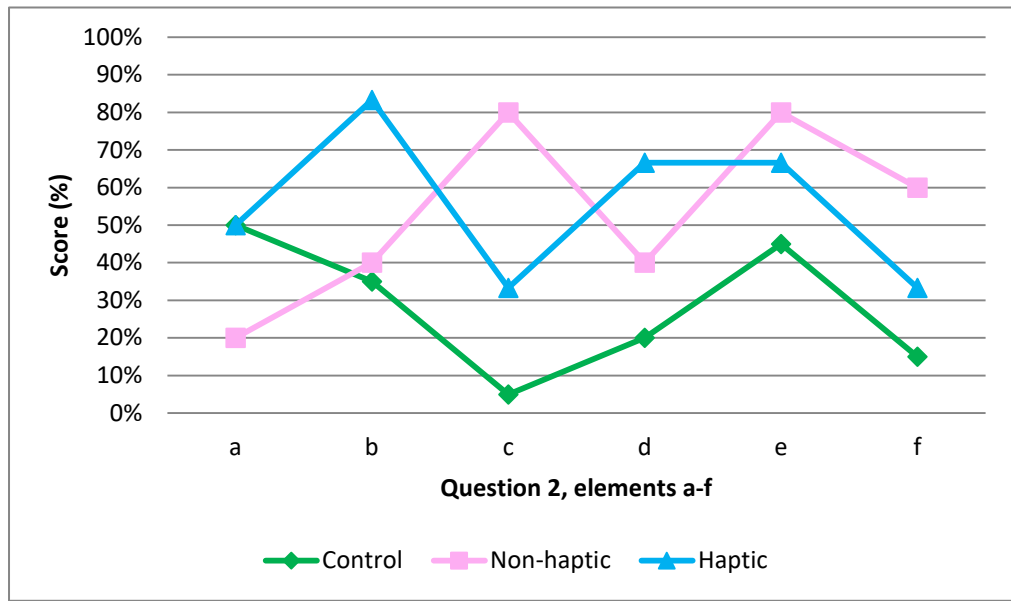

Figure 61, Graph of phase three results for question 2

Mann-Whitney U Test Results

Due to the small group sizes, partially non-normal distribution and to remain consistent with the previous phases, two Mann-Whitney U tests were performed. The first Mann-Whitney U test showed that the non-haptic group did not score significantly higher than the control group. The second Mann-Whitney U test showed that the haptic group did not score significantly higher than the control group.

The medians were also calculated for each group. The control group scored 16.6%, the non-haptic group 50% and the haptic group 66.3%.

Question Three

Sample Characteristics

A Shapiro-Wilk test (p>.05) (Shapiro and Wilk, 1965, Razali and Wah, 2011) and a visual inspection of their histograms, normal Q-Q plots and box plots (Figure 62) showed that the test scores were not consistently normally distributed across the three groups, for question three.
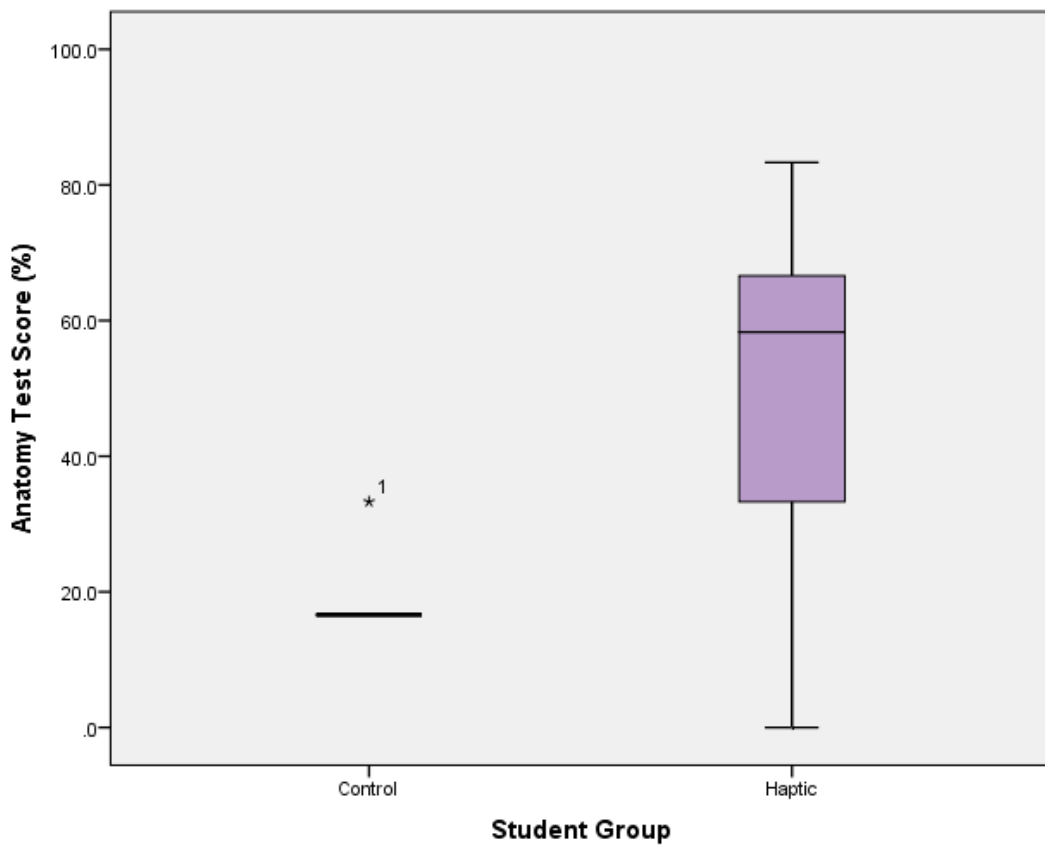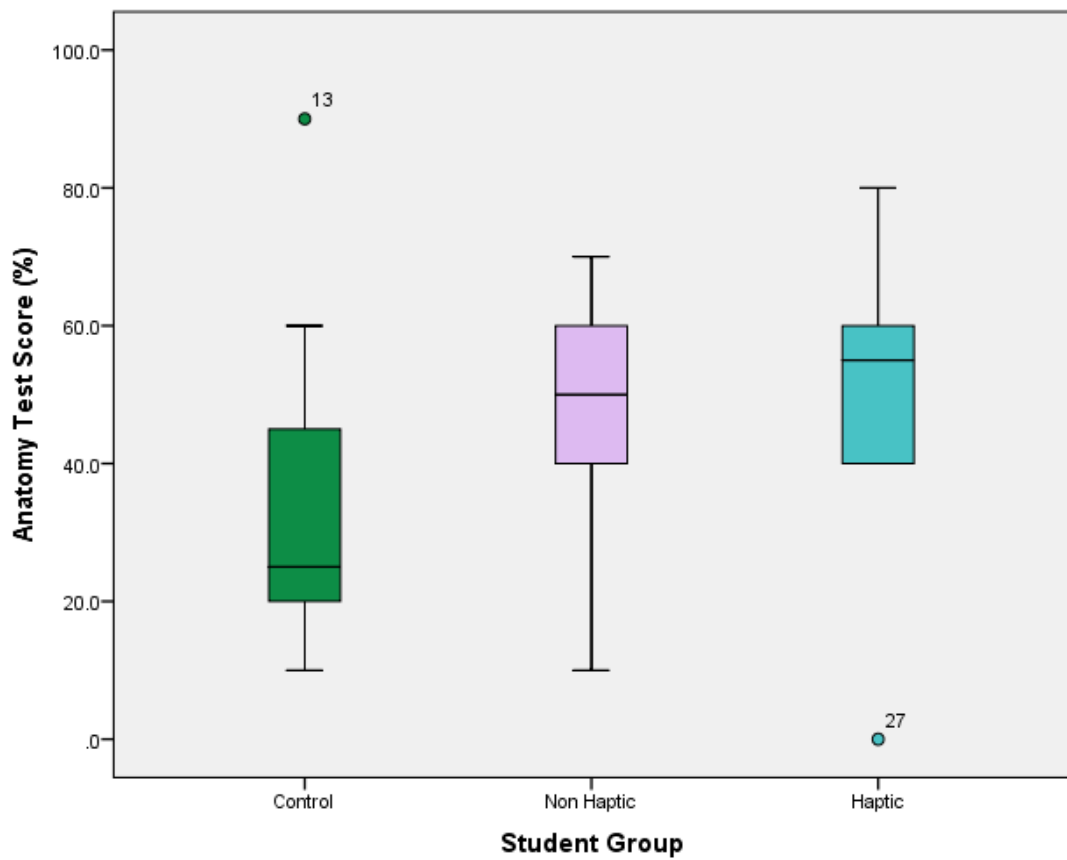

Figure 62, Box plots for phase three results for question 3

Summary of Results

Question three was a spot test consisting of ten elements. Figure 63 shows the scores for each group for all ten elements. The haptic group scored highest with a mean of 48.3%, followed by the non-haptic group with 46%, and finally the control group with 32%.
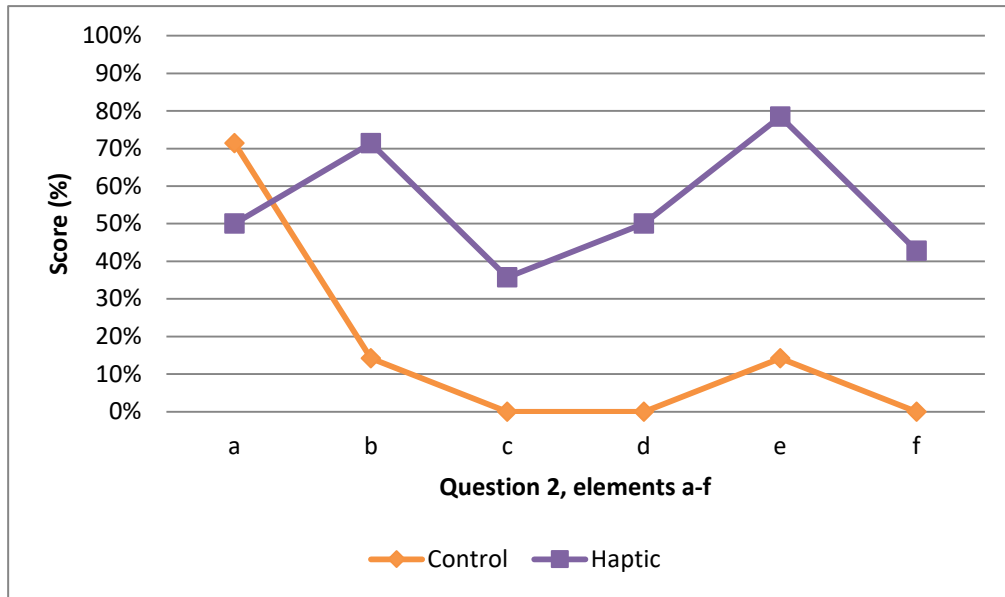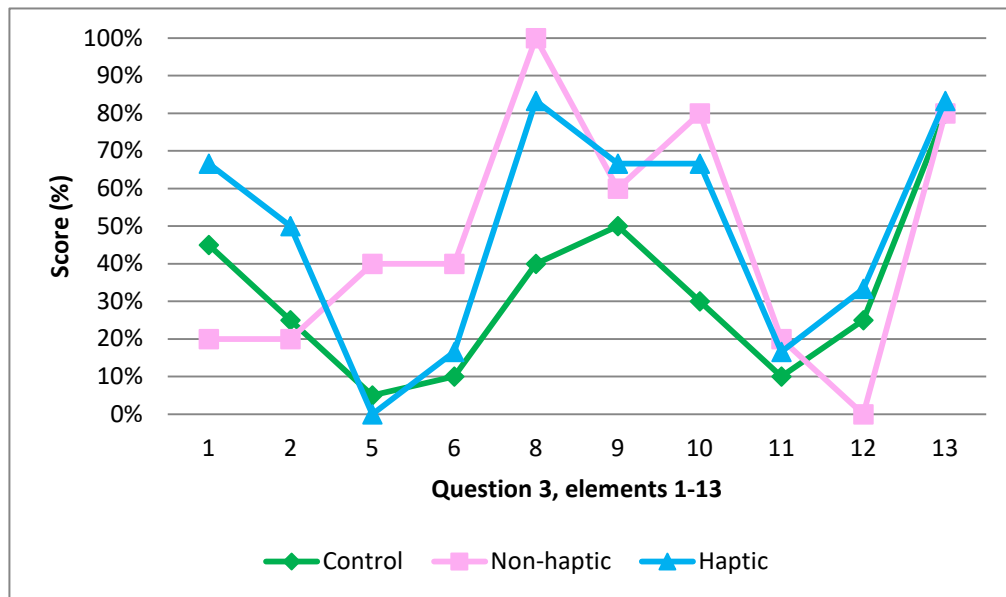
Mann-Whitney U Test Results

Due to the small group sizes, partially non-normal distribution and to remain consistent with the previous phases, two Mann-Whitney U tests were performed. The first Mann-Whitney U test showed that the non-haptic group did not score significantly higher than the control group. The second Mann-Whitney U test showed that the haptic group did not score significantly higher than the control group.

The medians were also calculated for each group. The control group scored 25%, the non-haptic group 50% and the haptic group 55%.

Questions Four - Eight

Sample Characteristics

A Shapiro-Wilk test (p>.05) (Shapiro and Wilk, 1965, Razali and Wah, 2011) and a visual inspection of their histograms, normal Q-Q plots and box plots (Figure 64) showed that the test scores were broadly normally distributed across the three groups, for questions four to eight.
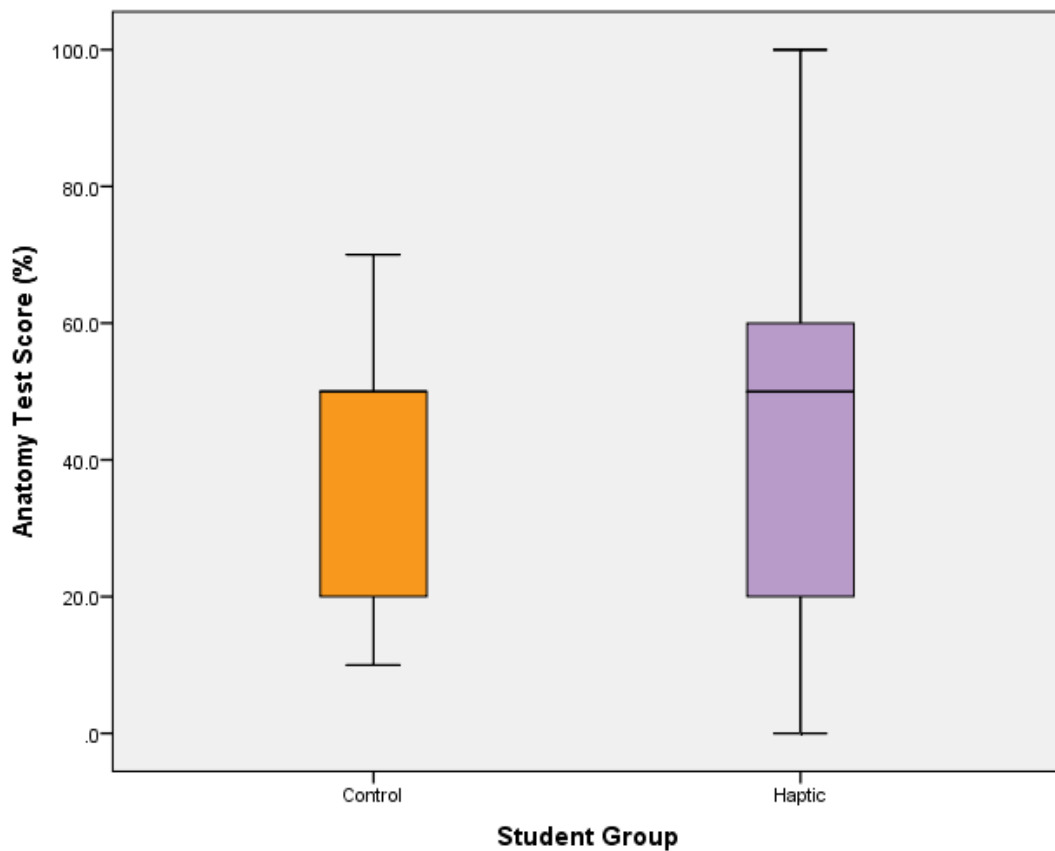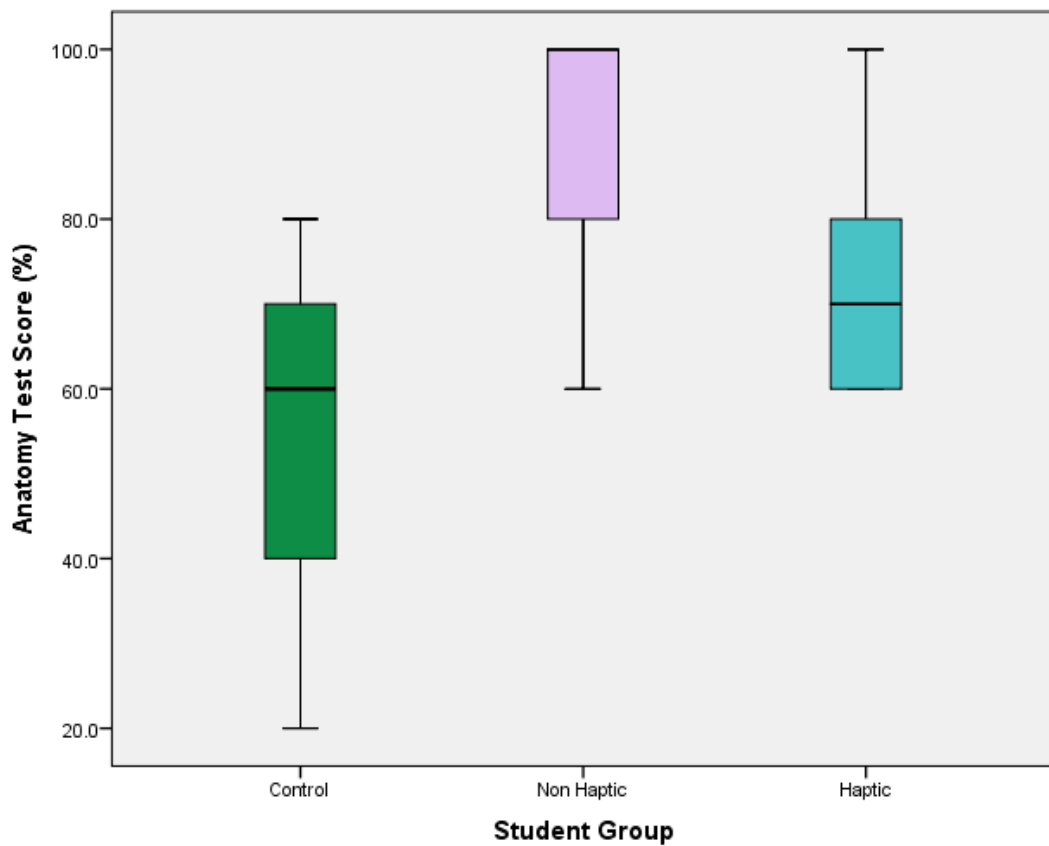

Figure 64, Box plots for phase three results for questions 4-8

Summary of Results

Questions 4 to 8 were multiple-choice. Figure 65 shows the scores for each group for all four questions. The non-haptic group scored highest with a mean (for all four questions combined) of 88%, followed by the haptic group with 73.3%, and finally the control group with 58%.
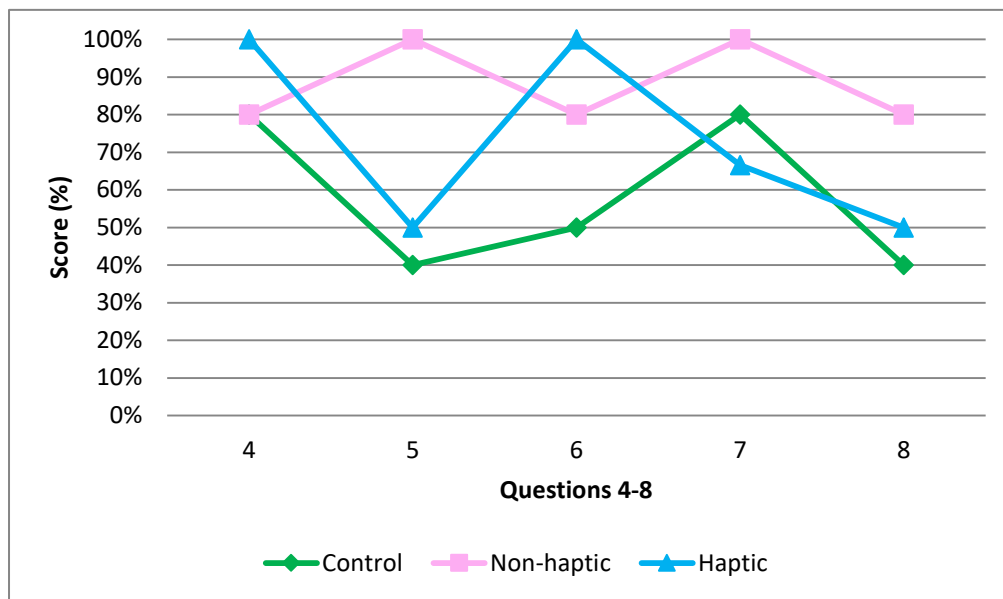
Figure 65, Graph of phase three results for questions 4-8

Mann-Whitney U Test Results

Although the results for questions four to eight appear to be close to normal, for consistency along with the small group sizes a Mann-Whitney U test was performed. The first Mann-Whitney U test showed that the non-haptic group scored significantly higher than the control group, scoring a p-value of 0.007. The second Mann-Whitney U test showed that the haptic group did not score significantly higher than the control group.

The medians were also calculated for each group. The control group scored 60%, the non-haptic group 100% and the haptic group 70%.

Summary of Anatomy Test Results

The means for all questions were combined. The non-haptic group scored highest with 54.6%, followed by the haptic group with 54.5%, and finally the control group with 32.5%. The means for the three spot tests were also combined with the haptic group scoring highest with 50.6%, followed by the non-haptic group with 48%, and finally the control group with 34.2% (Table 8). Figure 66 shows the overall mean of each group per question for the anatomy test; while Figure 67 compares the means of each group overall with those for the spot tests and multiple choice questions alone. Finally Table 9 summarises the p-values for all questions in the phase three anatomy test.

Table 8, Final anatomy test results for phase three

| Anatomy Test	Control	Non-haptic	Haptic
Overall Mean (Q's 1-8)	32.5%	54.6%	54.5%
Spot Test Mean (Q's 1-3)	34.2%	48%	50.6%
Multiple choice Mean (Q's 4-8)	58%	88%	73.3%
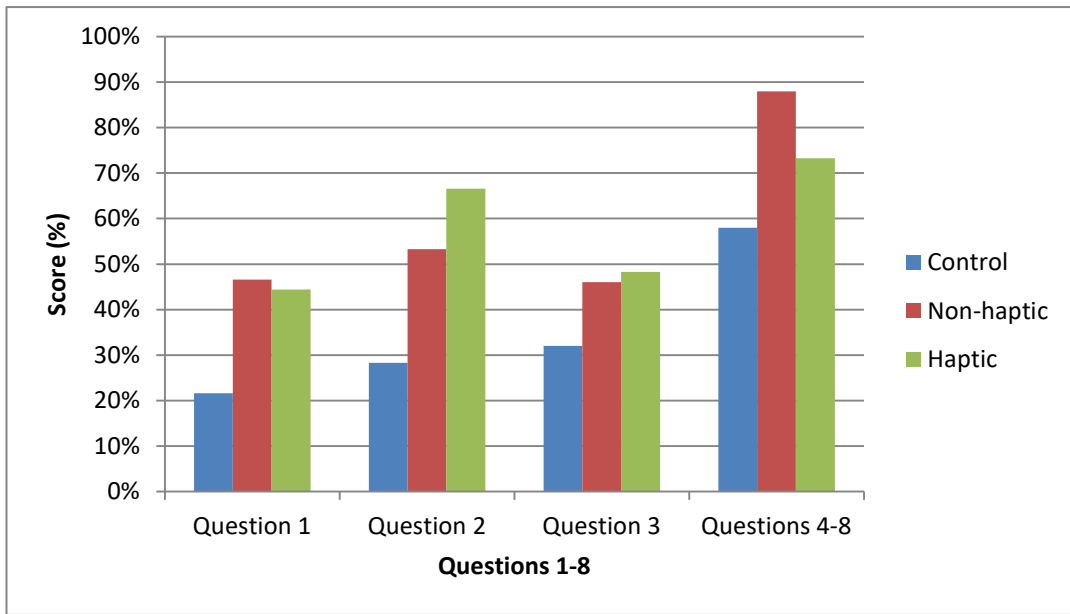
Figure 66, The overall means for each group per question of the anatomy test (phase three)
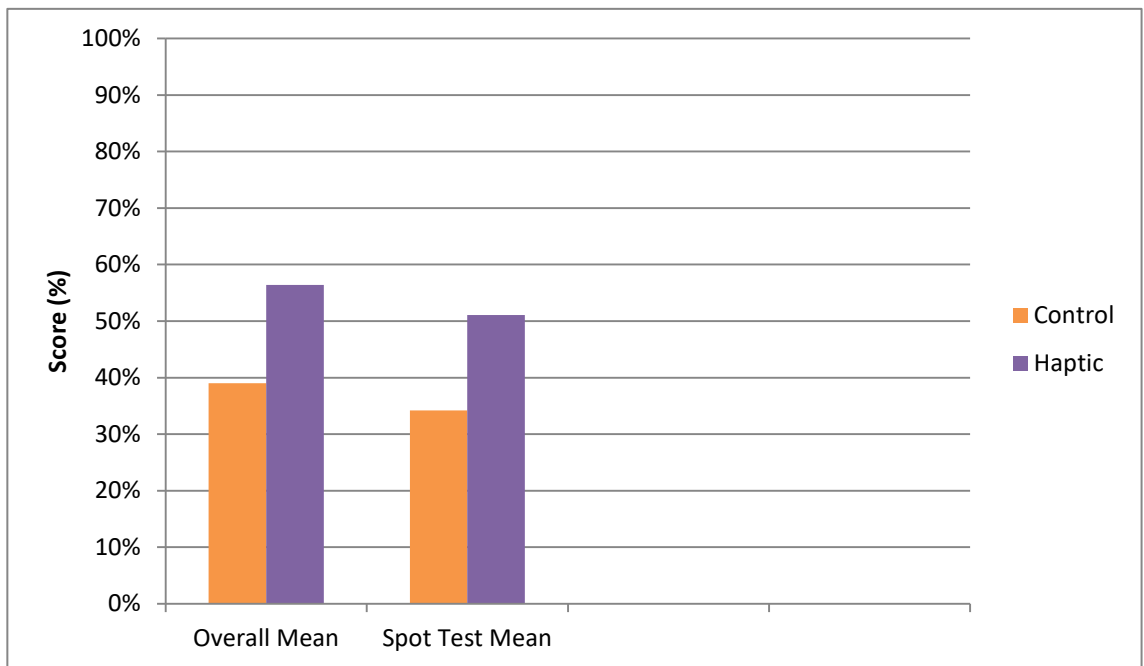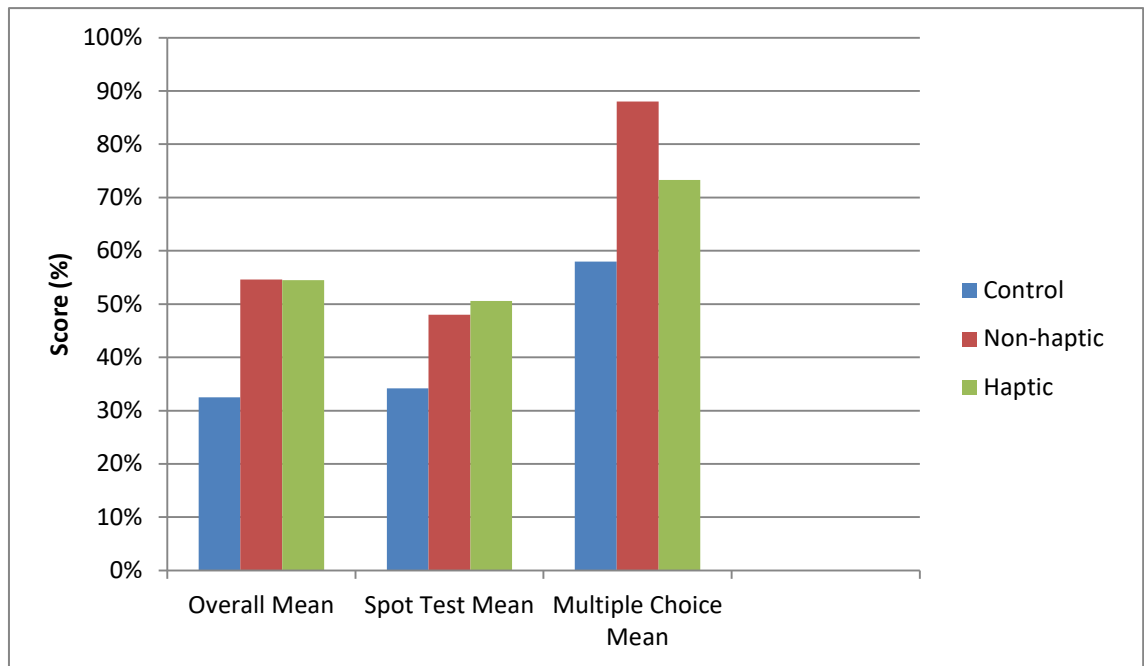

Figure 67, The means of each group overall, compared with the spot test and multiple choice style questions (phase three)

Table 9, Summary of p-values for all questions in the phase three anatomy test

Q1	Control/Non-Haptic 0.071	Control/Haptic 0.062
Q2	Control/Non-Haptic 0.097	Control/Haptic 0.095
Q3	Control/Non-Haptic 0.192	Control/Haptic 0.108
Q4-8	Control/Non-Haptic 0.007	Control/Haptic 0.108

Discussion of Anatomy Test Results

The results for each group follow a broadly similar pattern across most of the questions as demonstrated by Figures 59, 61, 63 and 65. This indicates that some questions (discussed below) were consistently more challenging than others. One prominent exception to this is question 2C which received low scores from both the control and haptic groups (of 5% and 16.6% respectively) but for which the non-haptic group scored 80%. Question 1B scored consistently poorly across all groups receiving only one correct answer from the non-haptic group, two from the haptic group and four (20%) from the control. While a range of (incorrect) answers were given, the majority opted for 'flexor pollicis', or 'flexor pollicis longus' (the correct answer being flexor pollicis brevis [superficial head]).   Flexor pollicis is a shortened version of the correct answer. However, this was not marked as correct due to there being a flexor pollicis brevis and longus. The muscle of flexor pollicis longus occurs in the forearm and wrist (rather than on the palmar surface of the thumb) with its tendon running inserting at the base of the

distal phalanx of the thumb. It appears therefore to have been confused due to its similarity in name rather than location.

Question 1C received consistently low scores across all groups with no correct answers from the haptic group, one from the non-haptic group and three (15%) from the control. While a range of (incorrect) answers were given, the majority opted for, 'opponens pollicis' (the correct answer being flexor pollicis brevis [deep head]). This is same answer that was most frequently given by the students in phases one and two. Opponens pollicis is a similar sized muscle in the same general vicinity as flexor pollicis brevis so it is possible to see how a student could confuse the two structures.

Question 1G received consistently low scores across all groups with only one correct answer from the control group, one correct answer from the non-haptic group and two correct answers (33.3%) from the haptic group. While a range of (incorrect) answers were given, the majority opted for either 'lumbrical' or 'median nerve' (the correct answer being common palmar digital artery). These are the same answers that were most frequently given by the students in phase one. As discussed previously, the median nerve is a similarly sized structure in the same general vicinity as the common palmer digital artery, so it is possible to see how these two structures could be confused. The lumbrical muscles however should appear quite distinct to an artery. However, looking at the photograph used in the anatomy test it is possible that these students thought the letter 'g' was above a difference structure, as the fourth lumbrical is only a couple of millimetres away.

Question 2C received low scores for the control and haptic groups, with both only receiving one correct answer each. The non-haptic group scored better however with 80% stating the correct answer. While there were a range of (incorrect) answers given, the majority opted for the tendon of extensor indices. The correct answer is the 2nd

metacarpal, however on re-assessing the image it can be seen how this could be quite unclear as previously discussed for phases one and two.

Questions 3.5, 3.6, 3.11, 3.12 received low scores across all of the groups. Question 3.5 received only one correct answer from the control group, no correct answers from the haptic group and two correct answers (40%) from the non-haptic group. While there were a number of blank responses, the two most frequent (incorrect) answers were 'palmaris longus' and 'extensor carpi radialis' (the correct answer being extensor carpi radialis brevis). Palmaris longus is a large muscle on the anterior of the forearm, whereas the tendon of extensor carpi radialis brevis is on the dorsum of the hand and should not therefore be confused. Extensor carpi radialis is a shortened version of the correct answer. However, this was not marked as correct due to there being an extensor carpi radialis brevis and longus.

Question 3.6 received low scores across all groups, receiving two correct answers from the control and non-haptic groups and one correct answer from the haptic group. While there were a number of blank responses, the two most frequent (incorrect) answers were extensor carpi radialis and carpi radialis brevis (the correct answer being extensor carpi radialis longus). Extensor carpi radialis is a shortened version of the correct answer. However, this was not marked as correct due to there being an extensor carpi radialis brevis and longus. Both muscles are found running alongside one another so it understandable that they could be confused.

Question 3.11 received low scores across all groups, receiving two correct answers from the control group and one from both the non-haptic and haptic groups. The most frequent incorrect answer was extensor pollicis longus (the correct answer being extensor pollicis brevis).

Question 3.12 received no correct answers from the non-haptic group. The control and haptic groups scored better with 25% (five individuals) and 33.3% (two individuals) respectively. The most frequent incorrect answer was extensor pollicis brevis, (the correct answer being extensor pollisis longus). While extensor pollicis longus is a longer muscles, it does occupy a similar region of the forearm to extensor pollis brevis. This along with the similarity in name makes it understand how they these two muscles could be confused, especially when only viewing a partial view of the structure.

The issues surrounding the quality of the images for questions 1 – 3 have already been discussed for phases one and two, and were likely a factor during phase three also.

There were no occasions where the control group scored higher than both the non-haptic and haptic groups.

As the groups consisted of small numbers of students (between five and twenty in each) from different years, there remains the possibility that the differences seen are due to differences in individual ability. To explore this further the results were compared with the average grades for each group in the Gross Anatomy (GA) one module. The control group (2015, 4th years) scored a B1, the non-haptic group (2015, 3rd years) scored an A5, and finally the haptic group (2015, 3rd years) scored an A4. The grading system changed from September 2015 to include five 'A' grades. Therefore, for this comparison a B1 grade is equivalent to 66-69% while an A5 is equivalent to 70-75% and an A4 is equivalent to 76-82%. There is therefore a difference of 1-9% between the control and non-haptic groups (a mean of 5%) and 7-16% between the control and haptic groups (a mean of 11.5%). The percent differences for the three significant results were as follows:

Question 1: Control/Non-haptic – 21.3%

Question 2: Control/Non-haptic – 30%

Question 4-8: Control/Non-haptic – 25.3%

This comparison indicates that while the non-haptic group (2015) did score slightly higher than the control group for GA1 the difference is not as large as that seen for these results.

The non-haptic group scored significantly higher than the control in one of the four question groups, while the haptic group did not score significantly higher on any occasion (despite scoring slightly higher than the non-haptic group on two occasions). This lends some support (albeit limited) to the findings from the previous two phases. While the haptic group does appear to be performing much closer to the non-haptic in this phase the results still indicate that use of the haptic device does not significantly improve student test results.

Student feedback again suggested a mixed response to the haptic interface with comments such as the following supporting the notion that for some at least there is an increased cognitive load imposed by the haptic device:

"(The haptic interface) slowed me down at first but it got better with time."

"It was easy to use the mouse and I just focused on the dissection, I didn't waste time learning how to use the haptic."

As before there were also those who found the haptic interface to be beneficial. There were more positive comments than negative within this particular group. Comments included:

"It made it far more enjoyable and engaging."

"Felt more realistic and allowed me to dissect one muscle at a time which I found helpful."

"Improved patience in dissection. Good to go through layer by layer."

"I personally learn more easily by interaction so the haptic component makes it better than other online or virtual things I've tried. Also, it was fun which I'm pretty sure made it more easy to spend time on it. The second time I came down to do it I passed 2 hours there and barely saw the time pass."

"It was helpful to focus on what I was doing. I probably wouldn't have stayed as long if it were just mouse and keyboard. And focus helps remembering things."

Some comments also suggested a feeling of missing out in not having access to the haptic interface:

"Non-haptic was suitable for revision, but I feel haptic would be better for dissection practice."

"It was easier to remove the layers all at once but no dissection experience was available."

As in the previous two phases it appears that there is considerable variation in how easy and intuitive students have found the haptic device to be. As stated previously this could be related to the individual's spatial ability as well as prior exposure to 3D computer models.

4.4 COMBINED RESULTS FOR PHASES TWO AND THREE

The data from phases two and three was combined to create larger groups for further analysis. The combined control group (2014 and 2015) consisted of 32 students, the non-haptic group (2015 only) of six and the combined haptic group (2014 and 2015) of twenty students. Five students were omitted from the control results and one from the non-haptic results however as they left over 40% of the questions unanswered.

Question One

Summary of Results

Question one was a spot test consisting of nine elements. Figure 68 shows the scores for each group for all nine elements. The haptic group scored highest with a total of 50%, followed by the non-haptic group with a total of 46.6%, and finally the control group with a total of 26.3%.
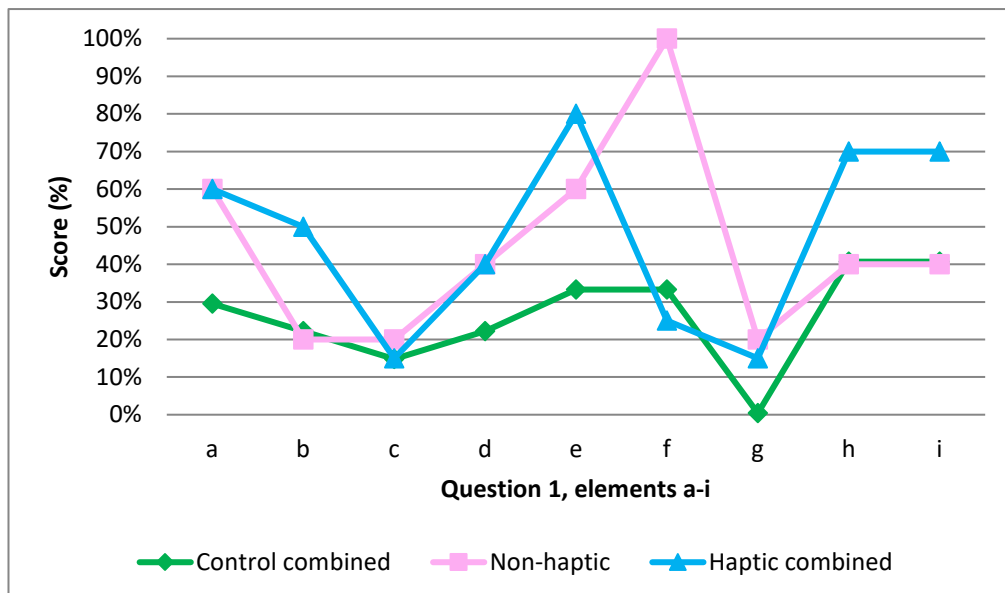
Figure 68, Graph of phases two and three combined results for question 1

Mann-Whitney U Test Results

Two Mann-Whitney U tests were performed. The first Mann-Whitney U test showed that the non-haptic group did not score significantly higher than the control group; whereas the second Mann-Whitney U test showed that the haptic group did score significantly higher than the control group, scoring a p-value of 0.001..

The medians were also calculated for each group. The control group scored 22.2%, the non-haptic group 33.3% and the haptic group 55.5%.

Question Two

Summary of Results

Question two was a spot test consisting of six elements. Figure 69 shows the scores for each group for all six elements. The haptic group scored highest with a total of 57.8%, followed by the non-haptic group with 53.3%, and finally the control group with 25.9%.
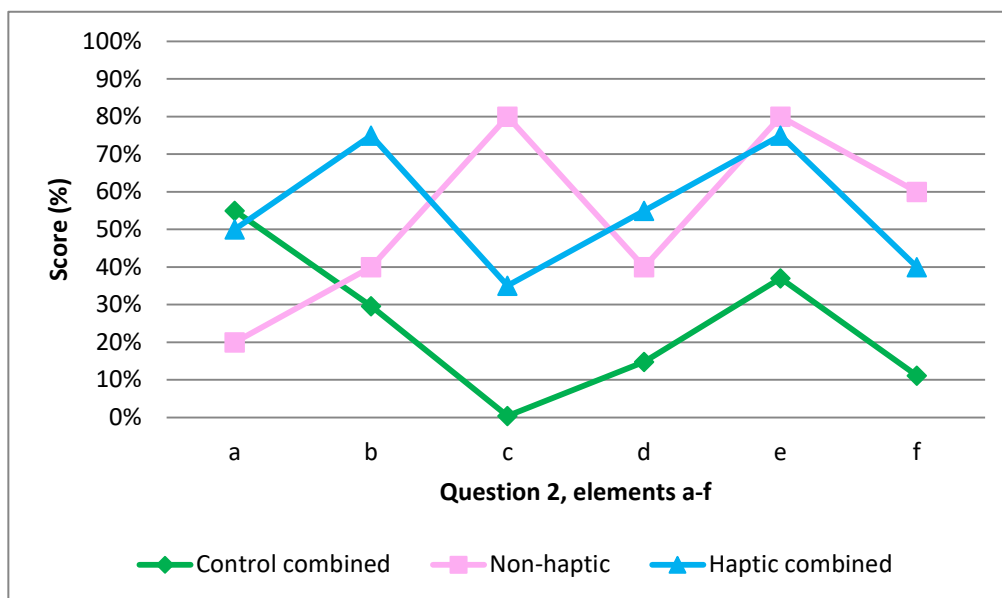
Figure 69, Graph of phases two and three combined results for question 2

Mann-Whitney U Test Results

Two Mann-Whitney U tests were performed. The first Mann-Whitney U test showed that the non-haptic group did not score significantly higher than the control group; whereas the second Mann-Whitney U test showed that the haptic group did score significantly higher than the control group, scoring a p-value of 0.002.

The medians were also calculated for each group. The control group scored 16.6%, the non-haptic group 50% and the haptic groups both scored 66.3%.

Question Three

Summary of Results

Question three was a spot test consisting of ten elements. Figure 70 shows the scores for each group for all ten elements. The haptic group scored highest with a total of 46.5%, followed by the non-haptic group with 46%, and finally the control group with 33.7%.
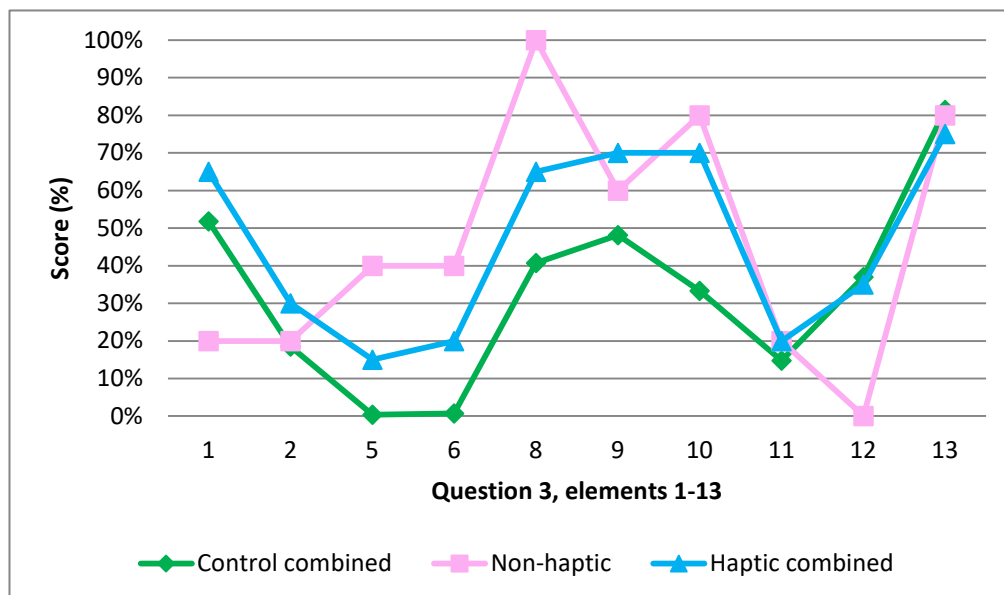
Figure 70, Graph of phases two and three combined results for question 3

Mann-Whitney U Test Results

Two Mann-Whitney U tests were performed. The first Mann-Whitney U test showed that the non-haptic group did not score significantly higher than the control group; whereas the second Mann-Whitney U test showed that the haptic group did score significantly higher than the control group, scoring a p-value of 0.076.

The medians were also calculated for each group. The control group scored 30%, while the non-haptic and haptic groups both scored 50%.

Questions Four - Eight

Summary of Results

Questions 4 to 8 were multiple-choice. Figure 71 shows the scores for each group for all four questions. The non-haptic group scored highest with a total (for all four questions combined) of 88%, followed by the haptic group with 80%, and finally the control group with 59.2%.
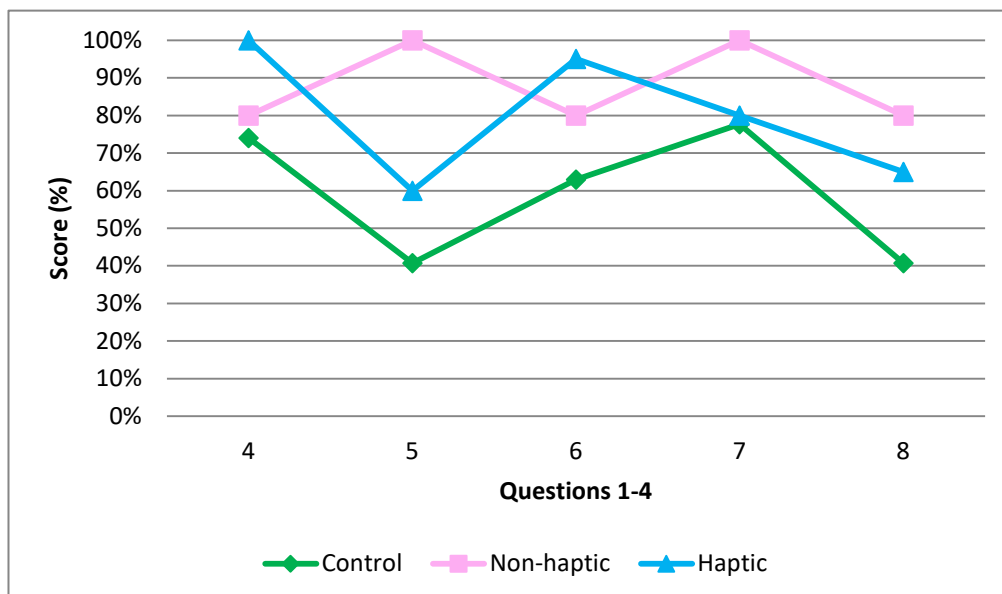
Figure 71, Graph of phases two and three results for questions 4-8

Mann-Whitney U Test Results

Two Mann-Whitney U tests were performed. The first Mann-Whitney U test showed that the non-haptic group scored significantly higher than the control group, scoring a p-value of 0.008. The second Mann-Whitney U test showed that the haptic group also scored significantly higher than the control group, scoring a p-value of 0.000. The control group scored 60%, the non-haptic group 100% and the haptic group 80%.

Summary of Combined Anatomy Test Results

The totals for all questions were combined. The haptic group scored highest with 55.3%, followed by the non-haptic group with 54.6%, and finally the control group with 34.1%. The totals for the three spot tests were also combined with the haptic group scoring highest with 50.4%, followed by the non-haptic group with 48%, and finally the control group with 29.1% (Table 10). Figure 72 shows the overall totals of each group per question for the anatomy test; while Figure 73 compares the totals of each group overall with those for the spot tests and multiple choice questions alone. Finally Table 11 summarises the p-values for all questions in the phase three anatomy test.

Table 10, Final anatomy test results for phases two and three combined

Anatomy Test	Control Combined (2014/15)	Non-haptic (2015)	Haptic Combined (2014/15)
Overall Mean	34.1%	54.6%	55.3%
Spot Test Mean	29.1%	48%	50.4%
Multiple choice Mean	59.2%	88%	80%
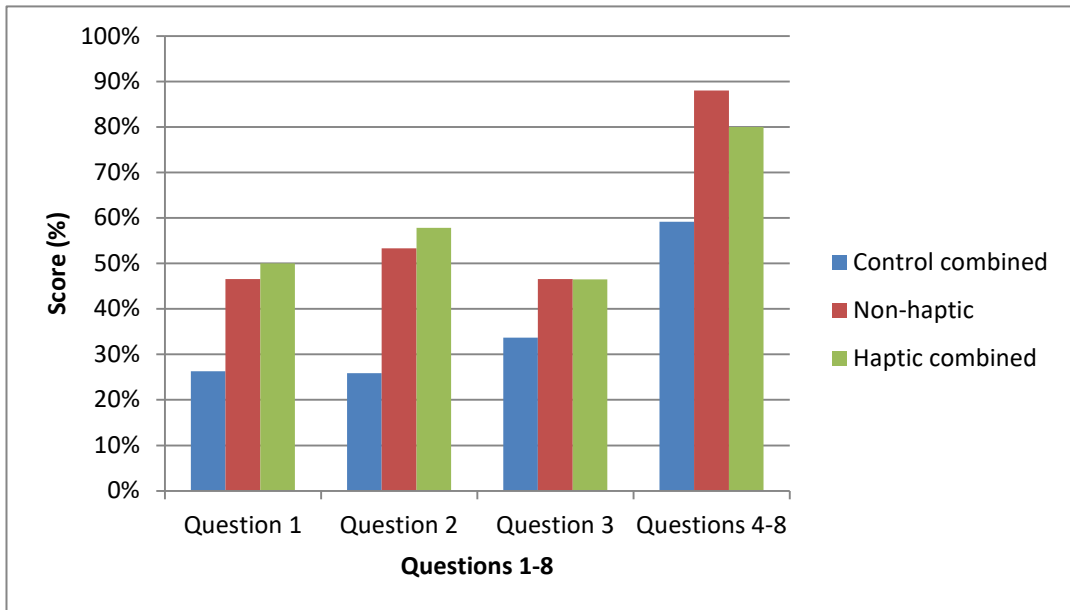
Figure 72, The overall means for each group per question of the anatomy test (phases two and three combined)
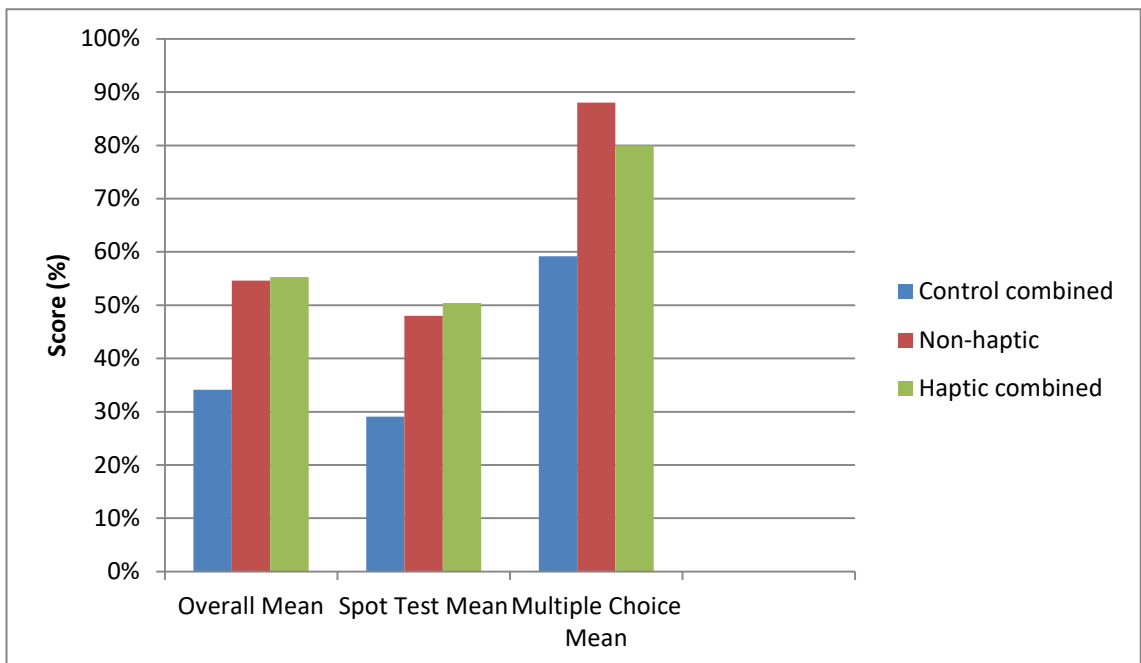
Figure 73, The means of each group overall, compared with the spot test and multiple choice style questions (phases two and three combined)

Table 11, Summary of p-values for all questions in phases two and three combined anatomy test

Q1	Control/Non-Haptic 0.183	Control/Haptic 0.001
Q2	Control/Non-Haptic 0.053	Control/Haptic 0.002
Q3	Control/Non-Haptic 0.241	Control/Haptic 0.076
Q4-8	Control/Non-Haptic 0.008	Control/Haptic 0.000

Discussion of Combined Anatomy Test Results

When data from phases two and three was combined the non-haptic group scored significantly higher than the control in one of the four question groups, however the haptic group scored significantly higher than the control in all four of the question groups. It should be noted however that as sample size increases the statistical significance of an effect becomes greater (a larger sample size increases the power of a test). Both the control and haptic groups where combined (2014/15) to create larger samples of twenty seven and twenty respectively, compared with the non-haptic group (2015 only) of five. While this may help to explain the difference between these results and those of previous phases, it also highlights the limitations surrounding the use of small sample sizes.

Comparison with Phase One and Two Results

Overall, the MSc groups (phase one) scored higher than the BSc groups (phases two and three) for questions one to three (spot tests). This is to be expected as they are studying at a higher level and have already completed an undergraduate program. Questions four to eight (multiple choice) where more equally answered across the groups however, with the phase three non-haptic BSc group scoring highest (Figure 74).
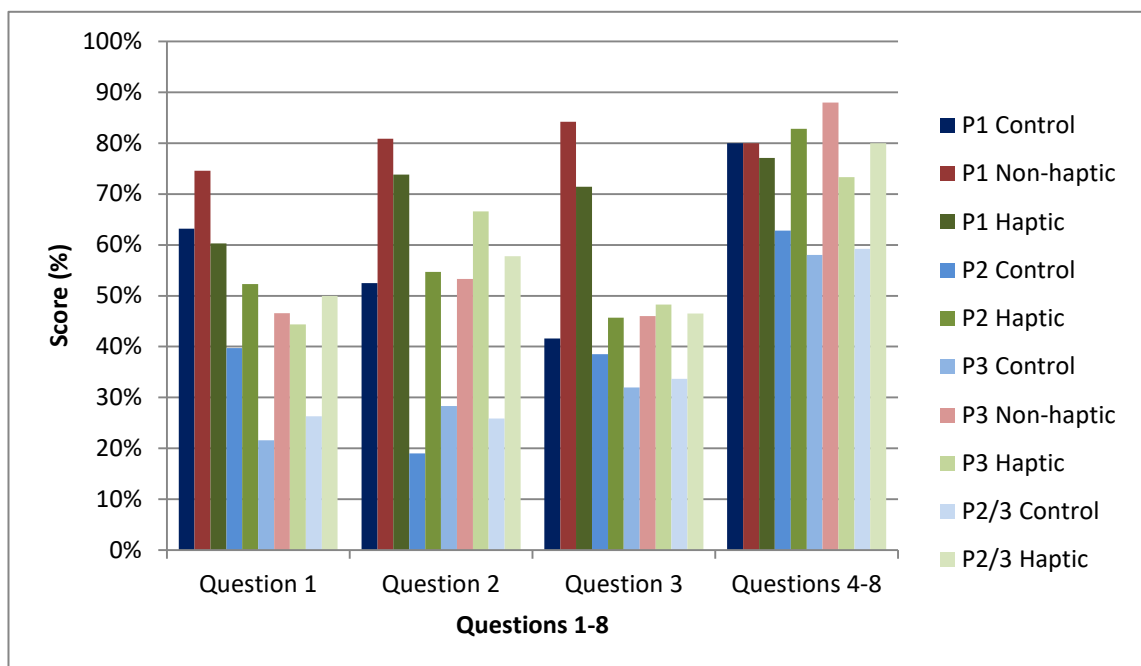
Figure 74, Graph comparing the anatomy test scores for questions 1-4 for all phases.

4.5 COMPARISON OF DISSECTION EVALUATION RESULTS (ALL PHASES)

As the BSc students (in both phases two & three) were a later addition to the study, the control groups were only for the purpose of comparing the anatomy test results as they had dissected the previous year. As such, the BSc dissection evaluation results from phases two and three were compared with those of the MSc/BMSc groups from phase one. Both the non-haptic and haptic results for phase three are combined, as students from both groups dissected cadavers together.

The following Tables and Figures compare the results for all three phases of the study. Questions 1-13 were scored using a five-point Likert scale, where 1= 'not at all', 3= 'moderately' and 5= 'extremely'. With the exception of question 8, they each asked 'how well' different aspects of the dissection had been performed (an example of the dissection evaluation form can be seen in appendix 12).

The phase one (MSc/BMSc) haptic group scored highest with 76.7% (a median and mode of 4), followed by the phase one (MSc/BMSc) control group with 74% (scoring a median and mode of 4), followed by the phase two (BSc) haptic group with 72.8% (scoring a median and mode of 4), followed by the phase three (BSc) combined non-haptic and haptic groups with 71.5% (scoring a median and mode of 4) and finally the phase one (MSc/BMSc) non-haptic group with 68% (scoring a median and mode of 4). There is no apparent significant difference between these results, as such they were not analysed further (Table 12 and Figure 75). Question 8 asked, 'How much damage to the structure is there?' In this instance a lower score was preferable. All groups across all phases scored a median of 2 (Figure 76).

Table 12, Dissection evaluation results for all phases for questions 1-13 (with the omission of question 8) asking how well various anatomical structures had been dissected

	Phase One Control	Phase One Non-haptic	Phase One Haptic	Phase Two Haptic	Phase Three Non-haptic & Haptic
Q1	75% median 4	74.3% median 4	65% median 3.5	66% median 3.5	81.8% median 4
Q2	75 median 4	77.1% median 4	85% median 4	80% median 4	81.8% median 4
Q3	70%median 3.5	60% median 3	65% median 3	62% median 3	63.6% median 3
Q4	85% median 4	80% median 4	80% median 4	74% median 4	80% median 4
Q5	85% median 4	74.3% median 4	70% median 3.5	66% median 3	80% median 4
Q6	46.6% median 1	45.7% median 3	60% median 3	62% median 3	41.8% median 2
Q7	75% median 4	82.8% median 4	90% median 4.5	82% median 4	80% median 4
Q9	80% median 4	77.1% median 4	80% median 4	78% median 4	76.3% median 4
Q10	50% median 3	57.1% median 3	75% median 4	64% median 3	63.6% median 3
Q11	85% median 4.5	60% median 3	90% median 4.5	84% median 4	76.3% median 4
Q12	75% median 3.5	65.7% median 3	80% median 4	76% median 4	67.2% median 4
Q13	80% median 4	62.8% median 3	80% median 4	80% median 4	65.4% median 4
Total	**74%** **Median = 4** **Mode = 4**	**68%** **Median = 4** **Mode = 4**	**76.7%** **Median = 4** **Mode = 4**	**72.8%** **Median = 4** **Mode = 4**	**71.5%** **Median =4** **Mode = 4**
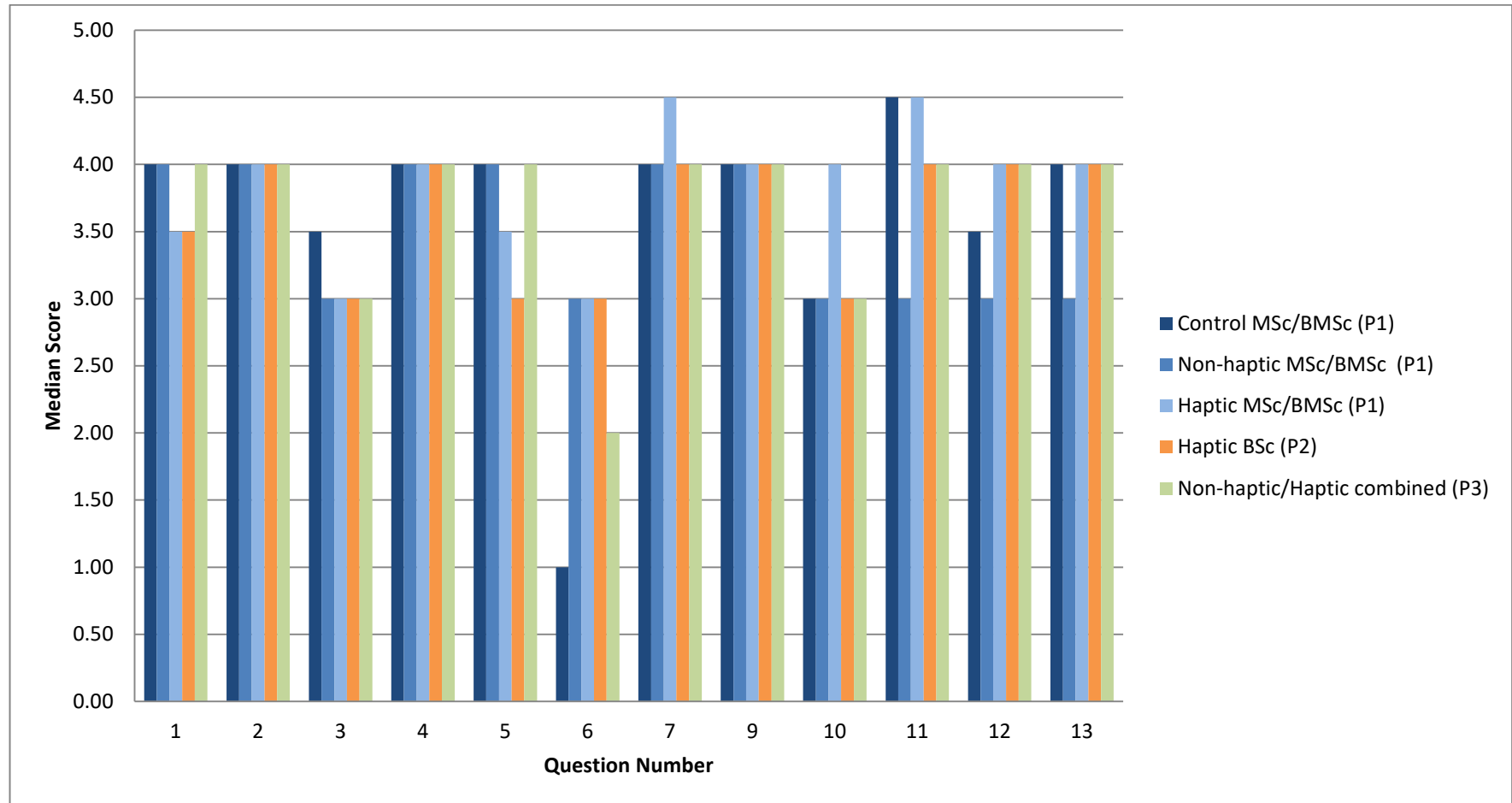
Figure 75, Dissection evaluation results for all phases for questions 1-13 (with the omission of question 8) asking how well various anatomical structures had been dissected
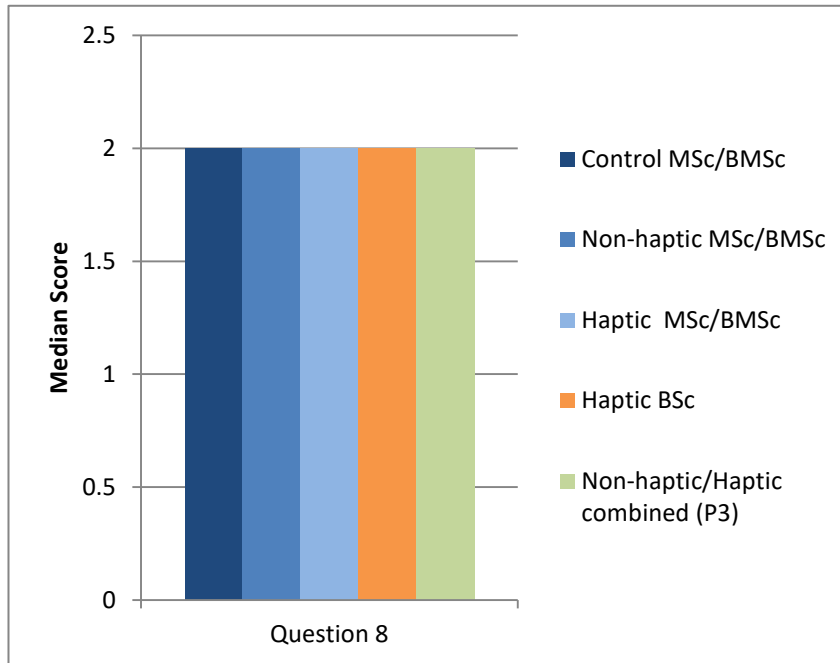
Figure 76, Question 8 results for phases one and two, where question 8 asked 'how much damage there was to the structures'

Discussion of Dissection Evaluation Results

The results of the dissection evaluation are somewhat subjective due to being based on the opinion of an anatomy lecturer. However the assessor was consistent throughout the study in order to minimize any subjective variation. While the results do not appear to be significantly different, it is interesting to note that the highest result was obtained by one of the haptic groups. It should also be noted that cadavers where dissected by groups of three or four students. Some students dissected the same cadaver as one another, while others dissected different cadavers with students who were not taking part in the study.

4.6 COMPARISON OF FEEDBACK QUSTIONNAIRE RESULTS (ALL PHASES)

As the BSc students (in both phases two and three) were a later addition to the study, the control groups were only for the purpose of comparing the anatomy test results as they had dissected during the previous year. As such, the BSc feedback questionnaire results from phases two and three were compared with those of the MSc/BMSc groups from phase one.

The feedback questionnaire consisted of a total of fifteen questions. The first 9 of these were scored using a five-point Likert scale where 1= 'not at all', 2 'somewhat', 3= 'moderately', 4= 'very', and 5= 'extremely'. The questions were as follows:

1, How easy and intuitive was the software to use?

2, How helpful was the training session?

3, How helpful was the dissection manual?

4, Is the model anatomically accurate?

5, How appropriate is the level of detail in the model?

6, Did you enjoy using the software?

7, Did the software improve your dissection (i.e. practical) skills?

8, Did use of the software improve your anatomical knowledge?

9, Did you felt more confident doing the cadaveric dissection after practicing on the software?

For these questions therefore a higher score is preferable. Following this there were two 'closed' questions asking, 'how much time did you spend using the software?' and 'how many training sessions did you attend?' These were followed by three 'open' questions asking, 'if you used the keyboard and mouse interface how do you feel this affected your experience?', 'If you used the haptic interface how much do you feel this affected your

experience?' and 'what improvements would you like to see made to the software?'
Finally there was a space for 'any other comments?' (an example of the feedback
questionnaire can be seen in appendix 13).

Likert Scale Questions

A Cronbach's alpha test was performed on questions 1 to 9 (those scored using a Likert
scale). Cronbach's alpha measures the internal consistency of a test or scale. It is
commonly used with questionnaires that employ multiple Likert questions. The result is
expressed as a number between 0 and 1, with a score closer to 1 being desirable (Table
13).

Table 13, Table correlating Cronbach's alpha to internal consistency

Cronbach's alpha	Internal consistency
α ≥ 0.9	Excellent
0.9 > α ≥ 0.8	Good
0.8 > α ≥ 0.7	Acceptable
0.7 > α ≥ 0.6	Questionable
0.6 > α ≥ 0.5	Poor
0.5 > α	Unacceptable

The Cronbach's alpha result for questions 1-9 was calculated for all results together (i.e.
both the haptic and non-haptic groups from all phases) at 0.616. It was also calculated
for the haptic groups only (phases 1-3) at 0.616 and for the non-haptic groups only
(phases 1 & 3) at 0.654. Finally the Cronbach's alpha was calculated the MSc and BMSc
students only at 0.623 and for the BSc students at 0.611.

As can be seen in table 13, these results fall under the 'questionable' category for internal
consistency. However it should be remembered that consistency is different to reliability.
Reliability refers to the quality of the instrument (questionnaire) to produce trustworthy
data, whereas consistency refers to the predictability of the data. Cronbach's alpha

therefore gives some insight into the consistency (or predictability) of the responses to the questionnaire, but not to the reliability of the questionnaire itself. The number of participants was low and their answers to questions 1-9 likely varied depending on a number of factors including which group (haptic or non-haptic) they were in, as well their personal preferences and learning styles.

A poor inter-relatedness between items on the questionnaire can also negatively impact the Cronbach's alpha result. In this case, although all of the questions were broadly related to using the Virtual Dissection Simulator, they did cover a number of different aspects such as the training sessions, dissection manuals, the interface and the model itself.

The following Tables and Figures compare the results for all groups for questions 1-9. The phase three (BSc) haptic group scored highest with 78.5% (scoring a median and mode 4), followed by the phase two (BSc) haptic group 73.5% (scoring a median and mode 4), followed by the phase one (MSc/BMSc) non-haptic group with 73% (scoring a median and mode 4), followed by the phase one (MSc/BMSc) haptic group with 70.8% (scoring a median and mode 4), and finally the phase three (BSc) non-haptic group with 70% (scoring a median and mode 4). There is no apparent significant difference between these results, as such they were not analysed further (Table 14 and Figure 77).

Table 14, Feedback questionnaire results for all phases for questions 1-9

	Phase One Non-haptic	Phase One Haptic	Phase Two Haptic	Phase Three Non-Haptic	Phase Three Haptic
Q1,	77.1% median 4	60% median 3	64.3% median 3	66.6% median 3	70% median 3.5
Q2	80% median 4	80% median 4	85.7% median 4	80% median 4	86.6% median 4
Q3	80% median 4	68.8% median 4	71.4% median 4	73.3% median 3.5	80% median 4
Q4	85.7% median 4	84.4% median 4	85.7% median 4.5	90% median 4.5	90% median 4.5
Q5	82.8% median 4	84.4% median 4	82.9% median 4	90% median 4.5	90% median 4.5
Q6	80% median 4	82.2% median 4	84.3% median 4	80% median 4	100% median 5
Q7	42.8% median 2	46.6% median 2	58.6% median 3	46.6% median 2.5	46.6% median 2
Q8	80% median 4	7.1% median 4	74.3% median 4	66.6% median 3	76.6% median 4
Q9	48.5% median 3	60% median 3	54.2% median 3	36.6% median 1.5	66.6% median 3
Total	**73% Median = 4 Mode = 4**	**70.8% Median = 4 Mode = 4**	**73.5% Median = 4 Mode = 4**	**70% Median = 4 Mode = 4**	**78.5% Median = 4 Mode = 4**
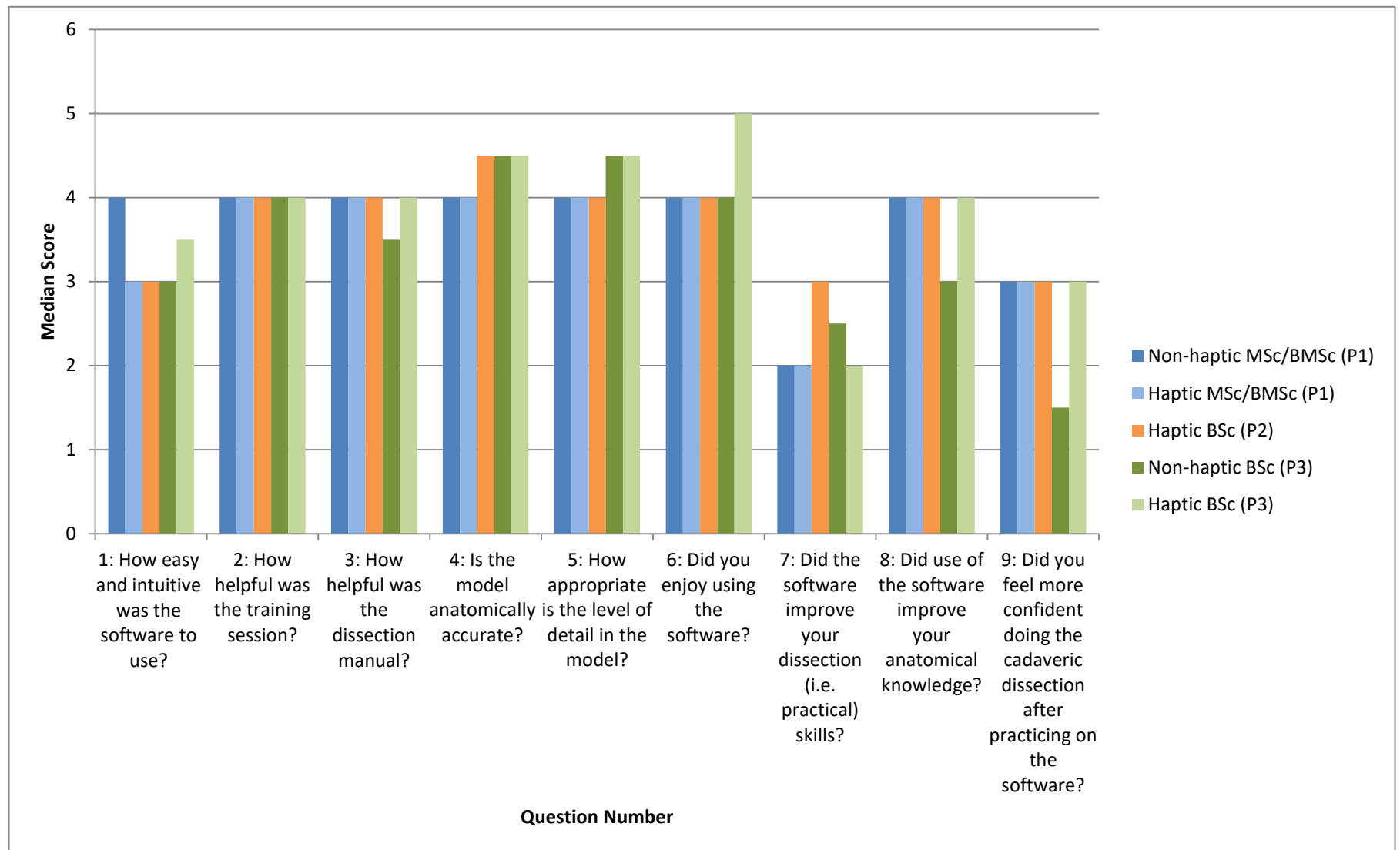
Figure 77, Feedback questionnaire results for all phases for questions 1-9

Questions 10 and 11 were 'closed' style questions asking, 'how much time did you spend using the software?' and 'how many training sessions did you attend?' Question 10 had five possible answers; 0 hours, 0-1 hour, 1-5 hours, 5-10 hours and 10+ hours for phases one and two. This was changed to 0-1 hour, 1-2 hours, 2-3 hours, 3-4 hours, 4-5 hours and 5+ for phase three. Question 11 also had five possible answers; 0, 1, 2, 3 and 4+. All students from all groups used the software for between 0-5 hours, with the majority using it for between 1-5 hours (Figure 78). For question 11 all students across all groups attended one training session.
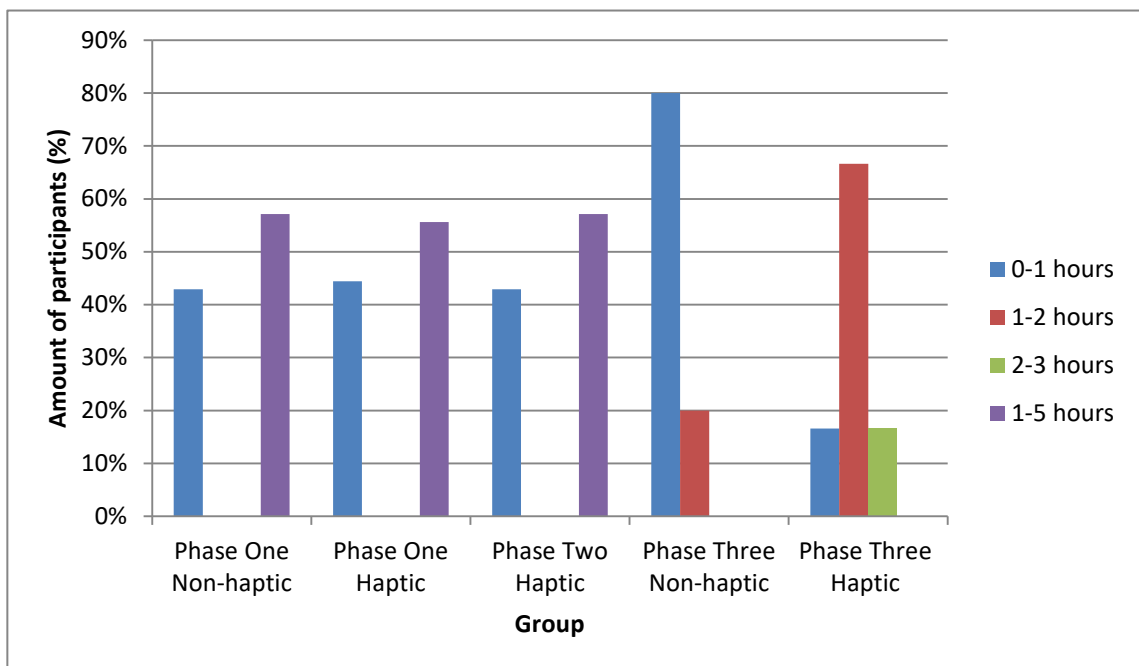
Figure 78, Feedback questionnaire results for question 10, asking 'how much time did you spend using the software'? For phases 1 and 2 the options were: 0 hours, 0-1 hour, 1-5 hours, 5-10 hours and 10+ hours. This was changed to 0-1 hour, 1-2 hours, 2-3 hours, 3-4 hours, 4-5 hours and 5+ for phase 3

Thematic Analysis

Finally questions 12 through 15 were 'open' free text questions asking, 'if you used the keyboard and mouse interface how do you feel this affected your experience?', 'If you used the haptic interface how much do you feel this affected your experience?', 'What improvements would you like to see made to the software?' and finally there was a space for 'any other comments?'

A thematic analysis of all of the comments was conducted following the method outlined by Braun and Clarke (2006). After reading through all of the comments several times (to become familiar with the content), they were all transcribed and manually coded (see Table 82 in appendix 9). The codes identified elements of the data that appeared to be relevant to the research question. 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. Several mind-maps were produced during this phase (examples can be seen in Figure 145 in appendix 9) which helped the author to visualise and consider the links and relationships between themes. Some of the codes went on to form the main themes and sub-themes, whereas others collapsed into each other or were discarded. A final thematic map was created that defined and named each of the themes and sub-themes (Figure 79).

The thematic analysis that was applied to the feedback comments elicited three primary themes that were evident in the data. These themes have been labelled as "Useful," "Problems," and "Engaging." Each primary theme also had a number of sub-themes associated with it.

Useful

This theme was defined as including all of the feedback comments that described finding the Virtual Dissector (either the non-haptic or haptic version) as being *useful* in some way. A number of sub-themes were also identified as follows:

A number of participants stated that the software helped them to **identify structures.**

"It was incredibly helpful though for singling out and individual structures, something which is impossible in the DR." (Phase 2 haptic)

As well as for helping them to understand the **3D structural relationships.**

"I think the haptic device is incredibly useful identifying the individual structures and their relationships to other structures." (Phase 2 haptic)

One comment in particular suggested that the addition of haptic feedback had helped them to understand the 3D structure better than vision alone:

"It was odd to get used to the resistance and being able to feel the surfaces, but it helped to make me realise it was 3D and that thumb structures would be more anteriorly placed." (Phase 1 haptic)

This is similar to the results Jones et al. (2005) found; that students who used a haptic and visual interface to explore virtual objects, spent more time exploring the entire structure of the objects compared to those using a visual interface only.

A large number of participants stated that it was particularly useful for **revision.** Some went on to specify that while they would have liked to use it more before cadaveric dissection, the module format didn't really allow for this, and as such they could only use it for revision.

"Very helpful in terms of revision." (Phase 1 non-haptic)

"The tool is very helpful as a revision aid however because of the structuring of the course I was unable to use it to improve my dissection. The lecture on the hand was immediately followed by the dissection. However it did help with my revision and helped me to visualise the structures better than a 2D image would." (Phase 2 haptic)

While the comments on the above sub-themes were largely consistent across the data set, one area that received more divided feedback was the use of the software for

dissection preparation. Across the haptic participants there were a number of individuals who commented that they felt it had aided their real life dissection:

"The haptic interface was very useful as you could literally feel as you were dissecting, and different layers felt differently. This aided with the real life dissection." (Phase 2 haptic)

However, there was a roughly even number who commented that it did not aid dissection and/or was unrealistic. Are discussed in the next theme.

Problems

This theme was defined as including all of the feedback comments that described *problems* with any aspect of the Virtual Dissector. A number of sub-themes were also identified as follows:

A number of participants described having problems with the **haptic interface**. These included its use (or otherwise) for dissection preparation. While a number of individuals found the haptic interface useful in this regard, many others found it unhelpful:

"I do not think this software is useful in terms of training or practicing dissection techniques." (Phase 1 haptic)

A small number of individuals in the haptic groups even chose to revert to just using just the keyboard and mouse:

"Sometimes difficult to control haptic device. Was interesting to feel the different movements at first but when I wanted to really study the structures I found it quite frustrating moving the device and returned to the keyboard." (Phase 2 haptic)

On a related but distinct sub-theme, a number of participants stated that they found the software to be **unrealistic** in a variety of ways. For the non-haptic groups these

comments tended to relate to the fact that 'dissection' was by means of the removal of entire structures:

"It removed the whole structure 'perfectly'. Good because less hard. Bad because in reality we had only a small window to see the deeper structures." (Phase 1 non-haptic)

Whereas for the haptic groups they tended to focus on haptic interface itself:

You hold it like a pen rather than a scalpel; and the movement's resistance I don't think was realistic." (Phase 1 haptic)

Another common problem that was cited was that use of the software was **time consuming**. Comments within this sub-theme tended to fall within two categories. The first was that it could be time consuming to search for and identify structures. This was particularly true for the non-haptic groups where there was no interactive labelling available:

"Relatively time consuming to have to click through everything to find the muscles." (Phase 1 non-haptic)

The second was that the haptic device itself took quite some time to learn before it could be applied to learning anatomy:

"I did try to use the haptic interface, but I felt I would need much more time with it in order to be quite confident using it." (Phase 2 haptic)

Finally, a large number of participants made suggestions for a variety **improvements**. While some of these were only suggested by individuals, others were mentioned several times by multiple participants. They included such things as; the ability to dissect through multiple structures, animating the model, the addition of textual information, the ability to highlight a structure with the mouse curser and more realistic tissue properties. These are all discussed in more depth in section 4.7.

While the above suggestions are all related to limitations in the existing software, by far the most frequent suggestion was more positive, in that asked for the software to be extended to encompass other body parts and frequently to the whole body:

"Software like this would be extremely useful when revising and to have this software for the entire body would be very helpful." (Phase 3 non-haptic)

Engaging

This theme was defined as including all of the feedback comments that described finding the Virtual Dissector (either the non-haptic or haptic version) as being *engaging* in some way. This theme was subsequently broken down into two sub-themes:

A number of participants stated that they found the software to be 'fun', 'engaging' 'enjoyable', 'a great experience' etc.

"I found it enjoyable to use." (Phase 2 haptic)

"Easy to use, very enjoyable." (Phase 1 haptic)

Comments such as these were considered to be qualitatively different to those where participants stated that they found the software to be 'interesting':

"It was interesting to get the feel of the structures." (Phase 2 haptic)

Although at first it may appear that these comments could fit within the *useful* theme, it was decided that usefulness and enjoyment should be treated as two distinct themes. It is possible for someone to enjoy using the software or haptic interface, yet at the same time to not find it useful:

"I think the haptic interface was interesting to use, but I don't this it is valuable in its 'dissection' actions." (Phase 1 haptic)
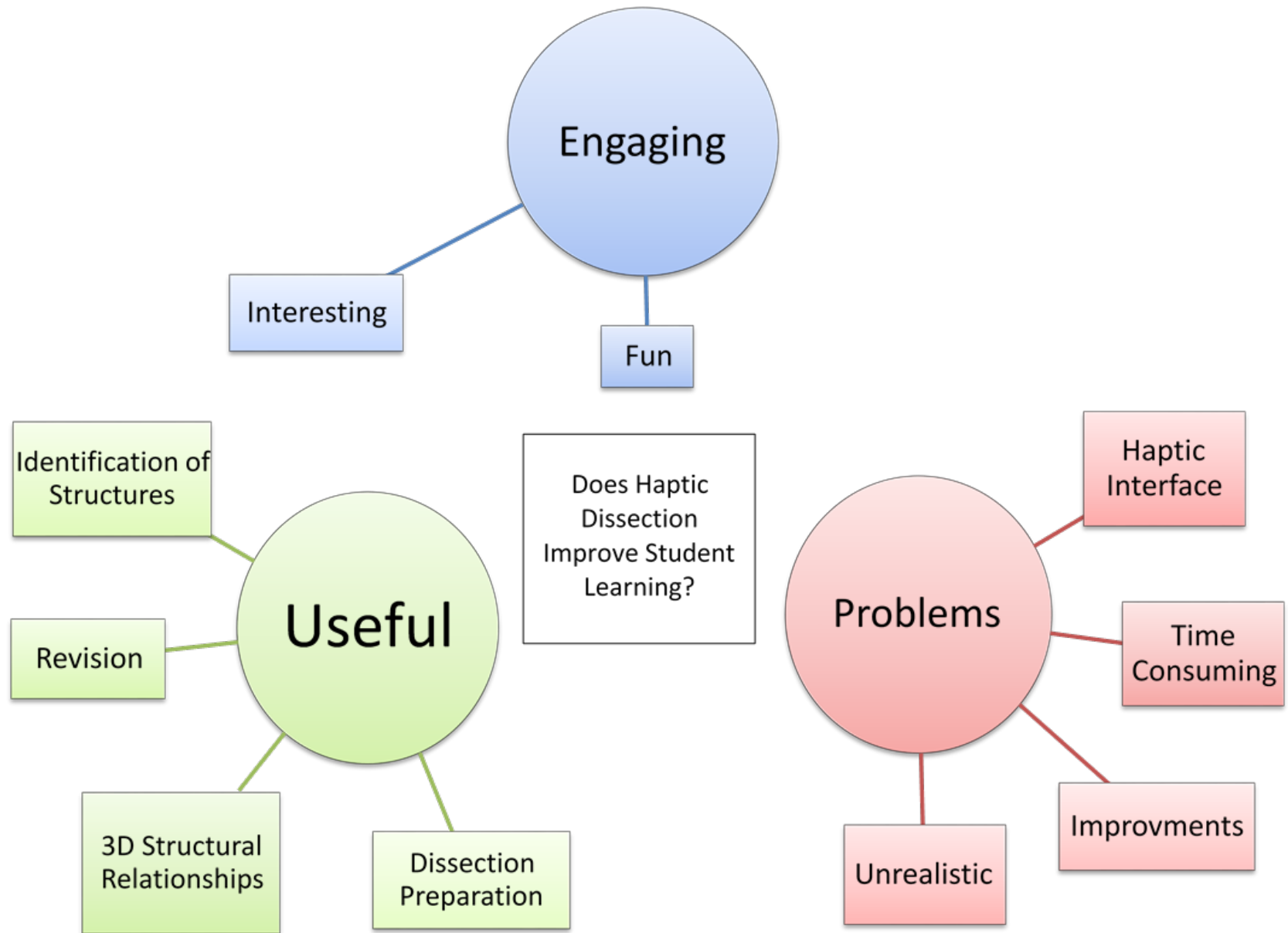
Figure 79, Thematic map of feedback questionnaire responses. Created following the method for thematic analysis outlined by Braun and Clarke (2006).

Comparison of Anatomy Test Results Between Groups Spending Differing Lengths of Time Using the Model

No student used either version of the model for more than five hours, with a little over 40% using it for less than one hour. It is possible that with increased exposure to the haptic device students may find it easier and thus more beneficial to use. The anatomy test results from students who used the haptic version of the model for either 1-2 hours or for over one hour were compared. Statistical analysis was performed using the Mann-Whitney U test. The results from individual students were used for the statistical analysis. There were no significant differences between the two groups.

Differences between Non-haptic and Haptic Groups

Differences between non-haptic and haptic groups were investigated across questions one through nine. Firstly the two phase three groups were compared, followed by combining all non-haptic groups and comparing with all haptic groups combined.

Questions One through Nine – Comparison of Phase Three Groups

Mann-Whitney U Test Results

A Mann-Whitney U test was performed to compare the difference between the phase three non-haptic and haptic groups for questions one through nine. The test showed that the haptic group did not score significantly higher than the non-haptic group. The mean ranks for each group were 8.28 for the non-haptic group and 10.72 for the haptic. The medians were also calculated for each group, with the non-haptic group scoring 3.7 and the haptic group 4.

Questions One through Nine – Comparison of All Groups

Mann-Whitney U Test Results

A Mann-Whitney U test was performed to compare the difference between the all the non-haptic groups and all the haptic groups for questions one through nine. The test showed that the haptic groups did not score significantly higher than the non-haptic groups. The mean ranks for each group were 21.94 for the non-haptic group and 23.70 for the haptic. The medians were also calculated for each group, with the non-haptic group scoring 4 and the haptic group 3.8.

Differences in scores for a number of individual questions were also investigated. The results for the three haptic groups (phases one, two and three) were combined, totalling 29 students and compared with those of the non-haptic groups (phases one and three) totalling 13 students. Only questions where a difference between the haptic and non-haptic groups was expected were investigated. These questions were:

- Question One: How easy and intuitive was the software to use?
- Question Six: Did you enjoy using the software?
- Question Seven: Did the software improve your dissection (i.e. practical) skills?
- Question Nine: Did you feel more confident doing the cadaveric dissection after practicing on the software?

Question One: How easy and intuitive was the software to use?

Mann-Whitney U Test Results

A Mann-Whitney U test was performed to compare the difference between the non-haptic group and haptic groups. The test showed that the haptic groups did not score significantly higher than the non-haptic groups. The mean ranks for each group were

25.38 for the non-haptic group and 19.76 for the haptic. The medians were also calculated for each group, with both groups scoring 3.

Spearman's Rank Order Correlation

A scatterplot and a Spearman's rank order correlation were performed to explore the relationship between the response to feedback question one and the anatomy test scores for all groups. The scatterplot did not appear to show any correlation, however there is one notable outlier within the haptic group (Figure 80).
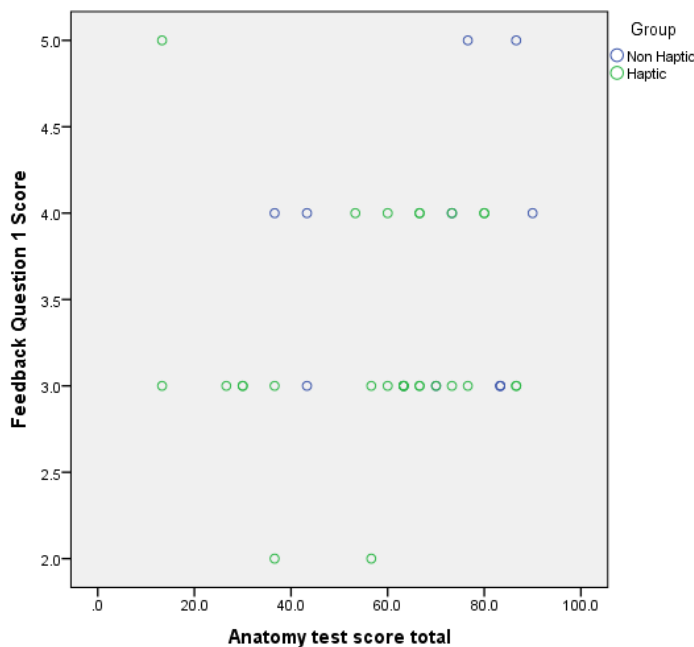
Figure 80, Scatterplot showing the correlation between the response to feedback question one and the anatomy test scores for all groups

With the outlier included, there was no significant positive correlation between the feedback response to question one (How easy and intuitive was the software to use?) and the anatomy test scores (rs = 0.190, p = 0.241, N = 40).

Correlations

			Feedback Question 1 Score	Anatomy test score total
Spearman's rho	Feedback Question 1 Score	Correlation Coefficient	1.000	.190
		Sig. (2-tailed)	.	.241
		N	40	40
	Anatomy test score total	Correlation Coefficient	.190	1.000
		Sig. (2-tailed)	.241	.
		N	40	40

With the outlier excluded, there was still no significant positive correlation between the feedback response to question one (How easy and intuitive was the software to use?) and the anatomy test scores. (r_s = 0.288, p = 0.075, N = 39).

Correlations

			Feedback Question 1 Score	Anatomy test score total
Spearman's rho	Feedback Question 1 Score	Correlation Coefficient	1.000	.288
		Sig. (2-tailed)	.	.075
		N	39	39
	Anatomy test score total	Correlation Coefficient	.288	1.000
		Sig. (2-tailed)	.075	.
		N	39	39

Question Six: Did the software improve your dissection (i.e. practical) skills?

Mann-Whitney U Test Results

A Mann-Whitney U test was performed to compare the difference between the non-haptic group and haptic groups. The test showed that the haptic groups did not score significantly higher than the non-haptic group. The mean ranks for each group were

18.04 for the non-haptic group and 23.05 for the haptic. The medians were also calculated for each group, with both groups scoring 4.

Question Seven: Did the software improve your dissection (i.e. practical) skills?

Mann-Whitney U Test Results

A Mann-Whitney U test was performed to compare the difference between the non-haptic group and haptic groups. The test showed that the haptic groups did not score significantly higher than the non-haptic group. The mean ranks for each group were 18.81 for the non-haptic group and 22.71 for the haptic. The medians were also calculated for each group. The non-haptic group scored 2, while the haptic groups scored 3.

Question Nine: Did the software improve your dissection (i.e. practical) skills? – compare student feedback to staff evaluation

Mann-Whitney U Test Results

A Mann-Whitney U test was performed to compare the difference between the non-haptic group and haptic groups. The test showed that the haptic groups did not score significantly higher than the non-haptic group. The mean ranks for each group were 16.46 for the non-haptic group and 23.76 for the haptic. The medians were also calculated for each group. The non-haptic group scored 2, while the haptic groups scored 3.

Discussion of Feedback Questionnaire Results

While there were no significant differences between the feedback scores of the groups for any of the above questions this may be due to the small sample sizes available. Although not statistically significant it is interesting to note that the highest scoring group

across all phases was the BSc haptic group from phase three and the lowest scoring group was the BSc non-haptic group from the same phase. The next lowest feedback score came from the MSc haptic group in phase one. It may be that the MSc students, being a little older and with more educational and often professional experience had higher expectations, and were therefore more critical. These figures largely fit with the feedback comments indicating that many students found the haptic interface fun and engaging to use (regardless of whether it improved their anatomy test scores).

The thematic analysis revealed some interesting patterns and themes within the feedback comments. There appeared to be a consensus of opinion regarding what the software is most **useful** for; i*dentification of structures, learning 3D structural relationships* and *revision*. It is inserting to note that none of these require the use of the haptic interface (although the 'labelling mode' is only available while using the haptic device). A number of participants stated that while they had problems with the haptic interface (and therefore didn't find it helpful for dissection preparation), the software was useful for things such as identifying structures and studying their spatial relationships. A large number of participants cited the software's usefulness for revision. While some appeared to be using it as such as a preference, others specified that the module format meant that they had little choice but to use it after cadaveric dissection had taken place. For example, one participant from the phase 2 haptic group stated that although they found it to be a great revision tool they also thought it would be perfect to use between the lecture and dissection. Other stated things like *"useful tool but perhaps not for primary learning"* (Phase 1 non-haptic), indicating that would only use it for revision out of choice. Another stated that *"it would be great to have access to the program at other times as well for revision"* (Phase 2 haptic), indicating that they would like more freedom to choose when to use it.

A fourth sub-theme under 'useful' was *dissection preparation*. This was a more divisive topic as there were around as many participants who stated that the software was not useful for dissection preparation as there were who felt it was. As stated previously this could be related to the individual's spatial ability as well as prior exposure to 3D computer models.

When and how students choose to use the resource (where choice was available) may be an indication of what sort learner they are. For example, those who enjoyed using the haptic interface may be more likely to be kinaesthetic learners. One participant from the phase 3 haptic group actually stated, "*I personally learn more easily be interactions so the haptic component makes it better than other online or virtual things I have tried.*" Others may be more visual and therefore prefer the ability to click through layers and see structure in their entirety, "*Overall the software is good, I enjoyed clicking through the layers and seeing the overall picture*" (Phase 1 haptic). A number of participants also made suggestions for additional textual information such as pop up text boxes and quiz mode. It may be that these individuals prefer a read/write learning style.

A number of **problems** were also identified, relating to; the *haptic interface* and that the dissection was *unrealistic* and *time-consuming*. Opinion on whether the haptic interface was helpful or a hindrance was split. As discussed in depth previously, this may relate to the additional cognitive load it placed upon the user. In addition there were a number of comments describing both the non-haptic and haptic modes of dissection as being unrealistic. Perhaps if the software had been used between the lecture and cadaveric dissection, the intention of it being a 'stepping-stone' between them would have been more apparent. There were several comments relating to the time consuming nature of the software as well as the need to practice using it. This feeling of it being a substantial time commitment may have impacted on the level of student engagement with project, at least for some. Adult learners in particular like to

know why they are learning something and are increasingly oriented around the things they need to know to carry their real-life roles. (Knowles et al, 2014). This is discussed in more depth in section 4.7.

The final sub-theme under 'problems' was *improvements*. The majority of these related to making the interface more intuitive and bespoke to the task at hand and are discussed in depth in section 4.7.

Finally a number of comments were themed under the heading of **engagement**.   This was further broken down into two sub-themes around the software being *fun* and *interesting*. As discussed earlier a distinction was made between individuals finding the software enjoyable and/or interesting to use and finding it useful. While ideally students would find the software both engaging and useful, in practice this is not always the case. In the same way as good teacher may not always be entertaining, and an entertaining teacher may not always be very good. However, there are advantages to educational resources being fun, engaging and interesting, beyond simply the enjoyment of the user. As one participant commented, *"also, it was fun which I'm pretty sure made it more easy to spend time on it. The second time I came down to it I passed 2 hours there and barley saw the time pass"* (Phase 3 haptic).

4.7 LIMITATIONS AND SUGGESTIONS FOR IMPROVEMENT

The hand and wrist model used in this study was created by the author in order to retain control, ensure accuracy and integration with the haptic device. However it must be remembered that this was not a commercial project and no additional funding beyond existing equipment was sought. The resulted in certain limitations and compromises being made which are discussed below.

Dissection and Modelling

Two dissections were undertaken on two differently embalmed cadavers, one formalin and one Thiel embalmed. At the University of Dundee, Thiel embalming replaced formalin embalming entirely in 2014. It is seen by many as being a preferable method of embalming as it retains life-like tissue qualities such as distinct colours and textures as well as greater flexibility (Kerckaert et al., 2008). Having dissected the hands and wrists of cadavers from both preservation methods these differences in colour, texture and flexibility are very apparent. Although the softer tissues of Thiel embalming are on the whole more fragile than those of formalin, they are not so delicate as to hinder the dissection process.

The dissections were undertaken in part to improve the author's anatomical knowledge of the region, but also to aid decision-making regarding the creation of the model and nature of any tissue properties which may be added in the future. Although the model is based upon a template exported from Amira® using the VHP female data it has been extensively re-modelled using the software Freeform® Modelling™. Throughout the modelling process decisions had to be made about how much detail and how realistic the model ought to be. The modelling software itself set certain limitations on detail; for example, it was not possible to model the very fine fascia surrounding muscles and other tissues as it is too thin to model with voxels and haptic feedback. This is because voxels are three-dimensional pixels used for modelling 3D 'solid' shapes. It is collision with these voxels that generates haptic feedback. Fascia, being very thin, is closer to being a 2D surface than a 3D volume and as such voxels are inappropriate for its modelling. Some decisions however were informed by the dissection process rather than the limitations of the software. For example, the greater colour difference observed between tissues in the Thiel dissection made them much easier to tell apart. As the intention for the final software is for it to act as an intermediary between

lectures/textbooks and cadaveric dissection, it was decided that an intermediate level of detail would best reflect this. The muscles, tendons and ligaments are more clearly defined as separate structures than is usually seen in cadaveric dissection (especially formalin embalmed), however they are not so simplified as to be inaccurate or misleading.

Colour could be added to objects within Freeform® ModellingTM in two ways; to the whole piece (piece colour) as a solid colour or to the surface (paint colour) which allows for the option of multiple colours and blending. Each structure type (bone, muscle etc.) was given a different piece colour. The colour was chosen to balance realism (for living or Thiel embalmed tissue) with meaning/ease of use and therefore colours consistent with those commonly used in anatomical illustration, such as blue for veins, red for arteries, yellow for nerves etc. were used. Initially the surface of the muscles was painted to depict the transition from muscle to tendon. However, this was later removed as it significantly increased the file size (from ~20,000kb to ~300,000kb) causing the software to perform poorly with increased system lag.

Prototype Virtual Dissector

The final model could be dissected using FreeForm® Modelling^{TM}, the same software in which it was created. Using FreeForm® Modelling^{TM} as a prototype VR dissector, each anatomical structure can be selected and virtually 'dissected' with the PHANTOM® Desktop™ haptic tool. Three methods of interacting with the model were identified: 1) using a cutting tool to cut through the selected layer; 2) using a selection paintball to first select and then delete the layer; and 3) using planes to cut the selected structure in standard anatomical views.

Use of a haptic interface not only adds the sense of touch but also alters the way in which the user interacts with and views the model. For example, the act of cutting

through the layers of the model (using methods 1 & 2 above) produces a 'window of view' similar to that produced during traditional cadaveric dissection. This is potentially useful in that it forces the user to try and identify anatomical structures from limited information (Figure 81a). Conversely, using a keyboard and mouse interface (as used by all VR human anatomy software packages currently available) would limit users to viewing structures only in their entirety (with the option to make them either invisible or transparent) thus making them easier to identify (Figure 81b).
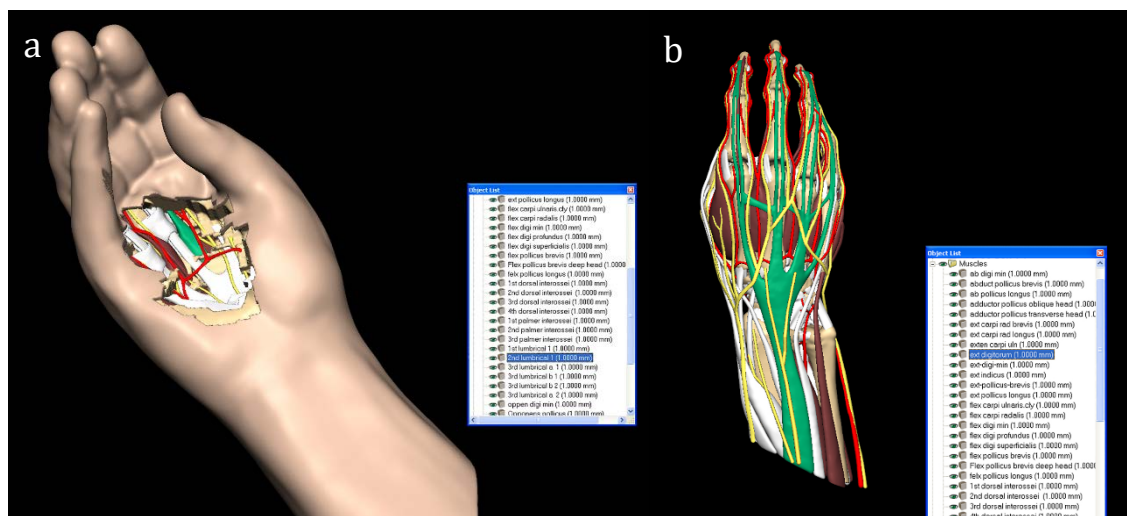
Figure 81a, This image demonstrates the 'window of view' created by use of the haptic cutting device
Figure 81b, This image demonstrates how the entire structure becomes visible when using a keyboard and mouse

As described through by the thematic analysis (section 4.6) many students found the haptic interface to be fun and engaging to use. However, it was also shown that some students found it difficult to use and time consuming to learn. These issues could perhaps be resolved by dedicating more time to its use prior to using it for virtual dissection. It may be beneficial to add a training session that does not include any anatomy but instead focuses solely on navigation and use of the haptic device.

No student used either version of the model for more than five hours, with over 40% using it for less than one hour. Participation in this study was voluntary and as such use of the software and model was not included in the core curriculum. However, if haptic

dissection was to be included at a curriculum level, especially if it were for the full body, students would likely use it for much greater periods of time and it is possible that with such increased exposure students would find it easier and thus beneficial to use.

The addition of a separate training session for students to learn how to use the haptic interface before applying it to anatomy would also have been beneficial. In this way, the intrinsic load of the subject (virtual dissection of the hand) could have been segmented into discreet packages. This would also have likely increased the total duration for which the students used the device, thereby increasing their familiarity with it. That said, the author found it difficult to get enough students to come along to one training session, without being embedded in the curriculum it may not have been possible to get them to come to both.

Although using Freeform® Modelling™ as the interface worked (there was no budget to develop a custom interface), it was not as refined as a bespoke user interface would have been. Limitations included:

Not being able to highlight the structure name with the mouse cursor:

"It would be helpful if you could click on a structure and it highlight the name."

"Maybe to have an option to click on a structure and see what it is."

"To be able to click on a muscle/tendon etc and have it labelled."

"Being able to click on or hover over a structure and have a box come up to tell you what it is."

No search function for structure names (although this was actually possible through search tab at the bottom on the object list):

"Relatively time consuming to have to scroll through everything to find the muscles"

No additional text boxes:

"A lot of time was spent trying to figure out relations/positions of different muscles. Although a text book was provided, would be helpful to see a muscle fact sheet (nerve innervations etc) on the screen, or for them to be highlighted when working with a particular section."

"Maybe add a quiz mode?"

The structures all felt the same:

"Tissues set to hardness they would not be in DR."

"Maybe more different textures between different types of structures like muscle and tendon for example."

Not possible to activate multiple structures:

"The only real downfall is that you cannot dissect through all the tissues, but only the one you have activated. Because of this it was more useful just taking layers off and looking at underlying structures."

"I would also like to see the ability to select whole layers e.g. 'muscle' instead of each muscle individually."

"I would like it to be easier to activate all the items in a folder."

"I think it'd be nice to also be able to dissect all layers together as well as separately, or just a level of structures."

"Possibility of activating more than one element."

 Not being able to make a section through all structures:

"Sections through the model would be nice."

No movement or animations:

"I would be great to (see) the movements of individual structures. Something I found very interesting in the DR was being able to pick out a structure and see how it moved the wrist/digits. By showing a movement and showing the individual structures that caused that movement would be interesting if possible."

As discussed in section 4.1, Cognitive Load Theory (CLT) may help to explain why the haptic interface may be a barrier to learning rather than enhancing it. In addition, a user interface that is difficult to use may increase the extraneous load resulting in an additional strain to the working memory and thus impeding learning (Verhoeven et al., 2009).

Accessibility

One of the limitations to this study was the relatively small number of students who chose to take part, which in turn impacted the reliability of the results. The student cohorts, especially at postgraduate level were not very large to begin with (ranging from five at the smallest to around forty for the BSc groups combined), so it was important that as many as possible took part. Initial interest was high each year, with over 80% of students taking away participant information and consent forms after their briefing at the beginning of the semester. However, when it was time to take part in the study students needed considerable encouragement and reminders to participate. In part this was likely due to them being busy with their studies and informal conversations with a number of students support this. However, the nature of the study and the need for students to use two specific machines located in one room (available 9am to 5pm, Monday to Friday) was also a factor. Students are used to being able to access

information remotely and at a time that suits them using both online resources and mobile 'apps'. Anatomy as a subject has no shortage of either (Lewis et al., 2014, Sugand et al., 2010). Conole et al (2008), in an in-depth study exploring students' experiences of e-learning, describe a number of factors which influenced the way in which students were using technologies. These factors included usability, accessibility and personalisation. The usability of the haptic device and user interface have already been discussed at length. In addition to remote access, accessibility also referred to student's ability to choose modalities that played to their strengths in terms of learning styles and preferences. Finally, personalisation again referred to the freedom to choose and discover technologies for themselves, allowing for a sense of ownership and integration of technologies.

The low number of participants for this study indicates that students were reluctant to use a resource that required the use of specific hardware and software, located on campus and only available weekdays from 9am to 5pm (during which students often have other commitments). This may be different if such a resource formed a part of timetabled teaching. However such a move would require a considerable financial investment to supply enough haptic devices (and high end computers to run them) for a whole class.

As discussed in the introduction, different individuals have different learning preferences. Some students will likely be content with the existing materials, while others may more inclined to try something new if it fits with how they naturally learn. Knowles et al (2014) describe six assumptions about the characteristics of adult learners, some of which may have played a role in the low turnout:

The need to know – Adults prefer to know why they need to learn something before they go about learning it.

The benefits of taking time out to participate in the study and use the software may not have been articulated clearly enough.

The learner's self-concept – Adults have a self-concept as being responsible for their decisions and lives. They need to be seen and treated by others as being capable of self-direction.

As participation in this study was optional, it may not have fitted with how they wished to spend their time. They may have considered other activities to be more worthwhile.

Readiness to learn & Orientation to Learning – Are both oriented increasingly around the things they need to know in order to carry out their real-life roles.

Participation in the study and use of the model may not have been considered relevant to the real life roles they were pursuing.

Finally, while this study was limited to students at the University of Dundee who were undertaking the Gross Anatomy 2 module, it would have been interesting to compare the results of these groups to student cohorts beyond Dundee to see how transferable the results were. It would also have been interesting to compare results across different disciplines, such as anatomy, medicine, and surgery. Such comparisons were limited by the necessity for access to the haptic devices and were not possible within the scope of the current study.

4.8 CHAPTER SUMMARY

This chapter has outlined, interpreted and discussed the results for the anatomy knowledge test, the dissection evaluation and the feedback questionnaire for all phases of the study. A number of statistically significant results were found for the anatomy

knowledge test. However, these failed to support the original hypothesis that the haptic group would score higher than the non-haptic group. Rather, the data gathered indicates that overall, those with access to the non-haptic version of the model performed equal or better than those with access to the haptic version.

While the dissection evaluation results did not indicate any significant differences, it was interesting to note that the group with the best score obtained by one of the haptic groups.

A thematic analysis of the comments from the feedback questionnaire revealed a number of key themes (*Useful*, *Problems* and *Engaging*) that were discussed and illustrated with comments from the data extracts.

Finally, the limitations of the model, interface and research design were outlined, along with suggestions for improvements.

Chapter 5: 'Conclusions and Future Work' summarises the findings of this study and relates these to suggestions for future work.

5: CONCLUSIONS AND FUTURE WORK

This chapter will summarise the overall conclusions that can be drawn from this study as well as outlining possibilities for future work.

5.1 CONCLUSION

The data gathered indicates that overall, those with access to the non-haptic version of the model performed equal or better than those without access and those with access to the haptic version.

Hypothesis 1 (*those students who used the [non-haptic] Dissection Simulator will attain higher test results and produce a better quality cadaveric dissection than those without access*) was found to be true for the anatomy test results overall, but not for the quality of the dissection where there was no significant difference between the groups.

Hypothesis 2 (*those students who use the Haptic Dissection Simulator will attain higher test results and produce a better quality cadaveric dissection than those without access*) was found to be true for the anatomy test results overall, but not for the quality of the dissection where there was no significant difference between the groups.

Hypothesis 3 (*those students who use the Haptic Dissection Simulator will attain higher test results and produce a better quality cadaveric dissection than those using the non-haptic version*) was found to be false for the anatomy test results overall, but not for the quality of the dissection where there was no significant difference between the groups.

These results are likely due to cognitive load being adversely affected by the addition of the haptic device. The fact that such a device was introduced without separate training

likely compounded this effect. Certain limitations of the interface (such as inability to dissect multiple structures, the lack of different tissue properties, easier activation of structures etc.) may also have been more apparent when used with haptic device.

A thematic analysis of the feedback comments suggested that students found the software most useful for, i*dentification of structures, learning 3D structural relationships* and *revision*, all of which are possible without using the haptic interface.

Some students reported that the haptic device was not intuitive to use and took some time to get used to, if at all. No student used either version of the model for more than five hours, with over 40% using it for less than one hour. It is possible that with increased exposure to the haptic device students may find it easier and thus beneficial to use. The findings of this study however indicate that when used for a short period of time only (-5 hours) the haptic device may impede rather than enhance learning.

5.2 FUTURE WORK

Considering the results of this study in combination with the feedback comments received, a number of suggestions for future research are proposed:

1. To create a website containing interactive (but not haptic) 3D models of the hand and wrist. Based upon the same model as used in this study but at various levels of dissection. Repeat the study with the same test and questionnaire, giving students access to the website for two weeks prior and one week after cadaver dissection. Compare the level of student participation and hours spent using the resource with the current study. It would also be possible to invite student cohorts beyond the University of Dundee to take art. It is hypothesised that with the greater accessibility of a web based resource students will be more likely to participate.

2. To use the 3D interactive models hosted on Sketchfab.com with Virtual Reality viewers such as Google Cardboard and/or HTC Vive to give students a stereoscopic view of the anatomy. Repeat the study with the same test and questionnaire, giving students access to the models for two weeks prior and one week after cadaver dissection.

3. To embed use of the model within the curriculum. Ideally this would be placed between the lecture and dissection room sessions. Currently these two sessions follow one another on the same day, so this would require a change to the timetable. Repeat the study with the same test and questionnaire. Compare the level of student participation and hours spent using the resource with the current study. It would also be worthwhile to compare the anatomy test results and feedback against the number of hours the resource (both haptic and non-haptic) was used for. It is hypothesised that once students become comfortable using the haptic interface, that they would outperform the non-haptic group.

The author has already began working on the first of these suggestions by creating a website where the models can be viewed and interacted with in 3D. It is available to view at: www.theinteractivehand.com.

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APPENDICIES

APPENDIX 1: DISSECTION OF THE HAND AND WRIST

Two dissections of the hand and wrist were undertaken in order to:

- Compare and contrast the traditional formalin with the Thiel method (Groscurth et al., 2001) of embalming

- Better understand the 'experience' of dissection in order to replicate it appropriately

- Ascertain the most essential elements of both the anatomy and the dissection process

The first dissection utilised a traditional formalin embalmed cadaver and the second of a Thiel embalmed cadaver. Notes were taken throughout each dissection to record both the sequence of dissection as well as the 'experience', from intellectual, tactile and visual perspectives.

Formalin Embalmed Dissection

Overweight female, late middle aged, left hand and wrist

Day One

- Remove skin and fat of palmar surface from wrist to elbow

- Identify superficial nerves, veins and arteries

- Remove fascia and flexor retinaculum

- Separate muscles from surrounding structures with blunt/gentle dissection

Day Two

- Remove skin and fat from dorsal surface from wrist to elbow

- Identify superficial nerves, veins and arteries

- Identify and cut extensor retinaculum

- Separate muscles from surrounding structures with blunt/gentle dissection

Notes: The skin was reasonably easy to remove as it was quite durable and could therefore be pulled away from the underlying muscles without tearing. It was removed using a scraping motion with the scalpel. The fat was also easy to remove (between 1-3mm in thickness, being thinner towards the wrist), but the superficial nerves and vessels were hard to identify and were removed with the fat layer. The deep fascia was harder to remove, being very thin and adhering strongly to the muscles. The superficial muscles could be easily separated from the surrounding structures usually with the fingers (blunt dissection). The palmar carpal ligament and extensor retinaculum were extremely tough to cut through (using scalpel and scissors). Note that it is a delicate area to dissect using a small scalpel blade (#15). Tools used include: scalpel, forceps, scissors and fingers.

Day Three

- Remove skin and fat from palmar and dorsal surfaces of hand

Day Four

- Continue to remove fat and fascia from hand

- Reveal palmar aponeurosis

Notes: Skin on palmar surface of hand was very tough in places, being much easier to remove on the dorsal surface. It was difficult to remove skin from the fingers, especially palmer surface and increasingly more difficult distally. Difficult to separate and remove

the skin and fascia due to adherence to the bone and a small scalpel blade had to be employed. Fat, fascia and palmar aponeurosis were hard to separate from one another.

Fat and fascia were easier to remove on the dorsal surface. Fat separated from the extensor tendons quite easily. Note inter-tendinous connections of extensor digitorum, should be included in model.

Day Five

- Continue to dissect dorsal surface:

  o Clean and separate muscles

  o Cut extensor ligaments from distal ends of fingers

  o Reflect extensor digitorum tendons, reveals thin layer of fat and fascia over interosseous muscles.

  o Cut through extensor retinaculum to reveal and release extensor digiti minimim

  o Cut and reflect pollicis longus

  o Cut and reflect extensor pollicis longus from extensor retinaculum to distal end of thumb

  o Cut and reflect extensor pollicis brevis from extensor retinaculum to base of 1st metacarpal

- Continue to dissect palmar surface (again more difficult):

  o Remove aponeurosis

  o Cut and reflect palmaris longus (note, it joins/becomes palmar aponeurosis)

  o Observe radial artery entering 1st dorsal interosseous

o   Observe superficial branch of radial nerve

Day Six

- Continue to dissect palmar surface:

    o   Reflect flexor pollicis brevis superficial head

Thiel Dissection

Slim, elderly female. Left hand and wrist

Day One (1.5 hours)

Removed skin and some superficial fat. Skin was very thin. The use of forceps and small scalpel required frequent blade changes and the fingers seemed 'softer' than with the formalin embalming. Tissues were easier to separate from one another and the palm was also easier to dissect. Skin and fat was relatively easy to remove, revealing the fibres of the palmar aponeurosis. There was much more fat on the palm and palmar side of forearm than elsewhere (Figure 82).

Figure 82, Dorsal and palmar surfaces at end of day one

Day Two (1.5 hours)

Removed fascia and subcutaneous fat from around muscles. Tendons and ligaments were quite tough but muscles seemed more fragile and easily torn compared with formalin (Figure 83).

Figure 83, Dorsal and palmar surfaces at end of day Two

Day Three (2.15 hours)

'Tidying up' of existing dissection to better reveal structures. Vessels seemed better preserved and easier to find than in formalin embalmed. Paid particular attention to adductor pollicis (Figure 84). Muscles needed separating through blunt dissection.

Figure 84, Close up of adductor pollicis at end of day three

APPENDIX 2: PHASE ONE CONTROL RESULTS 1 (MSC, 2011)

Year one acted as the control group for the study and therefore had no access to either version of the VR Dissection software. This year the study was open to MSc Human Anatomy students only. The group undertook dissection of the hand and wrist 'as normal', following lectures on the relevant region of anatomy. The year group consisted of four students, three of which took part in the study. Within ten days of completing their dissection the students undertook an anatomy knowledge test consisting of eight question; four 'spot tests' and five multiple choice on the anatomy of the hand and wrist. The quality of the cadaver (one cadaver was dissected between the group) was also evaluated by a qualified anatomist within ten days of dissection being completed. During the time between completion of dissection and evaluation of the cadaver no further invasive procedures were performed.

Anatomy Test 2011 (MSc Human Anatomy)

The individual results of the anatomy test are broken down in to four tables (Tables 15-18); three for each of the spot tests (multiple answers) and one for the multiple choice (single correct answer) questions.

Table 15, Phase one (Control 2011), anatomy test question 1 results

Q1	1	2	3	Total
A	1	1	1	3 (100%)
B	1	1	1	3 (100%)
C	0	0	0	0 (0%)
D	1	1	1	3 (100%)
E	1	1	1	3 (100%)
F	1	1	1	3 (100%)
G	0	0	0	0 (0%)
H	1	1	1	3 (100%)
I	1	0	1	2 (66.6%)
Total	7/9	6/9	7/9	**20/27 (74%)**

Table 16, Phase one (Control 2011), anatomy test question 2 results

Q2	1	2	3	Total
A	1	1	0	2 (66.6%)
B	1	1	0	2 (66.6%)
C	0	0	0	0
D	1	1	0	2 (66.6%)
E	0	1	1	2 (66.6%)
F	1	0	0	1 (33.3)
Total	4/6	4/6	1/6	**9/18 (50%)**

Table 17, Phase one (Control 2011), anatomy test question 3 results

Q3	1	2	3	Total
1	1	1	0	2 (66.6%)
2	1	0	0	1 (33.3%)
5	0	0	0	0 (0%)
6	1	0	0	1 (33.3%)
8	1	0	0	1 (33.3%)
9	1	0	0	1 (33.3%)
10	1	0	0	1 (33.3%)
11	1	0	1	2 (66.6%)
12	1	1	0	2 (66.6%)
13	1	1	1	3 (100%)
Total	9/10	3/10	2/10	**14/30 (46.6%)**

Table 18, Phase one (Control 2011), anatomy test questions 4 – 8 results

	1	2	3	Total
Q4	1	1	1	3 (100%)
Q5	0	1	0	1 (33.3%)
Q6	0	1	1	2 (66.6%)
Q7	1	1	1	3 (100%)
Q8	1	1	0	2 (66.6%)
Total	3/5	5/5	3/5	**11/15 (73.3%)**

Question one consisted of nine elements: the group scored a total of 20 out of 27 (74%), with two questions (Q1, C & G) receiving no correct answers (Table 15). Question two consisted of six elements: the group scored a total of 9 out of 18 (50%), with one question (Q2, C) receiving no correct answers (Table 16). Question three consisted of ten elements: the group scored a total of 14 out of 30 (46.6%), with one question (Q3, 5) receiving no correct answers (Table 17). Question four scored a total of 3 out of 3 (100%). Question five scored a total of 1 out of 3 (33.3%), Question six scored a total of 2 out of 3 (66.6%). Question seven scored a total 3 out of 3 (100%). Finally question eight scored a total 2 out of 3 (66.6%). The total for this section being 11 out of a possible 15 (73.3%) (Table 18).

Dissection Evaluation 2011 (MSc Human Anatomy)

As the student group only consisted of four individuals (three of whom took part in the study), one cadaver was dissected between the group. Therefore, only one dissection evaluation form is available for the group as a whole. Thirteen questions were asked regarding 'how well' different aspects of the dissection had been performed and were scored using a five-point Likert scale, where 1= 'not at all', 2 'somewhat', 3= 'moderately', 4= 'very', and 5= 'extremely'. For these questions therefore a higher score is preferable. One exception to this format is question 8, which asked, 'How much damage to the structure is there?' In this instance a lower score would be preferable. For this reason, this question is looked at in isolation from the others. Question 6 ('how well has the dorsal aspect of the fingers been dissected?') was deemed 'not applicable' by the evaluator as the group had not been asked to do this. Adding together the total score for the Likert scale therefore gave a score of 40 out of a possible 55 points (72.7%) (Table 20).

Question 8, 'how much damage to the structures is there?' was scored at 2 - 'somewhat'.

Table 19, Phase one (Control 2011), number of students in study per cadaver

Table number	Total in group	Total in study
Cadaver 1	4	3

Table 20, Phase one (Control 2011), dissection evaluation results

Table 1	1,2,3
Q1	4 (80%)
Q2	4 (80%)
Q3	3 (60%)
Q4	4 (80%)
Q5	4 (80%)
Q6	NA
Q7	4 (80%)
Q9	4 (80%)
Q10	3 (60%)
Q11	4 (80%)
Q12	3 (60%)
Q13	3 (60%)
Total	**40/55 (72.7%)** **Median = 4** **Mode = 4**

APPENDIX 3: PHASE ONE CONTROL RESULTS 2 (MSC/BMSC, 2012)

Year two acted as an additional control group for the study and students therefore had no access to either version of the VR Dissection software. This year the study was open to both MSc Human Anatomy and BMSc Anatomy students. Nine MSc students took part and one BMSc student. The BMSc students' results for the anatomy test were similar to those of the majority of the MScs, however their dissection evaluation differed dramatically in that they had left a number of areas untouched. It was therefore decided to omit their dissection from the evaluation results as they would unrealistically skew those of the MScs if grouped together, and were of little use as a single entry.

The group undertook dissection of the hand and wrist 'as normal', following lectures on the relevant region of anatomy. Within ten days of completing their dissection the students undertook an anatomy knowledge test consisting of eight questions; four 'spot tests' and five multiple choice on the anatomy of the hand and wrist. The quality of the cadaver dissections were evaluated by an anatomist within ten days of dissection being completed. During the time between completion of dissection and evaluation of the cadaver no further invasive procedures were performed.

Anatomy Test 2012 (MSc Human Anatomy/BMSc Anatomy)

The individual results of the anatomy test are broken down in to four tables (Tables 21-24); three for each of the spot tests (multiple answers) and one for the multiple choice (single correct answer) questions.

Table 21, Phase One (Control 2012), anatomy test question 1 results

Q1	1	2	3	4	5	6	7	8	9	10	Total
A	1	1	1	1	1	1	1	1	1	1	10 (100%)
B	1	1	1	1	1	1	1	1	1	1	10 (100%)
C	0	0	0	0	0	0	0	0	0	0	0 (0%)
D	1	0	1	1	1	0	0	1	1	1	7 (70%)
E	1	0	1	1	1	0	0	1	1	1	7 (70%)
F	1	0	1	1	0	0	0	1	1	1	6 (60%)
G	0	0	0	0	0	0	0	0	0	0	0 (0%)
H	1	1	1	1	0	0	0	1	1	1	7 (70%)
I	1	1	1	1	0	0	0	1	1	1	7 (70%)
Total	7/9	4/9	7/9	7/10	4/9	2/9	2/9	7/9	7/9	7/9	**54/90 (60%)**

Table 22, Phase One (Control 2012), anatomy test question 2 results

Q2	1	2	3	4	5	6	7	8	9	10	Total
A	1	1	1	1	1	0	0	0	0	1	6 (60%)
B	1	1	0	0	0	0	1	1	1	0	5 (50%)
C	0	0	1	0	0	0	0	0	0	1	2 (20%)
D	0	0	0	1	1	1	1	1	1	0	6 (60%)
E	1	1	1	1	1	1	1	1	1	1	10 (100%)
F	0	1	1	0	1	0	1	0	1	1	6 (60%)
Total	3/6	4/6	4/6	3/6	4/6	2/6	4/6	3/6	4/6	4/6	**35/60 (58%)**

Table 23, Phase One (Control 2012), anatomy test question 3 results

Q3	1	2	3	4	5	6	7	8	9	10	Total
1	1	1	1	1	0	1	0	1	0	1	7 (70%)
2	0	1	0	1	1	1	1	1	1	0	7 (70%)
5	0	0	0	1	0	0	0	0	1	0	2 (20%)
6	0	0	0	1	1	0	0	0	1	1	4 (40%)
8	1	1	1	0	1	1	1	0	1	1	8 (80%)
9	1	1	1	1	1	1	1	0	1	1	9 (90%)
10	1	0	1	1	1	1	1	0	1	1	8 (80%)
11	0	1	0	1	1	0	0	0	1	0	4 (40%)
12	1	1	1	1	1	0	0	0	1	1	7 (70%)
13	0	1	1	1	1	1	1	1	1	1	9 (90%)
Total	5/10	7/10	6/10	9/10	8/10	6/10	5/10	3/10	9/10	7/10	**65/100 (65%)**

Table 24, Phase One (Control 2012), anatomy test questions 4 – 8 results

	1	2	3	4	5	6	7	8	9	10	Total
Q4	1	1	1	1	1	1	1	1	1	1	10 (100%)
Q5	1	1	0	1	0	0	0	1	1	1	6 (60%)
Q6	1	1	1	1	0	1	1	1	1	1	9 (90%)
Q7	1	1	1	1	1	1	1	1	1	1	10 (100%)
Q8	1	1	1	1	1	0	0	1	0	0	6 (60%)
Total	5/5	5/5	4/5	5/5	3/5	3/5	3/5	5/5	4/5	4/5	**41/50 (82%)**

Question one consisted of nine elements: the group scored a total of 54 out of 90 (60%), with two questions (Q1, C & G) receiving no correct answers (Table 21). Question two consisted of six elements: the group scored a total of 35 out of 60 (58%) (Table 22). Question three consisted of ten elements: the group scored a total of 65 out of 100 (65%) (Table 23). Question four scored a total of 10 out of 10 (100%). Question five scored a total of 6 out of 10 (60%), Question six scored a total of 9 out of 10 (90%). Question seven scored a total 10 out of 10 (100%). Finally question eight scored a total 6 out of 10 (60%). The total for this section being 41 out of a possible 50 (82%) (Table 24).

Dissection Evaluation 2012 (MSc Human Anatomy)

Three cadavers were dissected between the group. Two cadavers were dissected by groups of four, all of whom were taking part in the study (numbers 28 & 29). The third (number 27) was dissected by a group of three, one of whom took part. Thirteen questions were asked regarding 'how well' different aspects of the dissection had been performed and were scored using a five-point Likert scale, where 1= 'not at all', 2 'somewhat', 3= 'moderately', 4= 'very', and 5= 'extremely'. For these questions therefore a higher score is preferable. One exception to this format is question 8, which asked, 'How much damage to the structure is there?' In this instance a lower score would be preferable. For this reason, this question is looked at in isolation from the others. For the Likert scale questions, cadaver 27 scored 36 out 60 (60%), cadaver 28 scored 53 out of 60 (88.3%) and cadaver 29 scored 45 out of 60 (75%). Adding together the three totals of for the likert scale questions gave a score of 134 out of a possible 180 points (74.4%) (Table 26).

For question 8 'how much damage to the structures is there?' cadaver 27 scored 3 - 'moderately', cadaver 28 scored 1 - 'not at all' and cadaver 29 scored 2 - 'somewhat'.

Table 25, Phase One (Control 2012), number of students in study per cadaver

Table number	Total in group	Total in study
Cadaver 27	3	1
Cadaver 28	4	4
Cadaver 29	4	4

Table 26, Phase One (Control 2012), dissection evaluation results

	Table 27: 1	Table 28: 2, 3, 4, 5	Table 29: 6, 7, 8, 9	Total
Q1	2	4	5	11 (73.3%) median 4 mode 2*
Q2	3	4	4	11 (73.3%) median 4 mode 4
Q3	3	4	4	11 (73.3%) median 4 mode 4
Q4	4	5	4	13 (86.6%) median 4 mode 4
Q5	4	5	4	13 (86.6%) median 4 mode 4
Q6	1	5	1	7 (46.6%) median 1 mode 1
Q7	3	4	4	11 (73.3%) median 4 mode 4
Q9	4	4	4	12 (80%) median 4 mode 4
Q10	1	3	3	7 (46.6%) median 3 mode 3
Q11	3	5	5	13 (86.6%) median 5 mode 5
Q12	4	5	3	12 (80%) median 4 mode 3*
Q13	4	5	4	13 (86.6%) median 4 mode 4
Total	**36/60 (60%)**	**53/60 (88.3%)**	**45/60 (75%)**	**134/180 (74.4%) Median = 4 Mode = 4**

* Multiple modes exist. The smallest value is shown

APPENDIX 4: PHASE ONE CONTROL GROUPS; COMBINED RESULTS (MSC, 2011 & MSC/BMSC, 2012)

A total of twelve students took part over the two control years. Their results have been added together to create a larger single control group.

Anatomy Test Combined 2011/12; Full Breakdown (MSc Human Anatomy/BMSc Anatomy)

The individual results of the anatomy test are broken down in to four tables (Tables 27-30); three for each of the spot tests (multiple answers) and one for the multiple choice (single correct answer) questions.

Table 27, Phase One Control years combined (2011/12), anatomy test question 1 results

Q1	1	2	3	1b	2b	3b	4b	5b	6b	7b	8b	9b	10b	Total
A	1	1	1	1	1	1	1	1	1	1	1	1	1	13 (100%)
B	1	1	1	1	1	1	1	1	1	1	1	1	1	13 (100%)
C	0	0	0	0	0	0	0	0	0	0	0	0	0	0 (0%)
D	1	1	1	1	0	1	1	1	0	0	1	1	1	10 (76.9%)
E	1	1	1	1	0	1	1	1	0	0	1	1	1	10 (76.9%)
F	1	1	1	1	0	1	1	0	0	0	1	1	1	9 (69.2%)
G	0	0	0	0	0	0	0	0	0	0	0	0	0	0 (0%)
H	1	1	1	1	1	1	1	0	0	0	1	1	1	10 (100%)
I	1	0	1	1	1	1	1	0	0	0	1	1	1	9 (69.2%)
Total	7/9 77.7%	6/9 66.6%	7/9 77.7%	7/9 77.7%	4/9 44.4%	7/9 77.7%	7/9 77.7%	4/9 44.4%	2/9 22.2%	2/9 22.2%	7/9 77.7%	7/9 77.7%	7/9 77.7%	**74/117 63.2%**

Table 28, Phase One Control years combined (2011/12), anatomy test question 2 results

Q2	1	2	3	1b	2b	3b	4b	5b	6b	7b	8b	9b	10b	Total
A	1	1	0	1	1	1	1	1	0	0	0	0	1	8 (61.5%)
B	1	1	0	1	1	0	0	0	0	1	1	1	0	7 (53.8%)
C	0	0	0	0	0	1	0	0	0	0	0	0	1	2 (15.3%)
D	1	1	0	0	0	0	1	1	1	1	1	1	0	8 (61.5%)
E	0	1	1	1	1	1	1	1	1	1	1	1	1	9 (69.2%)
F	1	0	0	0	1	1	0	1	0	1	0	1	1	7 (53.8%)
Total	4/6 66.6%	4/6 66.6%	1/6 16.6%	3/6 50%	4/6 66.6%	4/6 66.6%	3/6 50%	4/6 66.6%	2/6 33%	4/6 66.6%	3/6 50%	4/6 66.6%	4/6 66.6%	**41/78** **52.5%**

Table 29, Phase One Control years combined (2011/12), anatomy test question 3 results

Q3	P1	P2	P3	P1b	P2b	P3b	P4b	P5b	P6b	P7b	P8b	P9b	P10b	Total
1	1	1	0	1	1	1	1	0	1	0	1	0	1	9 (69.2%)
2	1	0	0	0	1	0	1	1	1	1	1	1	0	8 (61.5%)
5	0	0	0	0	0	0	1	0	0	0	0	1	0	2 (15.4%)
6	1	0	0	0	0	0	1	1	0	0	0	1	1	5 (38.4%)
8	1	0	0	1	1	1	0	1	1	1	0	1	1	9 (69.2%)
9	1	0	0	1	1	1	1	1	1	1	0	1	1	10 (76.9%)
10	1	0	0	1	0	1	1	1	1	1	0	1	1	9 (69.2%)
11	1	0	1	0	1	0	1	1	0	0	0	1	0	5 (38.4%)
12	1	1	0	1	1	1	1	1	0	0	0	1	1	9 (69.2%)
13	1	1	1	0	1	1	1	1	1	1	1	1	1	12 (92.3%)
Total	9/10 90%	3/10 30%	2/10 20%	5/10 50%	7/10 70%	6/10 60%	9/10 90%	8/10 80%	6/10 60%	5/10 50%	3/10 30%	9/10 90%	7/10 70%	**78/130 41.6%**

Table 30, Phase One Control years combined (2011/12), anatomy test questions 4-8 results

	1	2	3	1b	2b	3b	4b	5b	6b	7b	8b	9b	10b	Total
Q4	1	1	1	1	1	1	1	1	1	1	1	1	1	13 (100%)
Q5	0	1	0	1	1	0	1	0	0	0	1	1	1	7 (53.8%)
Q6	0	1	1	1	1	1	1	0	1	1	1	1	1	11 (84.6%)
Q7	1	1	1	1	1	1	1	1	1	1	1	1	1	13 (100%)
Q8	1	1	0	1	1	1	1	1	0	0	1	0	0	8 (61.5%)
Total	3/5 60%	5/5 100%	3/5 60%	5/5 100%	5/5 100%	4/5 80%	5/5 100%	3/5 60%	3/5 60%	3/5 60%	5/5 100%	4/5 80%	4/5 80%	**52/65 80%**

Question one consisted of nine elements: the group scored a total of 74 out of 117 (63.2%), with two questions (Q1, C & G) receiving no correct answers (Table 27). Question two consisted of six elements: the group scored a total of 41 out of 78 (52.5%), with one question (Q2, C) receiving only two correct answers (Table 28). Question three consisted of ten elements: the group scored a total of 78 out of 130 (41.6%) (Table 29). Question four scored a total of 13 out of 13 (100%). Question five scored a total of 7 out of 13 (53.8%). Question six scored a total of 11 out of 13 (84.6%). Question seven scored a total 13 out of 13 (100%). Finally question eight scored a total 8 out of 13 (61.5%) (Table 46). The total for this section being 52 out of a possible 65 (80%) (Table 30).

Anatomy Test Combined 2011/12; Comparison of Results (MSc Human Anatomy/BMSc Anatomy)

The following tables (Tables 31-34) compare the overall totals for each question from control years one, two and combined.

Table 31, Phase One Control years compared (2011/12), anatomy test question 1 results

Q1	Y1	Y2	COM
A	100%	100%	100%
B	100%	100%	100%
C	0%	0%	0%
D	100%	70%	85%
E	100%	70%	85%
F	100%	60%	80%
G	0%	0%	0%
H	100%	70%	85%
I	66.6%	70%	68.3%
Mean	**74%**	**60%**	**67%**

Table 32, Phase One Control years compared (2011/12), anatomy test question 2 results

Q2	Y1	Y2	COM
A	66.6	60%	63.3%
B	66.6%	50%	58.3%
C	0%	20%	10%
D	66.6%	60%	63.3%
E	66.6%	100%	83.3%
F	33.3%	60%	46.6%
Mean	50%	58%	54.1%

Table 33, Phase One Control years compared (2011/12), anatomy test question 3 results

Q3	Y1	Y2	COM
1	66.6%	70%	68.3%
2	33.3%	70%	51.7%
5	0%	20%	10%
6	33.3%	40%	36.7%
8	33.3%	80%	56.7%
9	33.3%	90%	61.7%
10	33.3%	80%	56.7%
11	66.6%	40%	53.3%
12	66.6%	70%	68.3%
13	100%	0%	50%
Mean	**46.6%**	**65%**	**51.3%**

Table 34, Phase One Control years compared (2011/12), anatomy test questions 4-8 results

	Y1	Y2	COM
Q4	100%	100%	100%
Q5	33.3%	60%	46.7%
Q6	66.6%	90%	78.3%
Q7	100%	100%	100%
Q8	66.6%	60%	63.3%
Mean	73.3%	82%	77.6%

Question one consisted of nine elements: the first control group scored a total of 74% and the second 60%, and a combined result of 67%. Two questions (Q1, C & G) received no correct answers (Table 31). Question two consisted of six elements: the first control group scored a total of 50% and the second 58%, and a combined result of 54.1% (Table 32). Question three consisted of ten elements: the first control group scored a total of 44.6% and the second 65%, and a combined result of 51.3% (Table 33). For question four both groups scored a total of 100%. For question five the first group scored a total of 33.3% and the second 60%, and a combined result of 46.7%. For question six the first group scored a total of 66.6% and the second 90%, and a combined result of 78.3%. For question seven both groups scored 100%. Finally for question eight the first group scored a total of 66.6% and the second 60%, and a combined total of 63.3%. The total for this section was 73.3% for the first group, 82% for the second and 77.6% combined score (Table 34).

Dissection Evaluation 2011-12 (MSc Human Anatomy)

Thirteen questions were asked regarding 'how well' different aspects of the dissection had been performed and were scored using a five-point Likert scale, where 1= 'not at all', 2 'somewhat', 3= 'moderately', 4= 'very', and 5= 'extremely'. For these questions therefore a higher score is preferable. One exception to this format is question 8, which asked, 'How much damage to the structure is there?' In this instance a lower score would be preferable. For this reason, this question is looked at in isolation from the others (Figure 85). The Likert scale questions scored a combined total of 174 out of a possible 235 (74%) (Table 35).

For question 8 'how much damage to the structures is there?' the cadaver from year one scored 2 – 'somewhat'. During year two cadaver 27 scored 3 - 'moderately', cadaver 28 scored 1 - 'not at all' and cadaver 29 scored 2 - 'somewhat' (Figure 85).
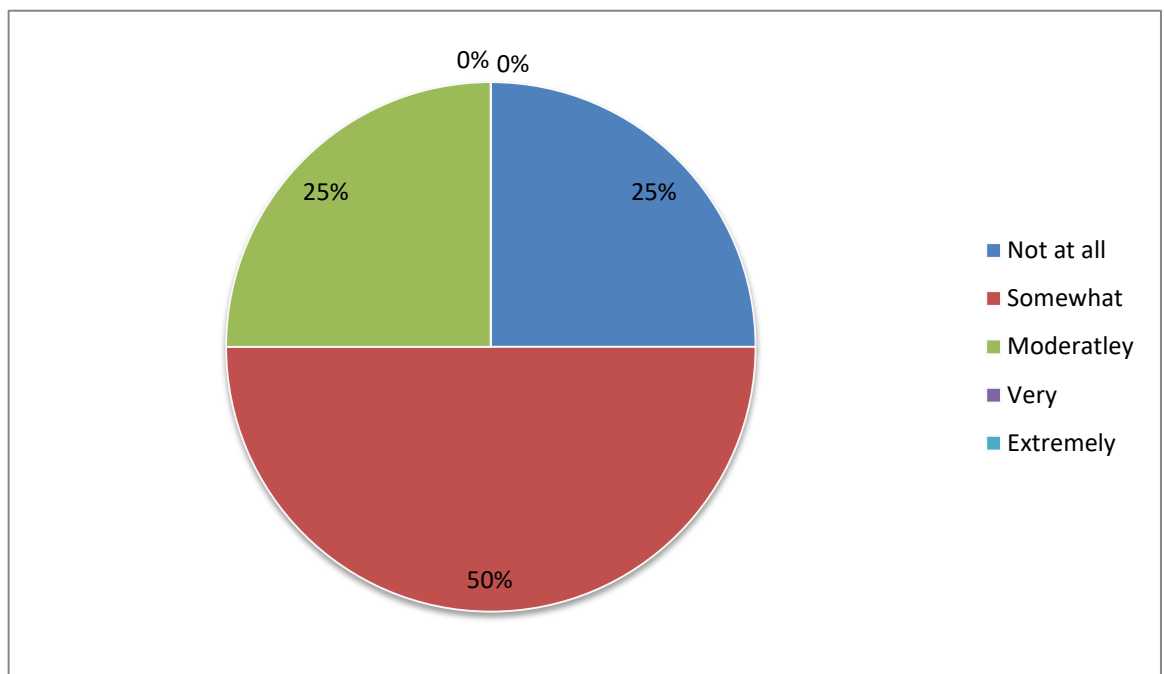
Figure 85, Question 8: How much damage to the structures is there? Phase One combined control years

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Table 35, Phase One Control years compared (2011/12), dissection evaluation results

	2011	2012	Total
Q1	4 (80%)	4 (73.3%)	15/20 (75%) median 4/mode 4
Q2	4 (80%)	4 (73.3%)	15/20 (75%) median 4/mode 4
Q3	3 (60%)	4 (73.3%)	14/20 (70%) median 3.5/mode 3*
Q4	4 (80%)	4 (86.6%)	17/20 (85%) median 4/mode 4
Q5	4 (80%)	4 (86.6%)	17/20 (85%) median 4/mode 4
Q6	NA	1 (46.6%)	7/15 (46.6%) median 1/mode 1
Q7	4 (80%)	4 (73.3%)	15/20 (75%) median 4/mode 4
Q9	4 (80%)	4 (80%)	16/20 (80%) median 4/mode 4
Q10	3 (60%)	3 (46.6%)	10/20 (50%) median 3/mode 3
Q11	4 (80%)	5 (86.6%)	17/20 (85%) median 4.5/mode 5
Q12	3 (60%)	4 (80%)	15/20 (75%) median 3.5/mode 3
Q13	3 (60%)	4 (86.6%)	16/20 (80%) median 4/mode 4
Total	40/55 (72.7%)	134/180 (74.4%)	174/235 (74%) Median = 4 Mode = 4

* Multiple modes exist. The smallest value is shown

APPENDIX 5: PHASE ONE NON-HAPTIC RESULTS (MSC/BMSC, 2013)

The testing of the non-haptic version of the model took place during year three. This year the study was open to both MSc Human Anatomy and Anatomy and Advanced Forensic Anthropology students, and BMSc Anatomy students. Seven students took part in total; two MSc Human Anatomy students, three MSc Anatomy and Advanced Forensic Anthropology students and three BMSc Anatomy students.

The group has access to the non-haptic version of the software in addition to their normal tuition from two weeks before to one week after cadaveric dissection of the hand and wrist took place. Use of the software was optional and tuition was provided at regular intervals during the time the software was available (3 tutorials, one per week). Within ten days of completing their dissection the students undertook an anatomy knowledge test consisting of eight questions; four 'spot tests' and five multiple choice on the anatomy of the hand and wrist. The quality of the cadaver dissections were evaluated by an anatomist within ten days of dissection being completed. During the time between completion of dissection and evaluation of the cadaver no further invasive procedures were performed. Students were also asked to complete a feedback questionnaire on how on how useful they felt the software to be.

Anatomy Test 2013 (MScs Human Anatomy and Anatomy & Advanced Forensic Anthropology/BMSc Anatomy)

The individual results of the anatomy test are broken down in to four tables (Tables 36-39); three for each of the spot tests (multiple answers) and one for the multiple choice (single correct answer) questions.

Table 36, Phase One (Non-haptic 2013), anatomy test question 1 results

Q1	1	2	3	4	5	6	7	Total
A	1	1	1	1	1	1	1	7/7 (100%)
B	0	1	1	1	1	1	1	6/7 (85.7%)
C	1	1	0	0	0	0	0	2/7 (28.5%)
D	1	1	1	1	1	1	0	6/7 (85.7%)
E	1	1	1	1	1	1	0	6/7 (85.7%)
F	1	1	1	1	1	1	1	7/7 (100%)
G	0	0	0	0	0	0	0	0/7 0%)
H	1	1	1	1	1	0	1	6/7 (87.5%)
I	1	1	1	1	1	1	1	7/7 (100%)
Total	7/9 77.7%	8/9 88.8%	7/9 77.7%	7/9 77.7%	7/9 77.7%	7/9 77.7%	5/9 55.5%	**47/63 (74.6%)**

Table 37, Phase One (Non-haptic 2013), anatomy test question 2 results

Q2	1	2	3	4	5	6	7	Total
A	1	1	1	1	1	1	1	7/7 (100%)
B	1	1	1	1	1	1	1	7/7 (100%)
C	1	1	0	0	0	1	0	3/7 (42.8%)
D	1	1	1	1	1	1	1	7/7 100%)
E	1	1	1	1	1	1	1	7/7 (100%)
F	1	0	0	0	1	1	0	3/7 (42.8%)
Total	6/6 100%	5/6 83.3%	4/6 66.6%	4/6 66.6%	5/6 83.3%	6/6 100%	4/6 66.6%	**34/42 (80.9%)**

Table 38, Phase One (Non-haptic 2013), anatomy test question 3 Results

Q3	1	2	3	4	5	6	7	Total
1	1	1	1	1	0	1	1	6/7 (85.7%)
2	1	1	1	1	1	1	1	7/7 (100%)
5	1	1	1	0	1	0	0	4/7 (57.1%)
6	1	1	1	0	1	0	0	4/7 (57.1%)
8	1	0	1	1	1	1	1	6/7 (85.7%)
9	1	1	1	1	1	1	1	7/7 (100%)
10	1	1	1	1	1	1	1	7/7 (100%)
11	1	1	1	1	0	0	1	5/7 (71.4%)
12	1	1	1	1	0	1	1	6/7 (85.7%)
13	1	1	1	1	1	1	1	7/7 (100%)
Total	10/10 100%	9/10 90%	10/10 100%	8/10 80%	7/10 70%	7/10 70%	8/10 80%	**59/70 (84.2%)**

Table 39, Phase One (Non-haptic 2013), anatomy test questions 4-8 results

	1	2	3	4	5	6	7	Total
Q4	1	1	1	1	1	1	1	7/7 (100%)
Q5	1	0	0	0	1	1	0	3/7 (42.8%)
Q6	0	1	1	1	0	1	1	5/7 (71.4%)
Q7	1	1	1	1	1	1	1	7/7 (100%)
Q8	1	1	1	0	1	1	1	6/7 (85.7%)
Total	4/5	4/5	4/5	3/5	4/5	5/5	4/5	**28/35 (80%)**
	80%	80%	80%	60%	80%	100%	80%	

Question one consisted of nine elements: the group scored a total of 47 out of 63 (74.6%), with one question (Q1, G) receiving no correct answers (Table 36). Question two consisted of six elements: the group scored a total of 34 out of 42 (80.9%) (Table 37). Question three consisted of ten elements: the group scored a total of 59 out of 70 (84.2%) (Table 38). Question four scored a total of 7 out of 7 (100%). Question five scored a total of 3 out of 7 (42.8%), Question six scored a total of 5 out of 7 (71.4%). Question seven scored a total 7 out of 7 (100%). Finally question eight scored a total 6 out of 7 (85.7%). The total for this section being 28 out of a possible 35 (80%) (Table 39).

Dissection Evaluation 2013 (MScs Human Anatomy and Anatomy & Advanced Forensic Anthropology/BMSc Anatomy)

Seven cadavers were dissected between the group. Each student dissected a different cadaver with students who were not taking part in the study. Each group consisted of three or four students per cadaver. Thirteen questions were asked regarding 'how well' different aspects of the dissection had been performed and were scored using a five-point Likert scale, where 1= 'not at all', 2 'somewhat', 3= 'moderately', 4= 'very', and 5= 'extremely'. For these questions therefore a higher score is preferable. One exception to this format is question 8, which asked, 'How much damage to the structure is there?' In this instance a lower score would be preferable. For this reason, this question is looked at in isolation from the others (Figure 86). For the Likert scale questions, cadaver 9 scored 39 out 60 (65%), cadaver 10 scored 39 out of 60 (65%), cadaver 12 scored 343 out of 60 (71.6%), cadaver 15 scored 40 out of 60 (66%), cadaver 22 scored 45 out of 60 (75%), cadaver 24 scored 48 out of 60 (80%) and cadaver 30 scored 32 out of 60 (53.3%). Adding together the seven totals of for the likert scale questions gave a score of 286 out of a possible 420 points (68%) (Table 41).

For question 8 'how much damage to the structures is there?' table 9 scored 2 - 'somewhat', table 10 scored 3 - 'moderately', table 12 scored 1 - 'not at all', table 15 scored 2 - 'somewhat', table 22 scored 1 - 'not at all', table 24 scored 1 - 'not at all', and table 30 scored 2 – 'somewhat' (Figure 86).
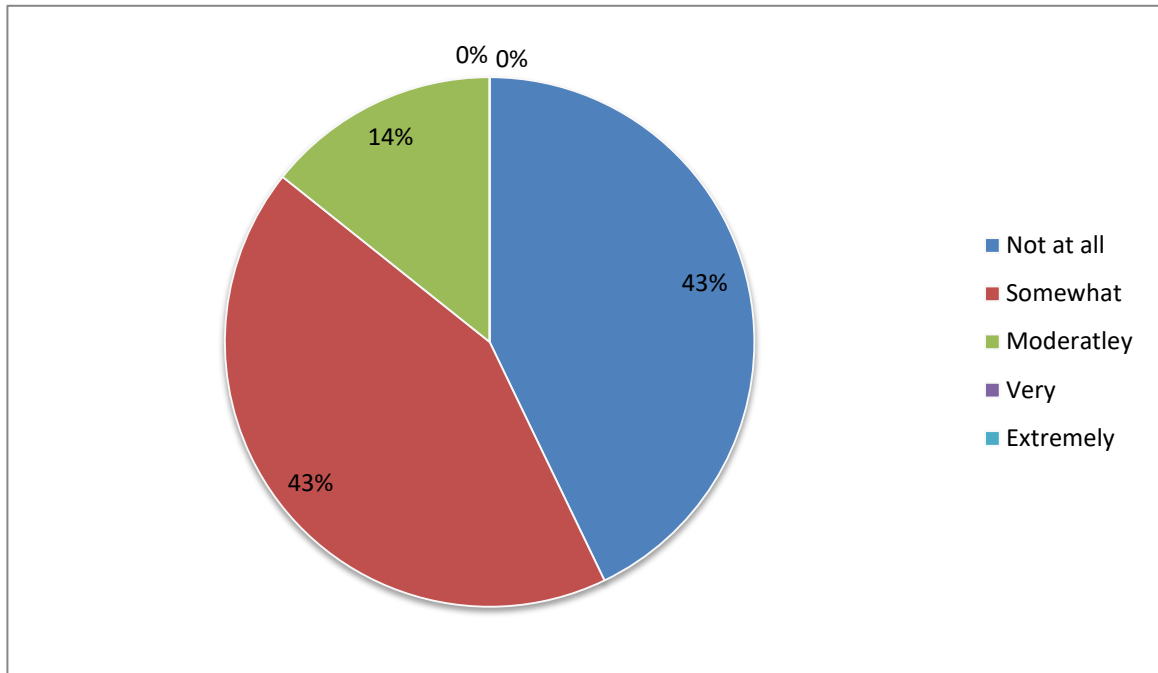
Figure 86, Question 8: How much damage to the structures is there? Phase One 2013, non-haptic group

Table 40, Phase One (Non-haptic 2013), Number of students in study per cadaver

Table number	Total in group	Total in study
9	4	1
10	4	1
12	3	1
15	3	1
22	4	1
24	3	1
30	4	1

Table 41, Phase One (Non-haptic 2013), Dissection evaluation results

	9: 2	10: 3	12: 7	15: 1	22: 4	24: 6	30: 5	Total
Q1	4	3	4	4	4	4	3	26/35 (74.3%) median 4 /mode 4
Q2	4	4	4	4	4	4	3	27/35 (77.1%) median 4 /mode 4
Q3	3	3	3	3	3	4	2	21/35 (60%) median 3/mode 3
Q4	4	4	3	4	5	4	4	28/35 (80%) median 4/mode 4
Q5	4	3	3	4	5	4	3	26/35 (74.3%) median 4/mode 3*
Q6	1	2	3	3	3	3	1	16/35 (45.7%) median 3/mode 3
Q7	4	4	4	4	4	5	4	29/35 (82.8%) median 4/mode 4
Q9	2	4	5	4	4	4	4	27/35 (77.1%) median 4/mode 4
Q10	4	4	3	2	2	4	1	20/35 (57.1%) median 3/mode 4
Q11	3	2	4	2	5	4	1	21/35 (60%) median 3/mode 2*
Q12	3	3	4	3	3	4	3	23/35 (65.7%) median 3/mode 3
Q13	3	3	3	3	3	4	3	22/35 (62.8%) median 3/mode 3
Total	39/60 (65%)	39/60 (65%)	43/60 (71.6)	40/60 (66.6)	45/60 (75%)	48/60 (80%)	32/60 (53.3%)	286/420 (68%) Median = 4 Mode = 4

* Multiple modes exist. The smallest value is shown

Feedback Questionnaire 2013 (MScs Human Anatomy and Anatomy & Advanced Forensic Anthropology/BMSc Anatomy)

The feedback questionnaire consisted of a total of fifteen questions. The first 9 of these were scored using a five-point Likert scale and asked questions such as how easy or enjoyable the software was to use or how the student felt it would improve their practical skills etc. where 1= 'not at all', 2 'somewhat', 3= 'moderately', 4= 'very', and 5= 'extremely'. For these questions therefore a higher score is preferable. Following this there were two 'closed' questions asking, 'how much time did you spend using the software?' And 'how many training sessions did you attend?' These were followed by three 'open' questions asking, 'if you used the keyboard and mouse interface how do you feel this affected your experience?' 'If you used the haptic interface how much do you feel this affected your experience?' And 'what improvements would you like to see made to the software?' Finally there was a space for 'any other comments?'

The results for questions 1-9 can be found in the following Table (41) and Figures (87-95).

Table 42, Phase One (Non-haptic 2013), Questionnaire results, questions 1-9

	1	2	3	4	5	6	7	Total
Q1	4	5	3	4	5	3	3	27/35 (77.1%) median 4/mode 3
Q2	4	4	3	4	4	4	5	28/35 (80%) median 4/mode 4
Q3	4	5	3	4	4	3	5	28/35 (80%) median 4/mode 4
Q4	5	5	4	4	5	3	4	30/35 (85.7%) median 4/mode 4*
Q5	5	4	4	3	5	3	5	29/35 (82.8%) median 4/mode 5
Q6	4	3	3	5	5	4	4	28/35 (80%) median 4/mode 4
Q7	3	4	1	1	1	2	3	15/35 (42.8%) median 2/mode 1
Q8	4	4	2	4	5	4	5	28/35 (80%) median 4/mode 4
Q9	4	1	1	3	1	4	3	17/35 (48.5%) median 3/mode 1
Total	37/45	35/45	24/45	32/45	35/45	30/45	37/45	230/315 (73%) **Median = 4** **Mode = 4**

* Multiple modes exist. The smallest value is shown
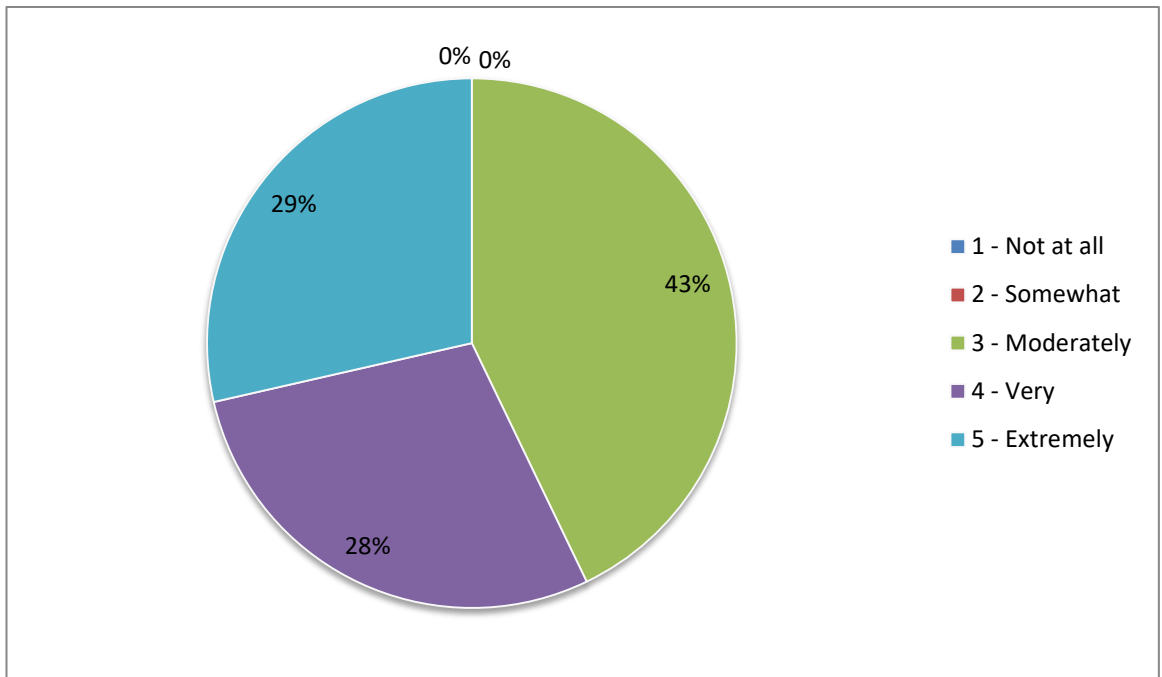
Figure 87, Question 1: How easy and intuitive was the software to use? Phase One 2013, non-haptic
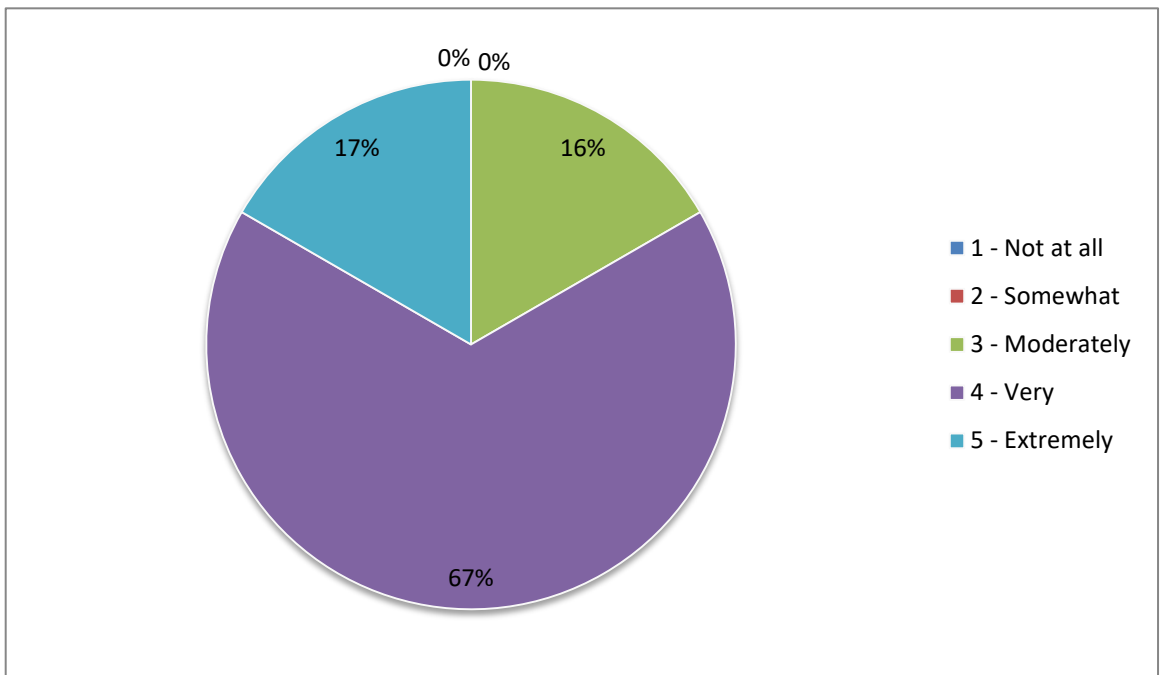
Figure 88, Question 2: How useful was the training session? Phase One 2013, non-haptic group
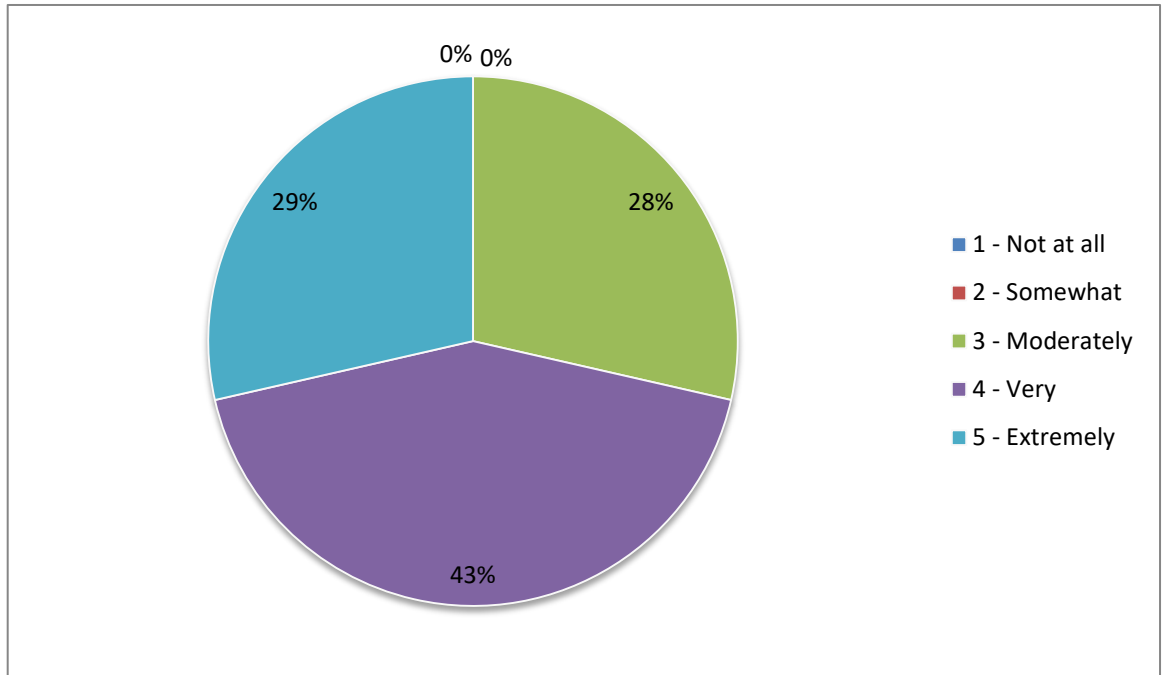
Figure 89, Question 3: How helpful was the dissection manual? Phase One 2013, non-haptic
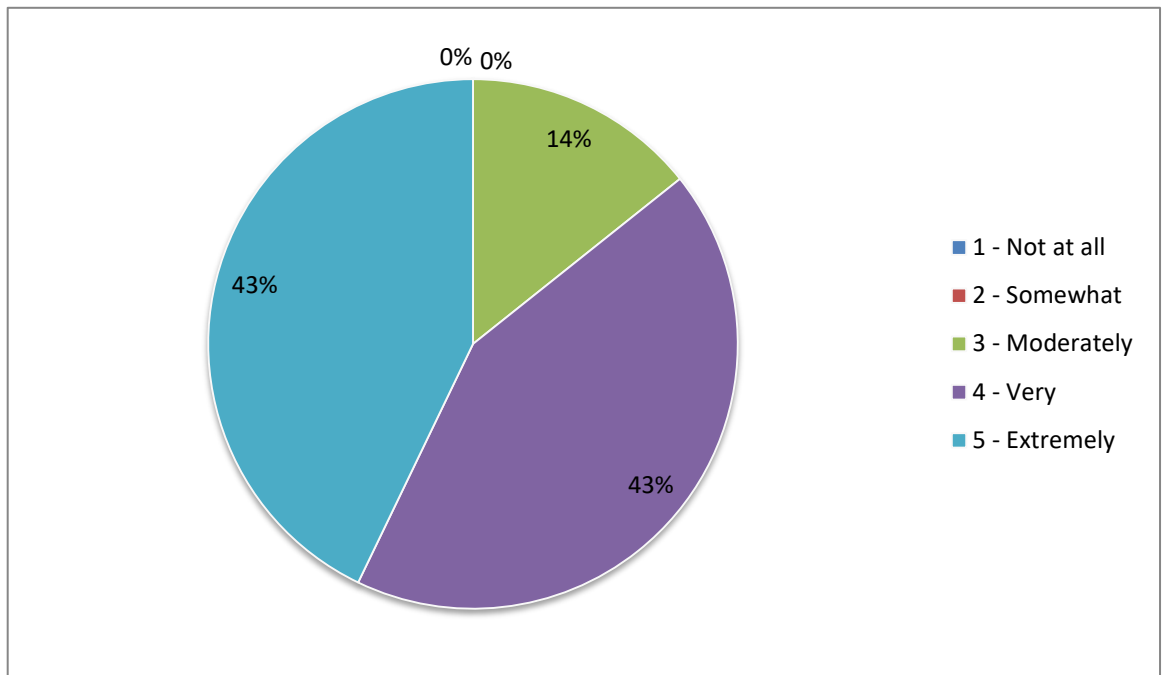
Figure 90, Question 4: Is the model anatomically accurate? Phase One 2013, non-haptic
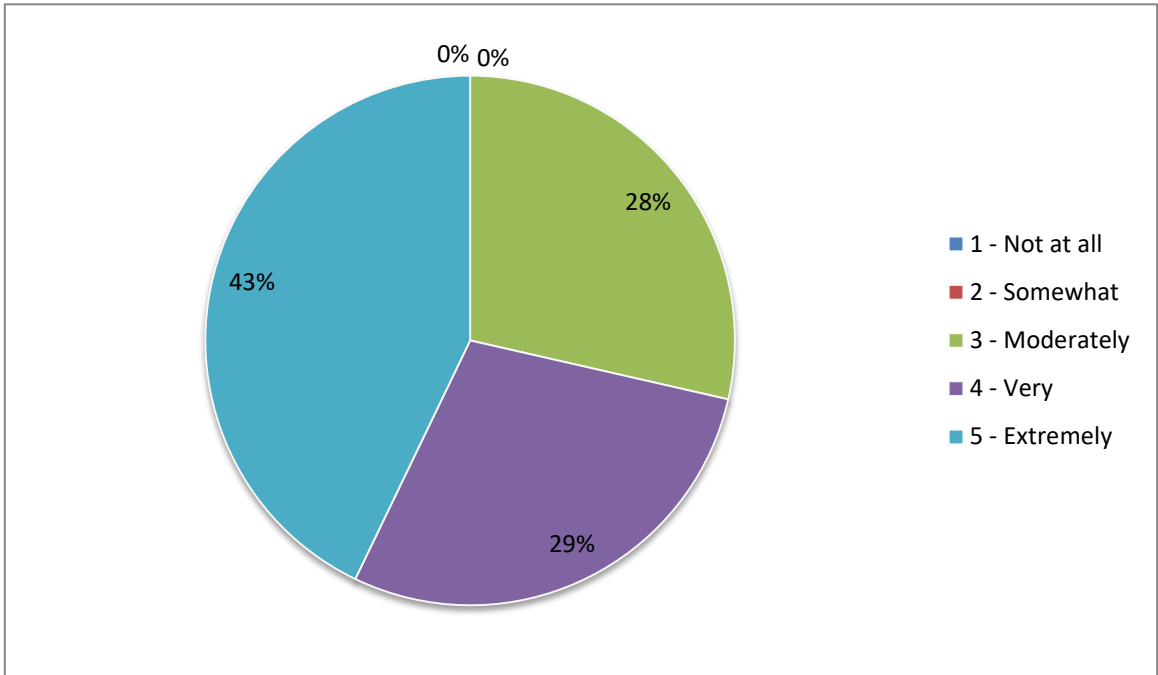
Figure 91, Question 5: How appropriate is the level of detail in the model? Phase One 2013, non-haptic
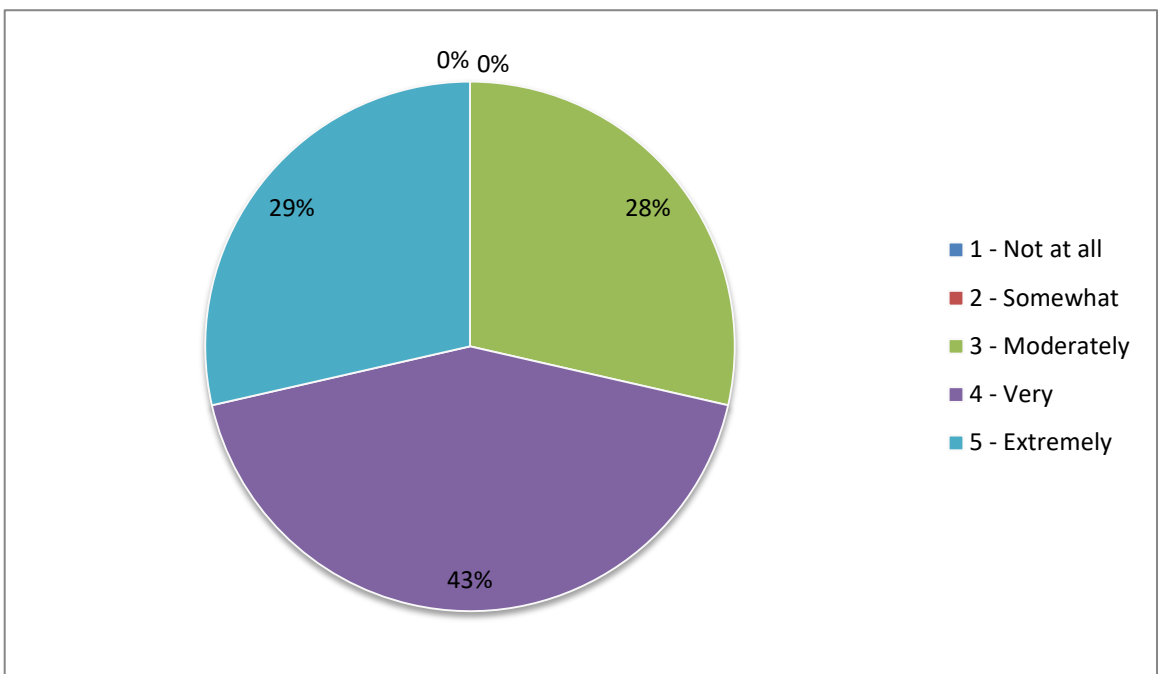
Figure 92, Question 6: Did you enjoy using the software? Phase One 2013, non-haptic
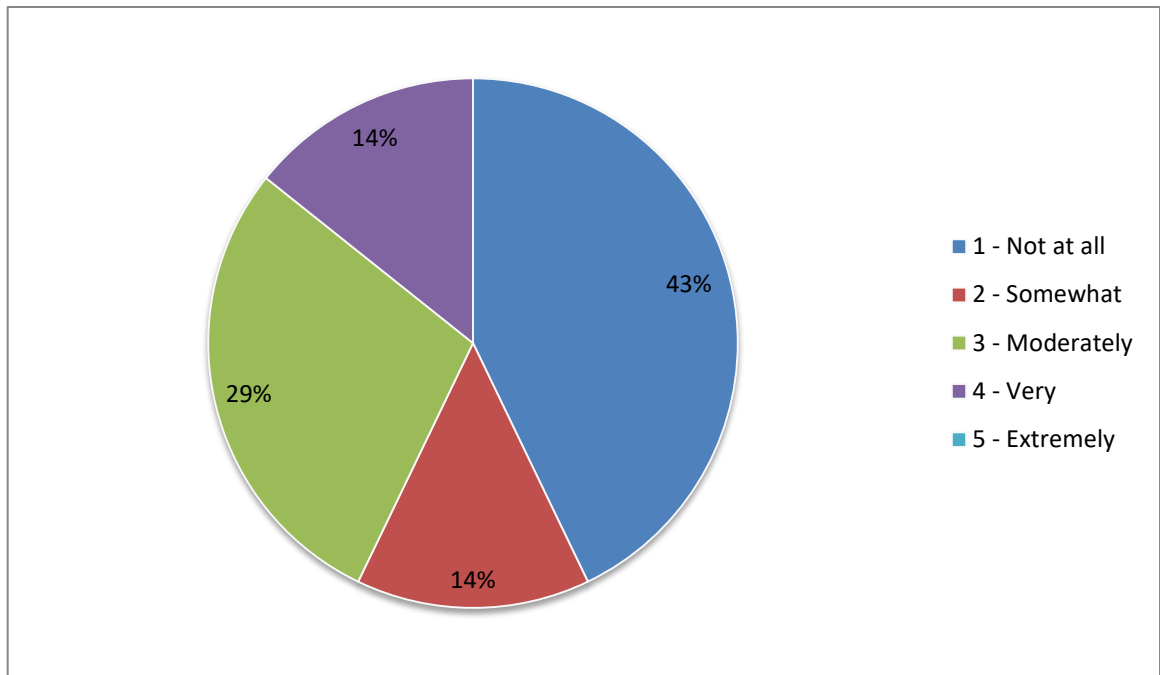
Figure 93, Question 7: Did the software improve your dissection skills? Phase One 2013, non-haptic
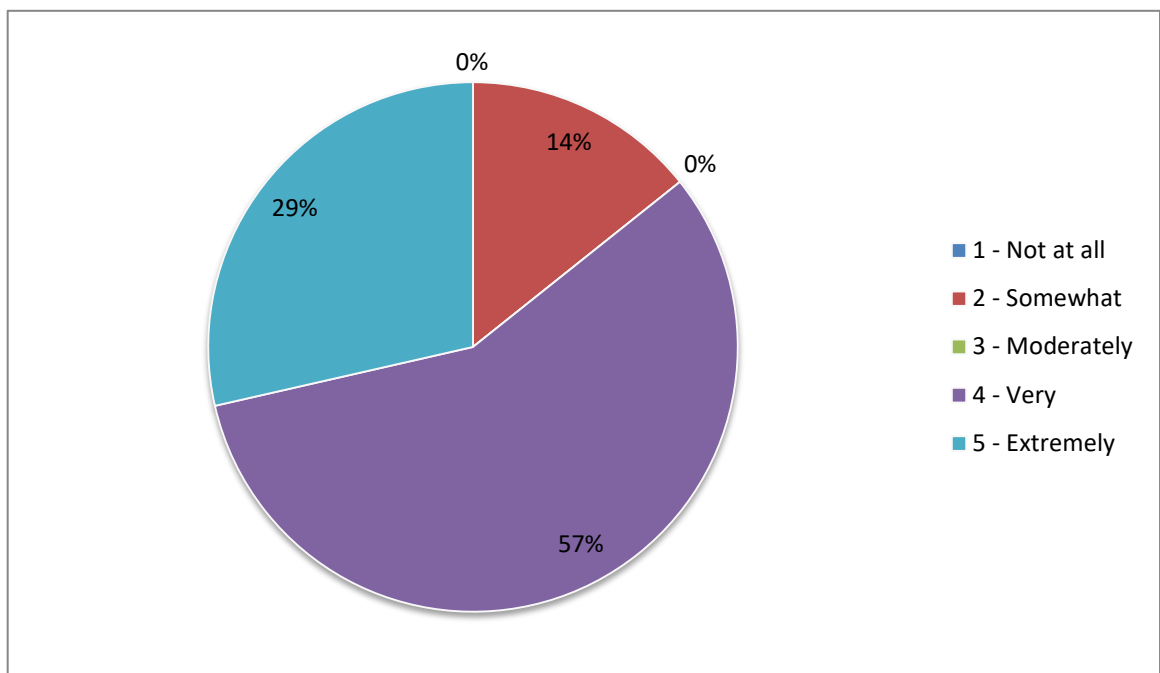
Figure 94, Question 8: Dis use of the software improve your anatomical knowledge? Phase One 2013, non-haptic
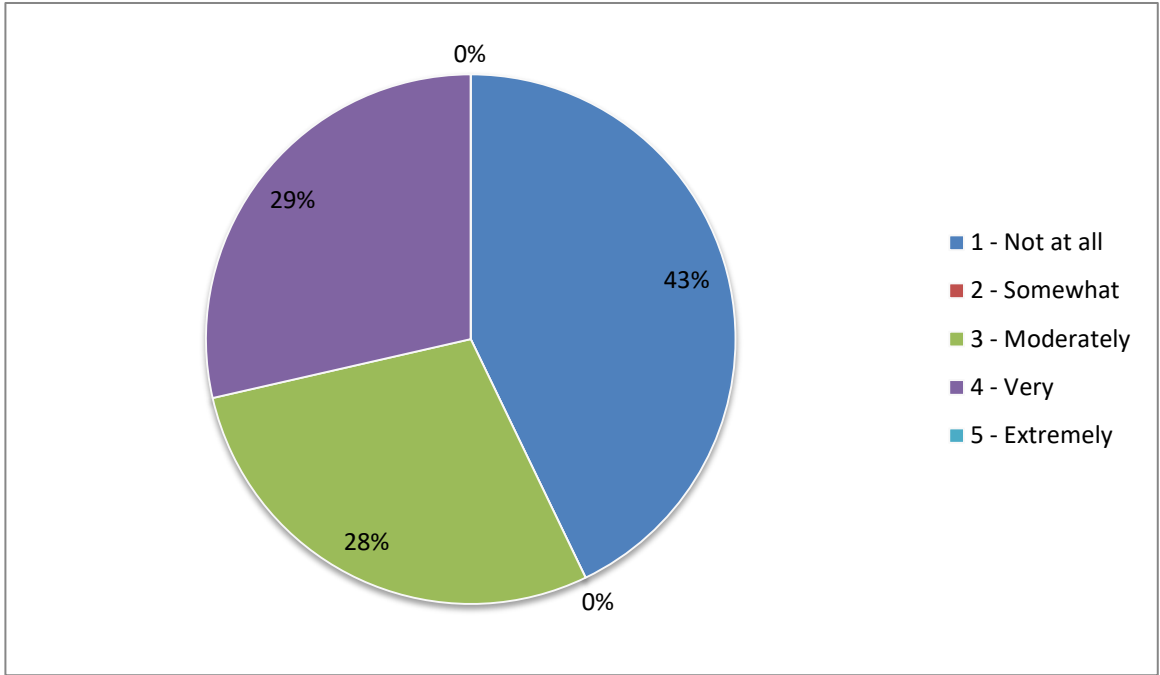
Figure 95, Question 9: Did you feel more confident doing cadaveric dissection after using the software? Phase One 2013, non-haptic

Questions 10 and 11 were 'closed' style questions asking, 'how much time did you spend using the software?' and 'how many training sessions did you attend?' Question 10 had five possible answers; 0 hours, 0-1 hour, 1-5 hours, 5-10 hours and 10+ hours. Question 11 had six possible answers; 0, 1, 2, 3, 4 and 5+. The results for questions 10 & 11 can be found in the following Table (42) and Figures (96-97).

Table 43, Questions 10 & 11 Compared to anatomy test results. Phase One 2013, non-haptic

	1	2	3	4	5	6	7
Q10	1-5	0-1	1-5	1-5	0-1	1-5	0-1
Q11	1	1	1	1	1	1	1
Total for anatomy test	90%	86.6%	83.3%	73.3%	76.6%	83.3%	70%
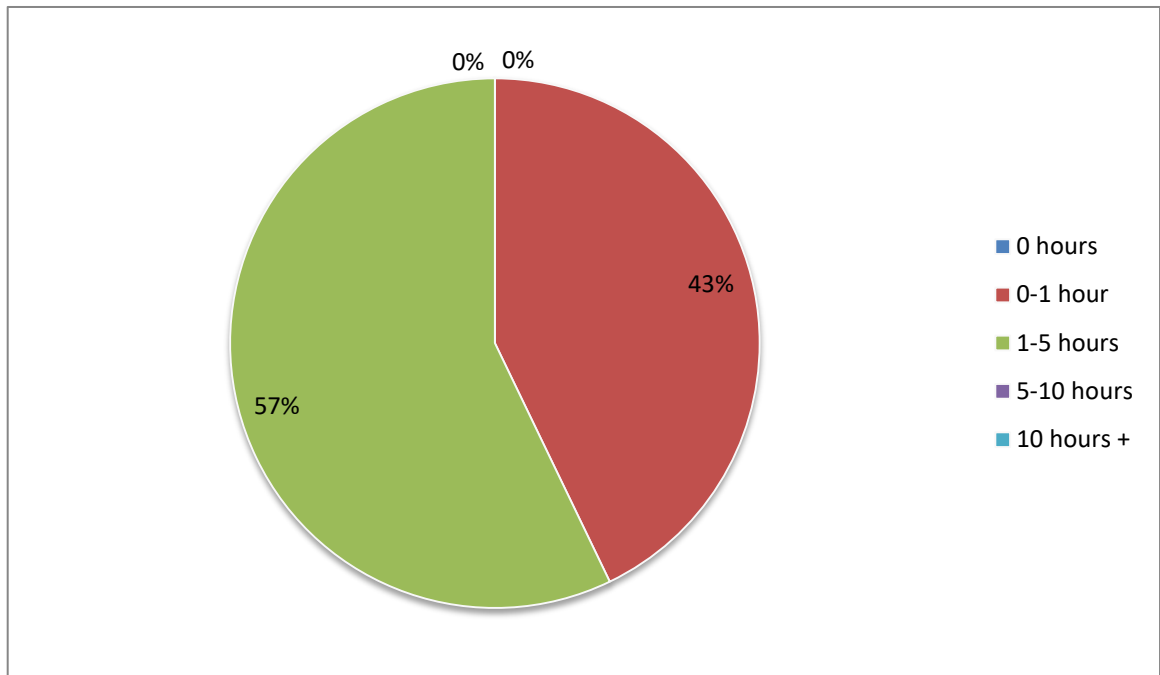
Figure 96, Question 10: How much time did you spend using the software? Phase One 2013, non-haptic
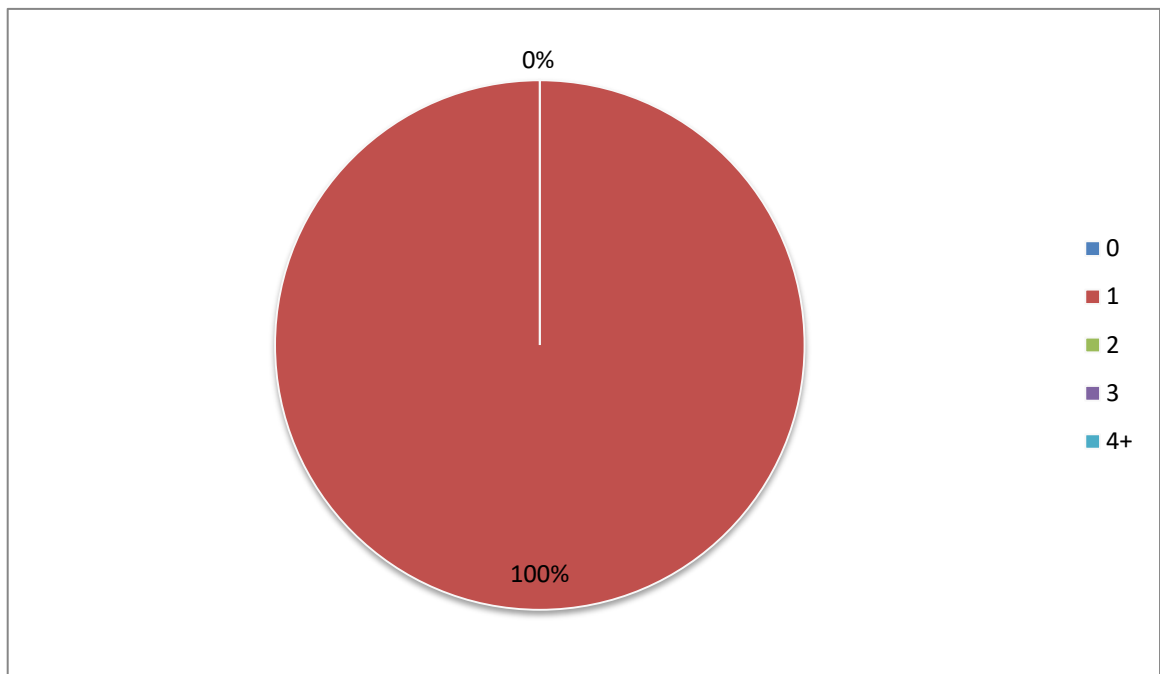
Figure 97, Question 11: How many training sessions did you attend? Phase One 2013, non-haptic

Finally questions 12 through 15 were 'open' free text questions asking, 'if you used the keyboard and mouse interface how do you feel this affected your experience?' 'If you used the haptic interface how much do you feel this affected your experience?' 'What improvements would you like to see made to the software?' And finally there was a space for 'any other comments?' Question 13 which asked about the haptic version of the software was not applicable to this user group. For ease of reading, comments from questions 12-15 have been grouped into the following recurring themes: useful tool for revision, useful for learning structures, keyboard and mouse interface, general ease of use, lack of interactive labelling, and suggestions for improvements. The numbers relate to the student making the comment.

2) Very useful in terms of revision

3) A useful revision tool but perhaps not for primary learning

3) A useful revision tool but no improvement on dissection skills.

1) Very useful, facilitates learning of the anatomy of the hand

4) Very useful in learning structures. I found it best to use after the lectures/dissection not before

5) It helped you to know where the structure are by highlighting in green as sometimes in dissection it is hard to know what you are looking at and helps you see where structures lie relative to each other

2) The mouse worked well but I found it restrictive

6) It removed the whole structure 'perfectly' = good. Also bad because in reality we had only a small window to see deeper structures

7) The dissection itself was not very realistic to an actual dissection, although being able to see everything was nice

2) I found the visible/see-through not very helpful. I worked best removing the structures all together to properly view what the underlying structure were.

4) It would be helpful if you could click on a structure and it highlight the name

6) Maybe to have an option to click on a structure and see what it is

7) To be able to click on a muscle/tendon etc and have it labelled

7) Relatively time consuming to have to scroll through everything to find the muscles.

4) Very useful software, I would be happy to use it again especially if it extended into the arm

APPENDIX 6: PHASE ONE HAPTIC RESULTS (MSC/BMSC, 2014)

The testing of the haptic version of the model took place during year four. This year the study was open to MSc Human Anatomy and Anatomy and the MSc Advanced Forensic Anthropology students, and BMSc Anatomy students. Nine students took part in total; eight MSc Anatomy and Advanced Forensic Anthropology students and one BMSc Anatomy student.

The group has access to the haptic version of the software in addition to their normal tuition from two weeks before to one week after cadaveric dissection of the hand and wrist took place. Use of the software was optional and tuition was provided at regular intervals during the time the software was available (3 tutorials, one per week). Within ten days of completing their dissection the students undertook an anatomy knowledge test consisting of eight questions; four 'spot tests' and five multiple choice on the anatomy of the hand and wrist. The quality of the cadaver dissections were evaluated by an anatomist within ten days of dissection being completed. During the time between completion of dissection and evaluation of the cadaver no further invasive procedures were performed. Students were also asked to complete a feedback questionnaire on how on how useful they felt the software to be.

Anatomy Test 2014 (MScs Human Anatomy and Anatomy & Advanced Forensic Anthropology/BMSc Anatomy)

The individual results of the anatomy test are broken down in to four tables (Tables 44-47); three for each of the spot tests (multiple answers) and one for the multiple choice (single correct answer) questions. Two students (numbers 5 and 10) have been omitted from the results as they left over 40% of the answers blank.

Table 44, Phase One (Haptic 2014), anatomy test question 1 results

Q1	1	2	4	6	7	9	11	Total
A	1	1	1	1	1	1	1	7/7 (100%)
B	1	1	1	1	0	1	0	5/7 (71.4%)
C	0	0	0	0	1	0	0	1/7 (14.2%)
D	1	0	1	1	1	1	0	5/7 (71.4%)
E	0	0	1	1	1	1	0	4/7 (57.1%)
F	0	1	1	1	1	1	0	5/7 (71.4%)
G	1	0	0	0	0	0	0	1/7 (14.2%)
H	1	1	0	1	1	1	1	6/7 (85.7%)
I	0	1	0	1	0	1	1	4/7 (57.1%)
Total	6/9 55.5%	7/9 55.5%	9/9 55.5%	13/9 77.7%	13/9 66.6%	16/9 77.7%	14/9 33.3%	**38/63 (60.3%)**

Table 45, Phase One (Haptic 2014), anatomy test question 2 results

Q2	1	2	4	6	7	9	11	Total
A	0	1	1	1	1	1	0	5/7 (71.4%)
B	1	1	1	1	1	1	0	6/7 (85.7%)
C	1	0	1	0	1	0	1	4/7 (57.1%)
D	1	1	1	1	1	1	0	6/7 (85.7%)
E	1	1	1	1	1	1	1	7/7 (100%)
F	0	0	1	1	0	1	0	3/7 (42.8%)
Total	5/6 66.6%	6/6 66.6%	10/6 100%	11/6 83.3%	12/6 83.3%	14/6 83.3%	13/6 33.3%	**31/42 (73.8%)**

Table 46, Phase One (Haptic 2014), anatomy test question 3 results

Q3	1	2	4	6	7	9	11	Total
1	0	1	1	1	1	0	0	4/7 (57.1%)
2	0	1	0	1	1	1	0	4/7 (57.1%)
5	0	1	0	1	0	1	0	3/7 (42.8%)
6	1	1	0	1	0	0	0	3/7 (42.8%)
8	1	1	1	1	1	1	1	7/7 (100%)
9	1	1	1	1	1	1	0	6/7 (85.7%)
10	1	1	1	1	1	1	1	7/7 (100%)
11	1	1	0	1	0	0	0	3/7 (42.8%)
12	1	1	1	1	0	1	1	6/7 (85.7%)
13	1	1	1	1	1	1	1	7/7 (100%)
Total	8/10 70%	12/10 100%	10/10 60%	16/10 100%	13/10 60%	16/10 70%	15/10 40%	**50/70 (71.4%)**

Table 47, Phase One (Haptic 2014), anatomy test questions 4-8 results

	1	2	4	6	7	9	11	Total
Q4	1	1	1	1	1	1	1	7/7 (100%)
Q5	0	1	0	0	1	0	0	2/7 (28.5%)
Q6	1	1	1	1	1	1	1	7/7 (100%)
Q7	1	1	1	1	0	1	1	6/7 (85.7%)
Q8	1	1	1	1	0	1	0	5/7 (71.4%)
Total	5/5 80%	7/5 100%	8/5 80%	10/5 80%	10/5 60%	13/5 80%	14/5 60%	**27/35 (77.1%)**

Question one consisted of nine elements: the group scored a total of 38 out of 63 (60.3%) (Table 44). Question two consisted of six elements: the group scored a total of 31 out of 42 (73.8%) (Table 45). Question three consisted of ten elements: the group scored a total of 50 out of 70 (71.4%) (Table 46). Question four scored a total of 7 out of 7 (100%). Question five scored a total of 2 out of 7 (28.5%), Question six scored a total of 7 out of 7 (100%). Question seven scored a total 7 out of 7 (85.7%). Finally question eight scored a total 5 out of 7 (71.4%). The total for this section being 27 out of a possible 35 (77.1%) (Table 47).

Dissection Evaluation 2014 (MScs Human Anatomy and Anatomy & Advanced Forensic Anthropology/BMSc Anatomy)

Four cadavers were dissected between the group. Some students dissected the same cadaver as one another, while others dissected different cadavers with students who were not taking part in the study. Each group consisted of three or four students per cadaver. Thirteen questions were asked regarding 'how well' different aspects of the dissection had been performed and were scored using a five-point Likert scale, where

1= 'not at all', 2 'somewhat', 3= 'moderately', 4= 'very', and 5= 'extremely'. For these questions therefore a higher score is preferable. One exception to this format is question 8, which asked, 'How much damage to the structure is there?' In this instance a lower score would be preferable. For this reason, this question is looked at in isolation from the others (Figure 98). For the Likert scale questions, cadaver 16 scored 44 out 60 (73.3%), cadaver 20 scored 51 out of 60 (85%), cadaver 24 scored 46 out of 60 (76.7%), cadaver 29 scored 43 out of 60 (71.6%). Adding together the four totals of for the likert scale questions gave a score of 184 out of a possible 240 points (76.7%) (Table 48).

For question 8 'how much damage to the structures is there?' table 16 scored 2 - 'somewhat', table 20 scored 1 - 'not at all', table 24 scored 2 - 'somewhat', and table 29 scored 2 - 'somewhat' (Figure 98).
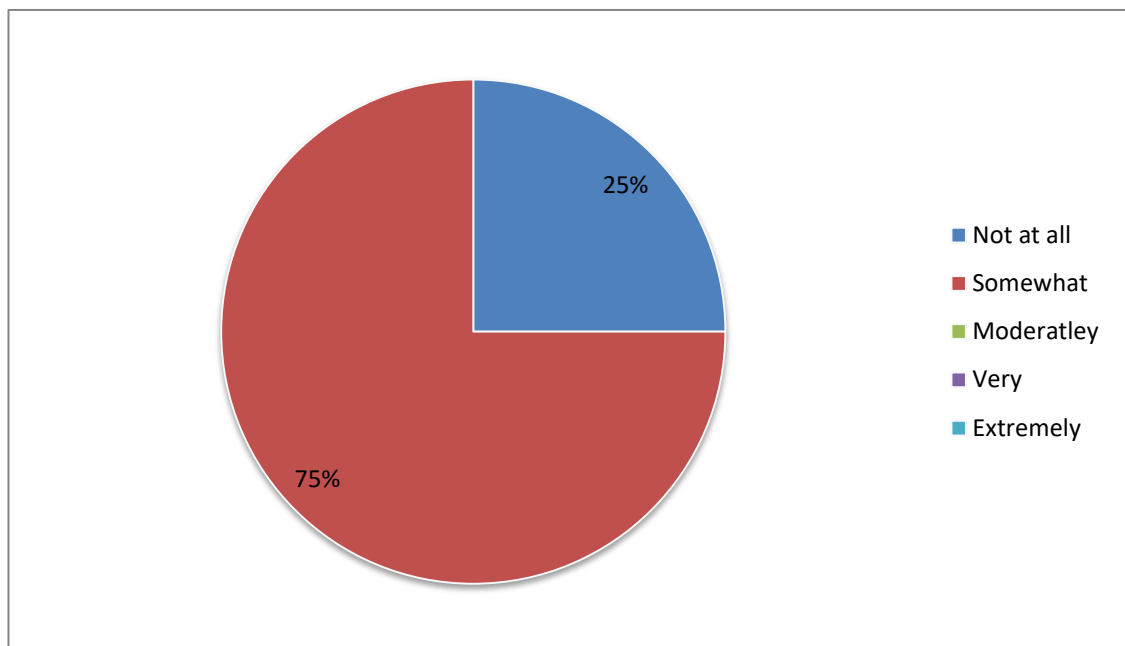
Figure 98, Question 8: How much damage to the structure is there? Phase One 2014, MSc BMSc haptic Group

The single BMSc student was on a table (17) with BSc students. As such their dissection evaluation is grouped with BScs in the following section.

Table 48, Phase One (Haptic 2014), number of students in study per cadaver

Table number	Total in group	Total in study
16	3	3
20	3	1
24	4	2
29	4	2

Table 49, Phase One (Haptic 2014), Dissection Evaluation results

	16: 5, 7, 10	20: 2	24: 4, 11	29: 1, 9	Total
Q1	3	4	4	2	13/20 (65%) median 3.5 mode 4
Q2	4	5	4	4	17/20 (85%) median 4 mode 4
Q3	3	4	3	3	13/20 (65%) median 3 mode 3
Q4	4	4	4	4	16/20 (80%) median 4 mode 4
Q5	4	4	3	3	14/20 (70%) median 3.5 mode 3*
Q6	2	4	3	3	12/20 (60%) median 3 mode 3
Q7	4	5	5	4	18/20 (90%) median 4.5 mode 4*
Q9	4	4	4	4	16/20 (80%) median 4 mode 4
Q10	3	4	4	4	15/20 (75%) median 4 mode 4
Q11	5	5	4	4	18/20 (90%) median 4.5 mode 4*
Q12	4	4	4	4	16/20 (80%) median 4 mode 4
Q13	4	4	4	4	16/20 (80%) median 4 mode 4
Total	**44/60 (73.3%)**	**51/60 (85%)**	**46/60 (76.7%)**	**43/60 (71.6%)**	**184/240 (76.7%) Median = 4 Mode = 4**

* Multiple modes exist. The smallest value is shown

Feedback Questionnaire 2014 (MScs Human Anatomy and Anatomy & Advanced Forensic Anthropology/BMSc Anatomy)

The feedback questionnaire consisted of a total of fifteen questions. The first 9 of these were scored using a five-point Likert scale and asked questions such as how easy or enjoyable the software was to use or how the student felt it would improve their practical skills etc. where 1= 'not at all', 2 'somewhat', 3= 'moderately', 4= 'very', and 5= 'extremely'. For these questions therefore a higher score is preferable. Following this there were two 'closed' questions asking, 'how much time did you spend using the software?' And 'how many training sessions did you attend?' These were followed by three 'open' questions asking, 'if you used the keyboard and mouse interface how do you feel this affected your experience?' 'If you used the haptic interface how much do you feel this affected your experience?' And 'what improvements would you like to see made to the software?' Finally there was a space for 'any other comments?' The results for questions 1-9 can be found in the following Table (50) and Figures (99-107)

Table 50, Phase One (Haptic 2014), questionnaire results, questions 1-9

	P1	P2	P4	P5	P6	P7	P9	P10	P11	Total
Q1	3	4	3	3	3	4	3	2	2	27/45 (60%) median 3/mode 3
Q2	4	5	5	4	4	4	4	3	3	36/45 (80%) median 4/mode 4
Q3	4	2	3	4	4	4	3	3	4	31/45 (68.8%) median 4/mode 4
Q4	4	4	4	3	4	5	5	4	5	38/45 (84.4%) median 4/mode 4
Q5	4	4	4	4	4	5	5	4	4	38/45 (84.4%) median 4/mode 4
Q6	4	5	5	4	5	4	4	3	3	37/45 (82.2%) median 4/mode 4
Q7	3	4	3	1	2	2	2	1	3	21/45 (46.6%) median 2/mode 2*
Q8	3	4	4	4	3	4	4	3	3	32/45 (7.1%) median 4/mode 4
Q9	3	4	4	3	3	2	2	3	3	27/45 (60%) median 3/mode 3
Total	32/45	36/45	35/45	30/45	32/45	34/45	32/45	26/45	30/45	0/405 (70.8%) Median = 4 Mode = 4

* Multiple modes exist. The smallest value is shown
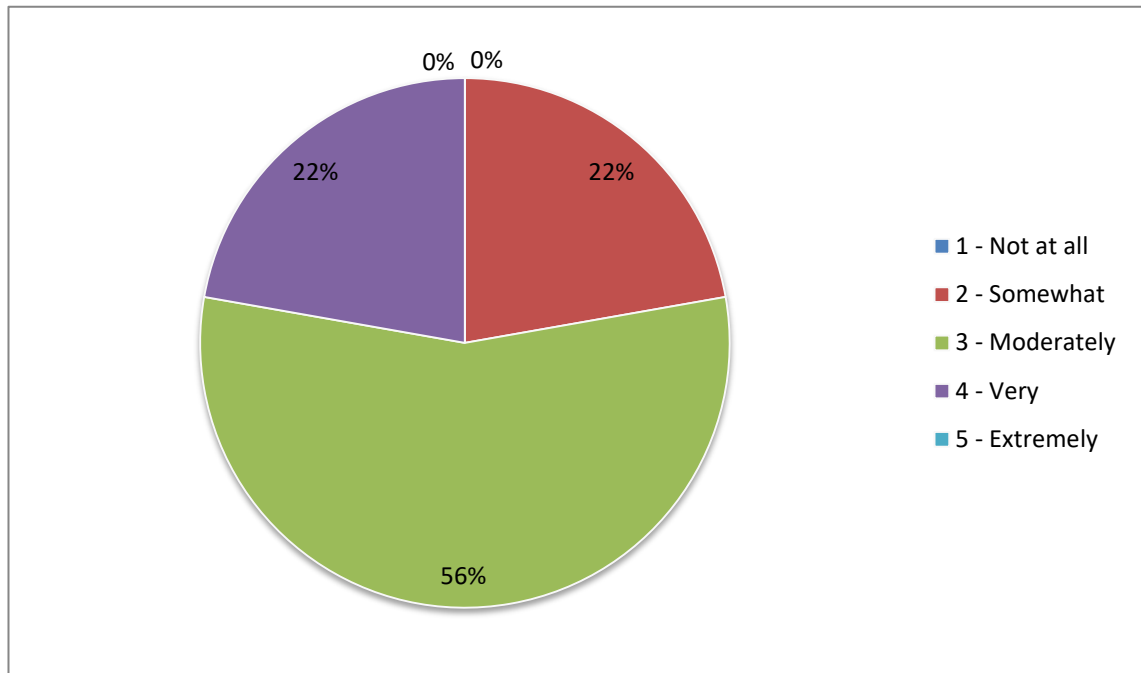
Figure 99, Question 1: How easy and intuitive was the software to use? Phase One 2014, MSc/BMSc haptic
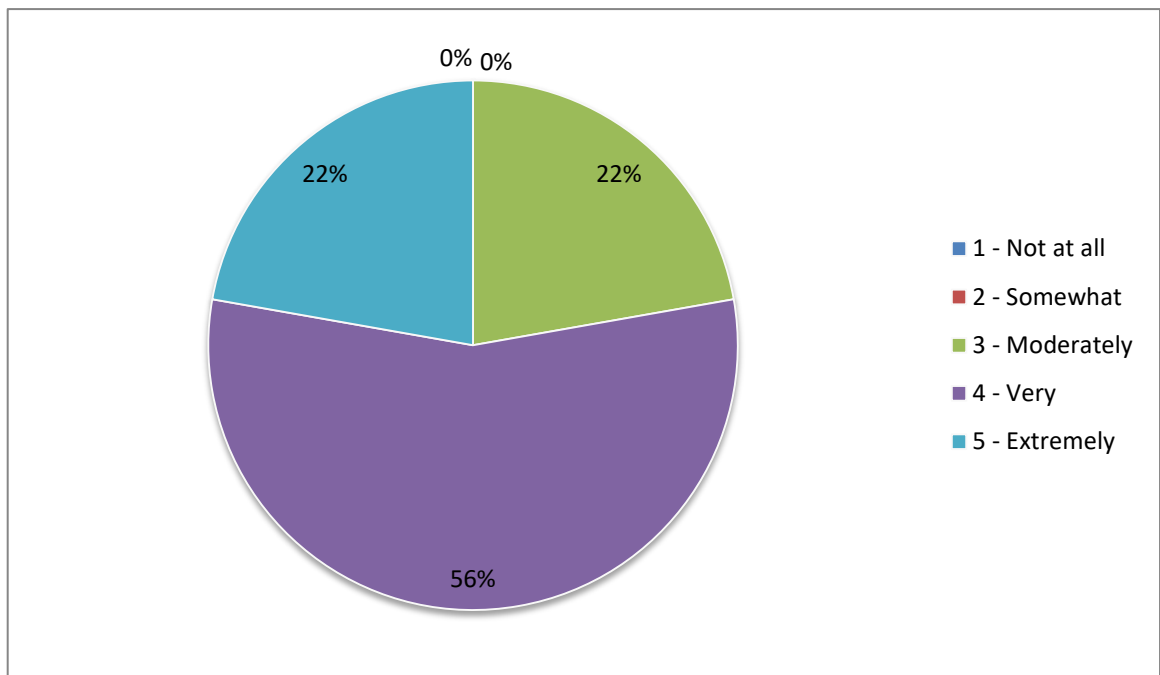
Figure 100, Question 2: How useful was the training session? Phase One 2014, MSc/BMSc haptic
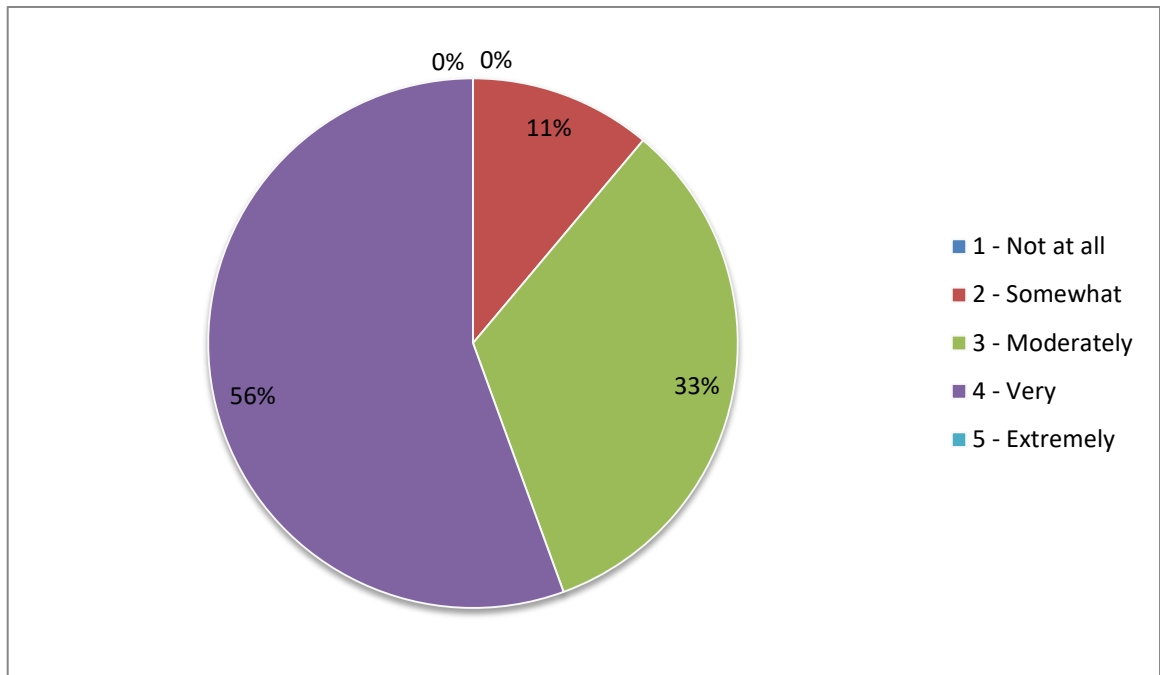
Figure 101, Question 3: How helpful was the dissection manual? Phase One 2014, MSc/BMSc haptic
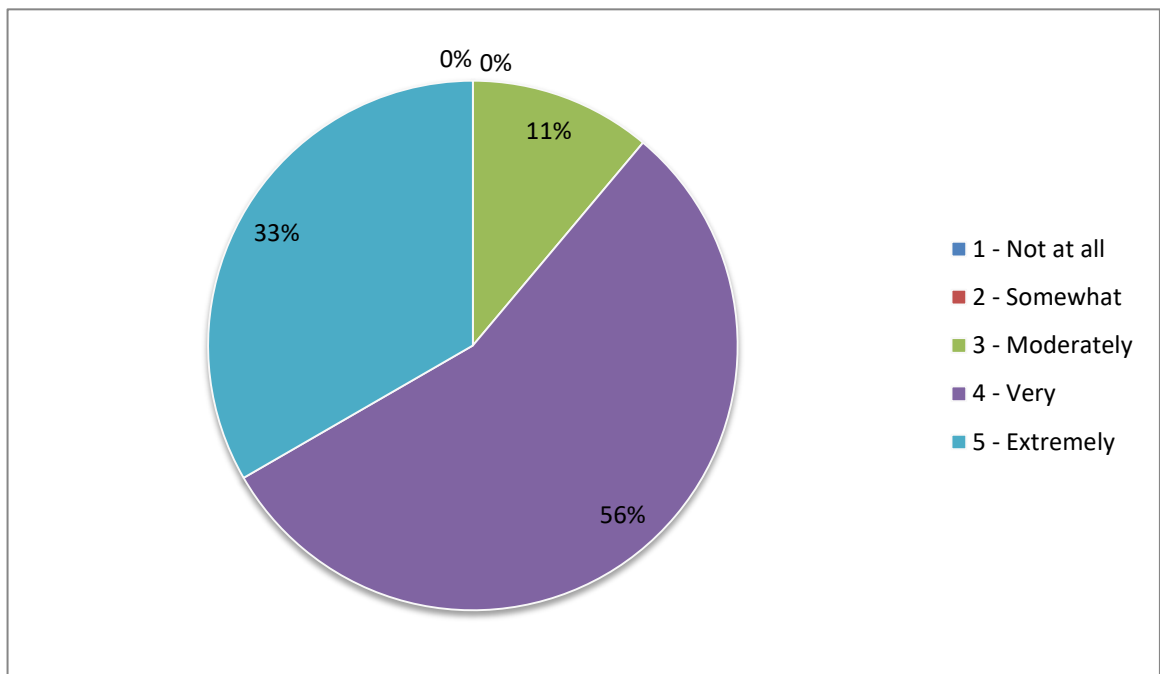
Figure 102, Question 4: Is the model anatomically accurate? Phase One 2014, MSc/BMSc haptic
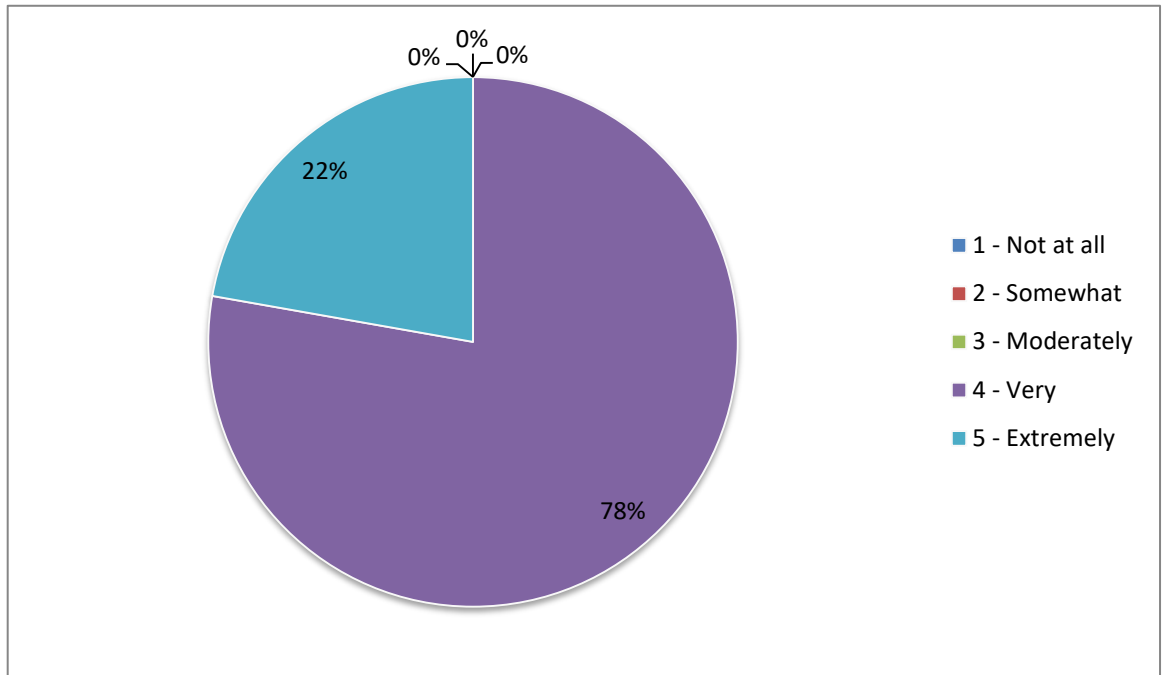
Figure 103, Question 5: How appropriate is the level of detail in the model? Phase One 2014, MSc/BMSc haptic
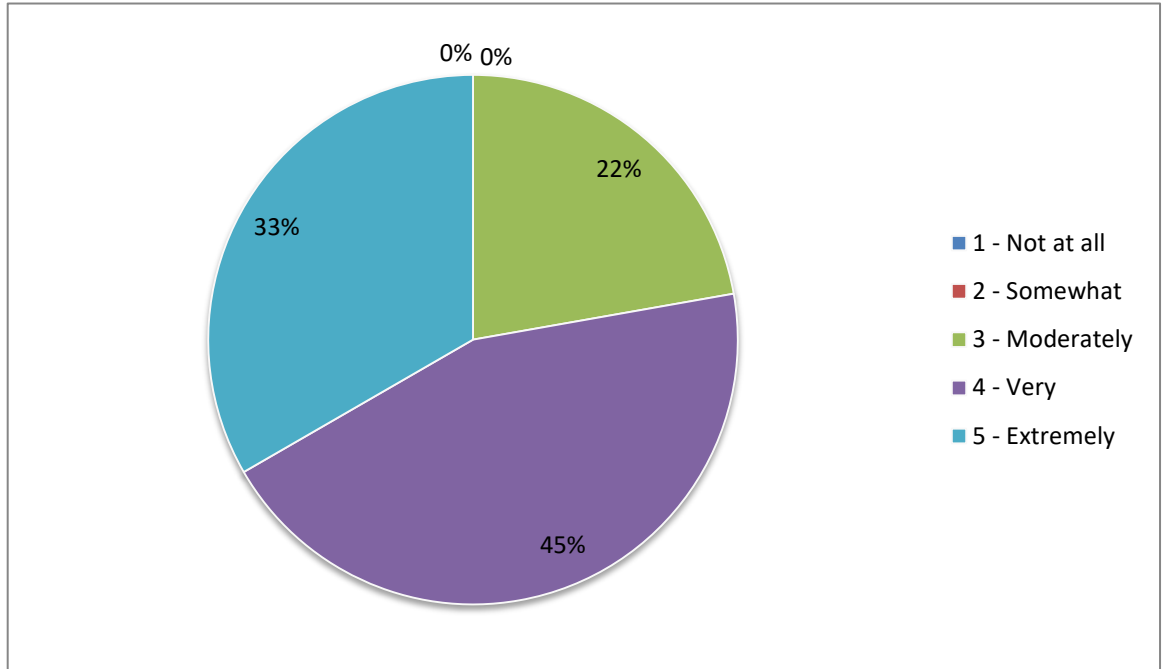
Figure 104, Question 6: Did you enjoy using the software? Phase One 2014, MSc/BMSc haptic
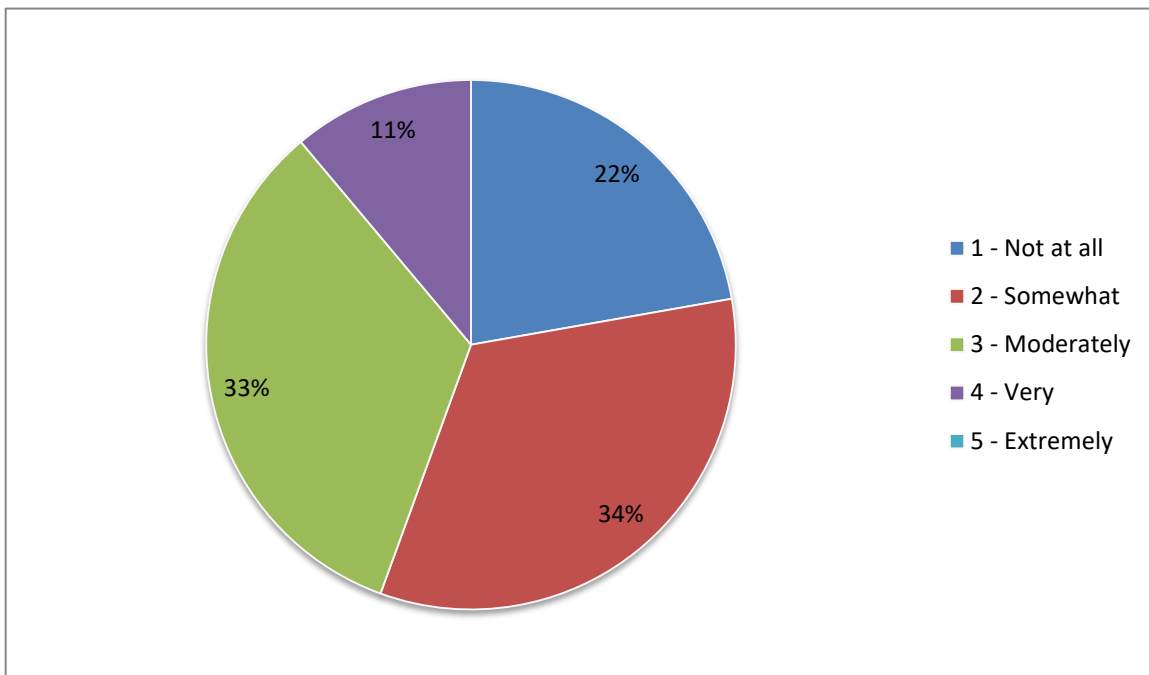
Figure 105, Question 7: Did the software improve your dissection skills? Phase One 2014, MSc/BMSc haptic
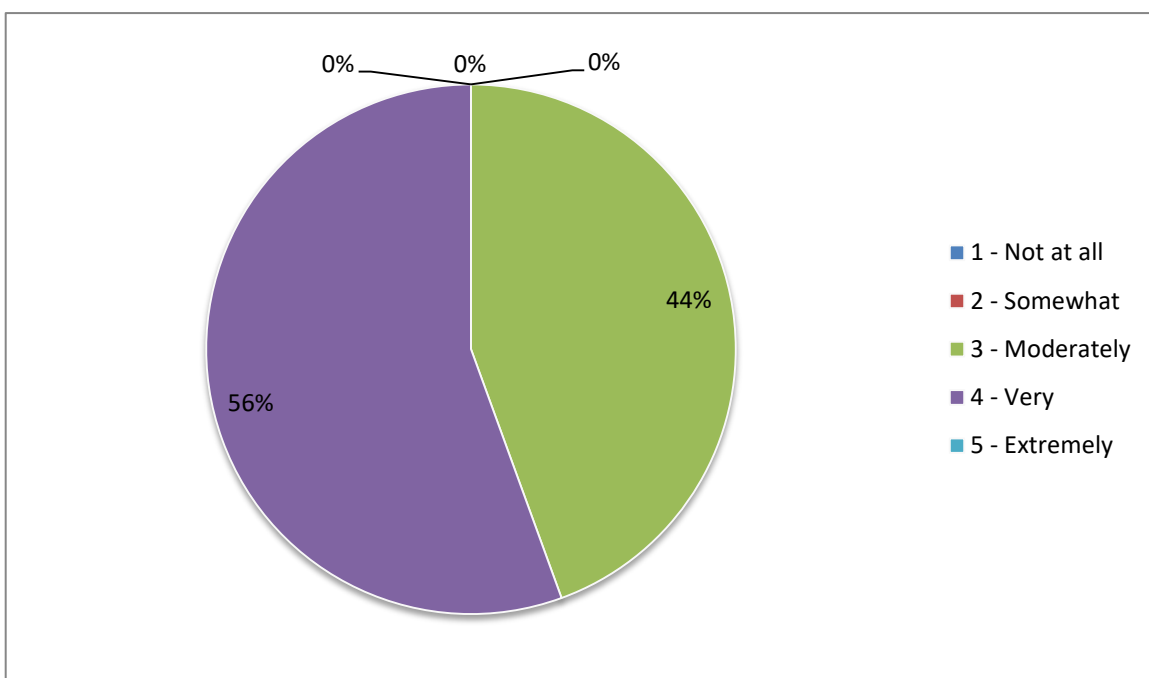
Figure 106, Question 8: Did use of the software improve your anatomical knowledge? Phase One 2014, MSc/BMSc haptic
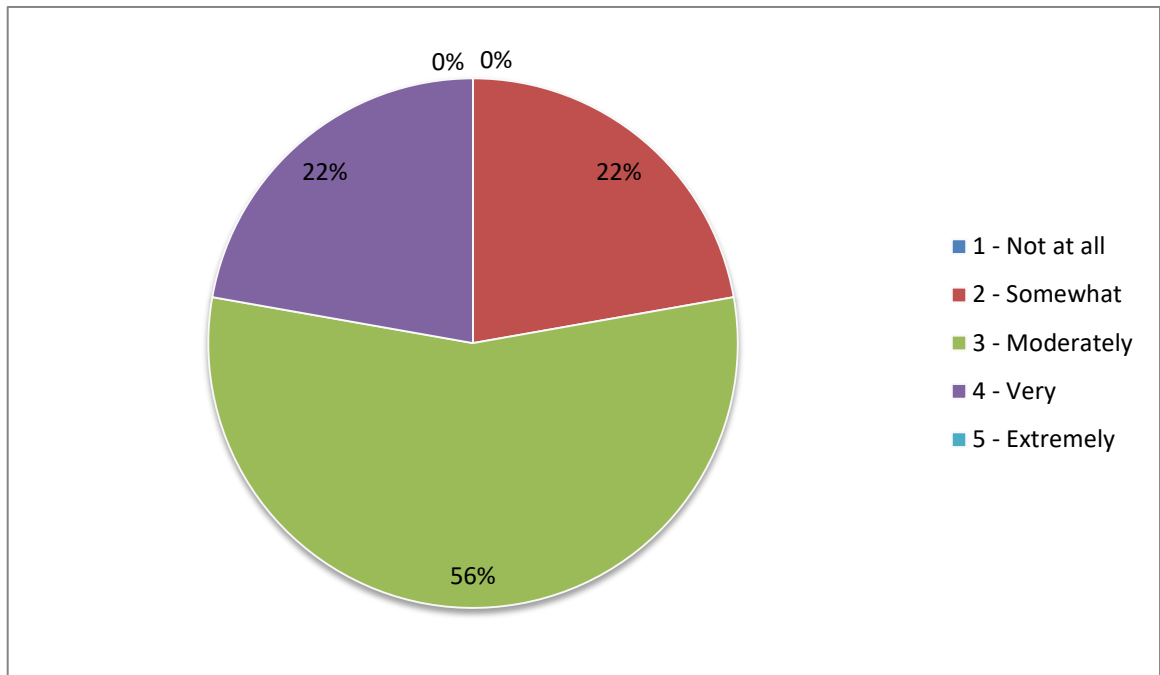
Figure 107, Question 9: Did you feel more confident doing cadaveric dissection after using the software? Phase One 2014, MSc/BMSc haptic

Questions 10 and 11 were 'closed' style questions asking, 'how much time did you spend using the software?' and 'how many training sessions did you attend?' Question 10 had five possible answers; 0 hours, 0-1 hour, 1-5 hours, 5-10 hours and 10+ hours. Question 11 had six possible answers; 0, 1, 2, 3, 4 and 5+. The results for questions 10 & 11 can be found in the following Table (50) and Figures (108-109).

Table 51, Questions 10 & 11 compared to anatomy test results. Phase One 2014, MSc/BMSc haptic

	P1	P2	P4	P6	P7	P9	P11
Q10	0-1	1-5	1-5	1-5	0-1	0-1	0-1
Q11	1	1	1	1	1	1	1
Total for anatomy test	66%	80%	70%	86.6%	66.6%	76.6%	36.6%
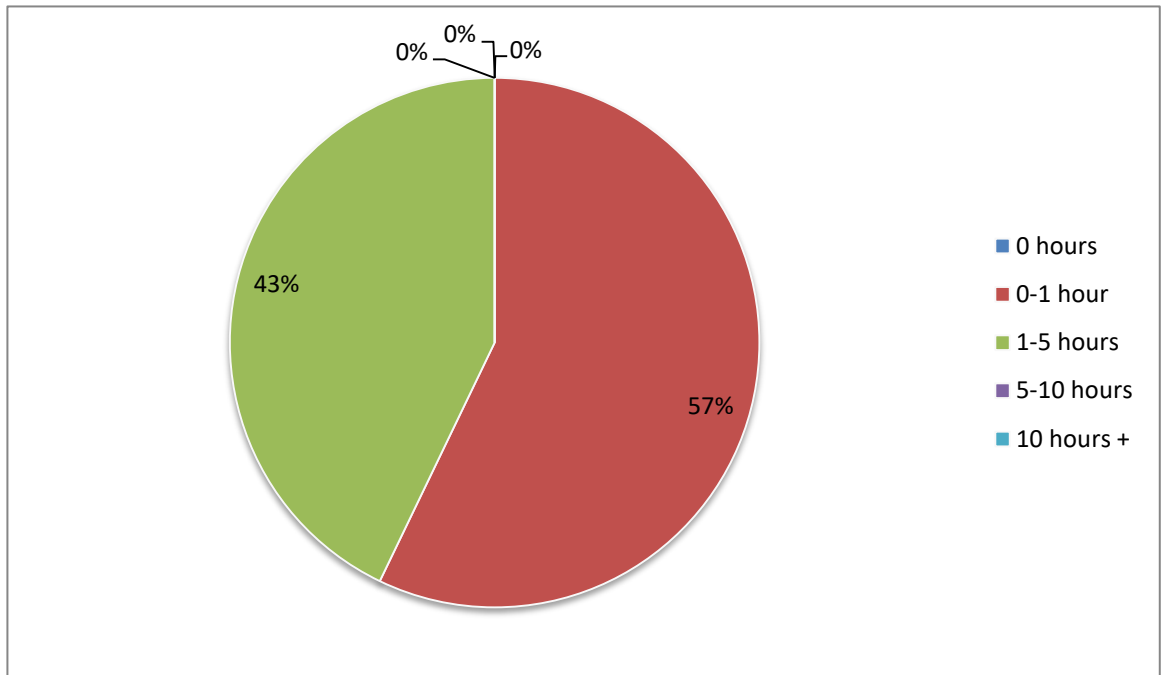
Figure 108, Question 10: How much time did you spend using the software? Phase One 2014, MSc/BMSc haptic
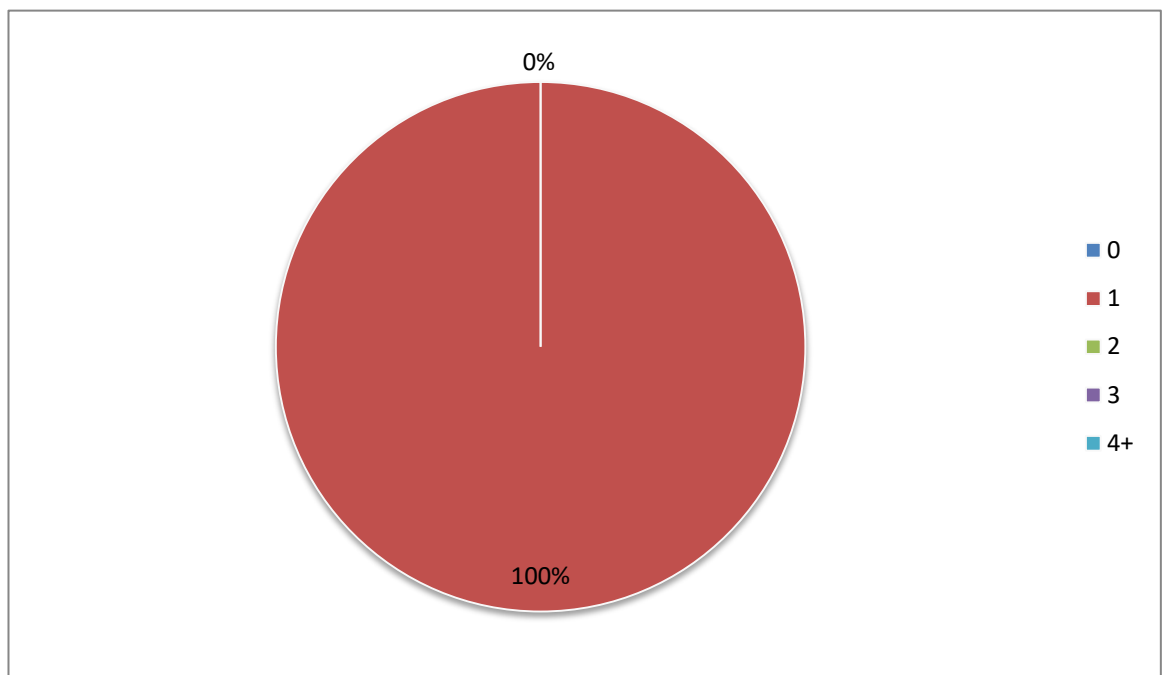
Figure 109, Question 11: How many training sessions did you attend? Phase One 2014, MSc/BMSc haptic

Finally questions 12 through 15 were 'open' free text questions asking, 'if you used the keyboard and mouse interface how do you feel this affected your experience?' 'If you used the haptic interface how much do you feel this affected your experience?' 'What improvements would you like to see made to the software?' And finally there was a space for 'any other comments?' Question 12 which asked about the non-haptic version of the software was not applicable to this user group. For ease of reading, comments from questions 13-15 have been grouped into the following recurring themes: useful tool for revision, useful for learning structures, the haptic interface, keyboard and mouse interface, general ease of use, and interactive labelling. The numbers relate to the student making the comment.

5) Very useful for revision and understanding the anatomical relations among each structure

9) I used the tool after doing dissection

10) I do not think this software is useful in terms of training or practicing dissection techniques. It is however, useful for studying/revising hand anatomy

1) Although it can be frustrating to find every muscle and tendon to be able to dissect it, it does help with identifying as you have to identify muscles (you) want to remove.

5) Useful as you can dissect only a small part of and try to identify the structures

1) It was odd to get used to the resistance and being able to feel the surfaces, but it helped to make (me) realise that it was 3D and the thumb structures would be more anteriorly placed

4) The haptic interface took some getting used to, but was quite helpful

You can 'feel' the tissue

6) I like the haptic interface. Good for learning dissection experience

7) I found the haptic device difficult to use, the tool kept getting stuck inside the hand and the resistance made me tire quickly and my wrist sore. After a short time with the device I resorted to using the mouse and keyboard and clicking through the layers

9) It was useful to be able to feel what was being dissected. Also felt more like using the dissection tools.

9) (it would be useful) to activate more than one layer at a time

10) I think the haptic interface was interesting to use, but I don't think it is valuable in its 'dissecting' actions. You hold it like a pen rather than a scalpel; and the movements/resistance, I don't think was realistic

10) I used the mouse and keyboard when I was having difficulties with the haptic interface. This therefore improved my experience and made using the software easier

2) Easy to use, very enjoyable

2) The dissection manual is a little bit confusing (on) how to operate the software

6) A list of hot keys would be good and add to the ease of use

7) Overall the software is good, I enjoyed clicking through the layers and seeing the overall picture. I would love to see it for the whole body. I have trouble memorising isolated faces but being able to put it in such good context would really help. 3d is really good

1) Maybe as there is so much going on in the hand an easier way to find different muscles and tendons to be able to make them active or remove it. Took time just scrolling the list

APPENDIX 7: PHASE TWO RESULTS (BSC, 2014)

During the fourth year (2014) 3rd year BSc Anatomy and BSc Forensic Anthropology students (who dissected the hand and wrist at the same time as the MSc/BMSc students) were also included in the study.

In order to create a control group the returning 4th years were invited to complete the anatomy test, after being given a week to revise if they wished. The 3rd year students were given the opportunity to use the haptic software in addition to their normal tuition in the same way as the MSc students. The control group consisted of seven students while the haptic group consisted of fourteen students.

The 3rd year BSc students had access to the haptic version of the software in addition to their normal tuition from two weeks before to one week after cadaveric dissection of the hand and wrist took place. Use of the software was optional and tuition was provided at regular intervals during the time the software was available (3 tutorials, one per week). Within ten days of completing their dissection the students undertook an anatomy knowledge test consisting of eight questions; four 'spot tests' and five multiple choice on the anatomy of the hand and wrist. The quality of the cadaver dissections were evaluated by an anatomist within ten days of dissection being completed. During the time between completion of dissection and evaluation of the cadaver no further invasive procedures were performed. Students were also asked to complete a feedback questionnaire on how on how useful they felt the software to be.

Anatomy Test 2014 (Control BSc)

The individual results of the anatomy test are broken down in to four tables (Tables 52-55); three for each of the spot tests (multiple answers) and one for the multiple choice (single correct answer) questions.

Table 52, Phase Two (Control 2014), anatomy test question 1 results

Q1	1	2	3	4	5	6	7	Total
A	1	1	1	0	0	1	0	4/7 (57.1%)
B	0	0	1	0	1	0	0	2/7 (28.6%)
C	0	0	0	0	0	0	1	1/7 (14.3%)
D	0	0	0	0	0	0	0	0/7 (0%)
E	0	0	0	0	0	0	1	1/7 (14.3%)
F	1	0	0	0	0	1	1	3/7 (42.9%)
G	0	0	0	0	0	0	0	0/7 (0%)
H	1	1	1	1	1	1	1	7/7 (100%)
I	1	1	1	1	1	1	1	7/7 (100%)
Total	4/9 44.4%	3/9 33.3%	4/9 44.4%	2/9 22.2%	3/9 33.3%	4/9 44.4%	5/9 55.5%	**25/63 (39.7%)**

Table 53, Phase Two (Control 2014), anatomy test question 2 results

Q2	1	2	3	4	5	6	7	Total
A	1	1	1	0	0	1	1	5/7 (71.4%)
B	0	0	0	0	1	0	0	1/7 (14.2%)
C	0	0	0	0	0	0	0	0/7 (0%)
D	0	0	0	0	0	0	0	0/7 (0%)
E	1	0	0	1	0	0	0	1/7 (14.2%)
F	0	0	0	0	0	0	0	0/7 (0%)
Total	2/6 33.3%	1/6 16.6%	1/6 16.6%	1/6 16.6%	1/6 16.6%	1/6 16.6%	1/6 16.6%	**8/42 (19%)**

Table 53, Phase Two (Control 2014), anatomy test question 2 results

Table 54, Phase Two (Control 2014), anatomy test question 3 results

Q3	1	2	3	4	5	6	7	Total
1	1	1	0	1	1	1	0	5/7 (71.4%)
2	0	0	0	0	0	0	0	0/7 (0%)
5	0	0	0	0	0	0	0	0/7 (0%)
6	0	0	0	0	0	0	0	0/7 (0%)
8	1	0	0	1	0	0	1	3/7 (42.8%)
9	1	0	0	0	0	1	1	3/7 (42.8%)
10	1	0	0	0	0	1	1	3/7 (42.8%)
11	1	0	0	1	0	0	0	2/7 (28.5%)
12	1	0	0	1	1	1	1	5/7 (71.4%)
13	1	0	1	1	1	1	1	6/7 (85.7%)
Total	7/10 70%	1/10 10%	1/10 10%	5/10 50%	3/10 30%	5/10 50%	5/10 50%	**27/70 (38.5%)**

Table 55, Phase Two (Control, 2014), anatomy test question 4-8 results

	1	2	3	4	5	6	7	Total
Q4	0	1	1	1	1	0	0	4/7 (57.1%)
Q5	0	0	1	0	0	1	1	3/7 (42.8%)
Q6	1	1	1	1	1	1	1	7/7 (100%)
Q7	0	1	0	1	1	1	1	5/7 (71.4%)
Q8	0	1	0	0	1	0	1	3/7 (42.8%)
Total	1/5 20%	4/5 80%	3/5 60%	3/5 60%	4/5 80%	3/5 60%	4/5 80%	**22/35 (62.8%)**

Question one consisted of nine elements: the group scored a total of 25 out of 63 (39.6%), with two questions (Q1, D& G) receiving no correct answers (Table 52). Question two consisted of six elements: the group scored a total of 8 out of 42 (19%) (Table 53). Question three consisted of ten elements: the group scored a total of 27 out of 70 (38.5%) (Table 54). Question four scored a total of 4 out of 7 (57.1%). Question five scored a total of 3 out of 7 (42.8%), Question six scored a total of 7 out of 7 (100%). Question seven scored a total 5 out of 7 (71.4%). Finally question eight scored a total 3 out of 7 (42.8%) (Table 71). The total for this section being 22 out of a possible 35 (62.8%) (Table 55).

Anatomy Test 2014 (Haptic BSc)

The results of the anatomy test are broken down in to four tables (Tables 56-59); three for each of the spot tests (multiple answers) and one for the multiple choice (single correct answer) questions.

Table 56, Phase Two (Haptic 2014), anatomy test question 1 results

Q1	4b	5b	6b	7b	8b	9b	10b	11b	12b	13b	14b	15b	16b	17b	Total
A	1	1	1	0	1	0	0	1	1	1	0	0	1	0	8/14 (57.1%)
B	1	0	1	0	1	1	0	1	1	1	0	1	0	0	8/14 (57.1%)
C	0	1	0	1	0	0	0	0	0	0	1	0	0	0	3/14 (21.4%)
D	1	0	0	0	1	0	1	1	1	0	1	0	0	0	6/14 (42.8%)
E	0	0	0	0	1	1	1	0	0	1	1	0	0	0	5/14 (35.7%)
F	1	1	1	1	1	1	1	1	1	1	1	1	0	0	12/14 (85.7%)
G	1	0	0	1	0	0	0	0	1	0	0	0	0	0	3/14 (21.4%)
H	1	0	1	1	1	1	1	1	1	1	1	0	0	1	11/14 (78.5%)
I	0	0	1	1	1	1	1	1	1	1	1	0	0	1	10/14 (71.4%)
Σ	6/9 66.6%	3/9 33.3%	5/9 55.5%	5/9 55.5%	7/9 77.7%	4/9 44.4%	5/9 55.5%	6/9 66.6%	7/9 77.7%	6/9 66.6%	6/9 66.6%	2/9 22.2%	1/9 11.1%	2/9 22.2%	**66/126 (52.3%)**

Table 57, Phase Two (Haptic 2014), Anatomy test question 2 results

Q2	4b	5b	6b	7b	8b	9b	10b	11b	12b	13b	14b	15b	16b	17b	Total
A	1	1	0	0	0	1	0	0	1	0	1	1	0	1	7/14 (50%)
B	1	0	1	1	1	1	1	0	1	1	1	0	0	1	10/14 (71.4%)
C	0	1	0	0	1	1	0	0	1	0	1	0	0	0	5/14 (35.7%)
D	0	0	0	1	1	1	0	0	1	1	1	0	0	1	7/14 (50%)
E	1	0	1	1	1	1	1	1	1	1	1	1	0	0	11/14 (78.5%)
F	1	1	0	1	0	1	1	0	0	1	0	0	0	0	6/14 (42.8%)
Total	4/6 66.6%	3/6 50%	2/6 33.3%	4/6 66.6%	4/6 66.6%	6/6 66.6%	3/6 50%	1/6 16.6%	5/6 83.3%	4/6 66.6%	5/6 83.3%	2/6 33.3%	0/6 0%	3/6 50%	**46/84 (54.7%)**

Table 58, Phase Two (Haptic 2014), Anatomy test question 3 results

Q3	4b	5b	6b	7b	8b	9b	10b	11b	12b	13b	14b	15b	16b	17b	Total
1	1	1	1	0	1	1	0	1	1	0	1	1	0	0	9/14 (64.2%)
2	1	0	1	0	0	0	0	0	0	0	1	0	0	0	3/14 (21.4%)
5	0	0	0	1	0	1	0	0	0	0	1	0	0	0	3/14 (21.4%)
6	0	0	1	0	1	0	0	0	0	0	1	0	0	0	3/14 (21.4%)
8	1	0	1	1	1	0	1	0	1	1	1	0	0	0	8/14 (57.1%)
9	1	0	1	1	1	1	1	1	1	1	1	0	0	0	10/14 (71.4%)
10	1	1	1	1	1	0	1	1	1	1	1	0	0	0	10/14 (71.4%)
11	0	0	1	0	0	0	0	0	1	0	1	0	0	0	3/14 (21.4%)
12	0	0	1	0	0	0	0	1	1	1	1	0	0	0	5/14 (35.7%)
13	0	0	1	1	1	1	1	1	1	1	1	1	0	0	10/14 (71.4%)
Total	5/10	2/10	9/10	5/10	6/10	4/10	4/10	5/10	7/10	5/10	10/10	2/10	0/10	0/10	64/140 (45.7%)
	50%	20%	90%	50%	60%	40%	40%	50%	70%	50%	100%	20%	0%	0%	

Table 59, Phase Two (Haptic 2014), Anatomy test questions 4-8 results

	4b	5b	6b	7b	8b	9b	10b	11b	12b	13b	14b	15b	16b	17b	Total
Q4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	14/14 (100%)
Q5	1	0	0	1	1	1	0	1	1	0	1	1	1	0	9/14 (64.2%)
Q6	1	0	1	1	1	1	1	1	1	1	1	1	1	1	13/14 (92.8%)
Q7	1	0	1	1	1	1	1	1	1	1	1	1	0	1	12/14 (85.7%)
Q8	0	0	1	1	1	1	1	1	1	1	1	1	0	0	10/14 (71.4%)
Total	4/5 80%	1/5 20%	4/5 80%	5/5 100%	5/5 100%	5/5 100%	4/5 80%	5/5 100%	5/5 100%	4/5 80%	5/5 100%	5/5 100%	3/5 60%	3/5 60%	**0/70 (82.8%)**

Question one consisted of nine elements: the group scored a total of 66 out of 126 (52.3%) (Table 56). Question two consisted of six elements: the group scored a total of 46 out of 84 (54.7%) (Table 57). Question three consisted of ten elements: the group scored a total of 64 out of 140 (45.7%) (Table 58). Question four scored a total of 14 out of 14 (100%). Question five scored a total of 9 out of 14 (64.2%), Question six scored a total of 13 out of 14 (92.8%). Question seven scored a total 12 out of 14 (85.7%). Finally question eight scored a total 10 out of 14 (71.5%) (Table 75). The total for this section being 58 out of a possible 70 (82.8%) (Table 59).

Dissection Evaluation 2014 (Haptic BSc)

Ten cadavers were dissected between the group. Some students dissected the same cadaver as one another, while others dissected different cadavers with students who were not taking part in the study. Each group consisted of four students per cadaver. Thirteen questions were asked regarding 'how well' different aspects of the dissection had been performed and were scored using a five-point Likert scale, where 1= 'not at all', 2 'somewhat', 3= 'moderately', 4= 'very', and 5= 'extremely'. For these questions therefore a higher score is preferable. One exception to this format is question 8, which asked, 'How much damage to the structure is there?' In this instance a lower score would be preferable. For this reason, this question is looked at in isolation from the others (Figure 110). For the Likert scale questions, cadaver 14 scored 48 out 60 (80%), cadaver 15 scored 45 out of 60 (75%), cadaver 17 scored 42 out of 60 (70%), cadaver 18 scored 46 out of 60 (76.7%), cadaver 19 scored 41 out of 60 (68.3%), cadaver 21 scored 40 out of 60 (66.7%), cadaver 22 scored 44 out of 60 (73.3%), cadaver 23 scored 41 out of 60 (68.3%), cadaver 27 scored 47 out of 60 (78.3%) and finally cadaver 30 scored 43 out of 60 (71.7%). Adding together the ten totals of for the likert scale questions gave a score of 437 out of a possible 600 points (72.8%) (Table 61).

For question 8 'how much damage to the structures is there?' all tables scored 2 - 'somewhat' (Figure 110).

The single BMSc student (6) was on a table (17) with the BSc students and as such is grouped with BScs here.
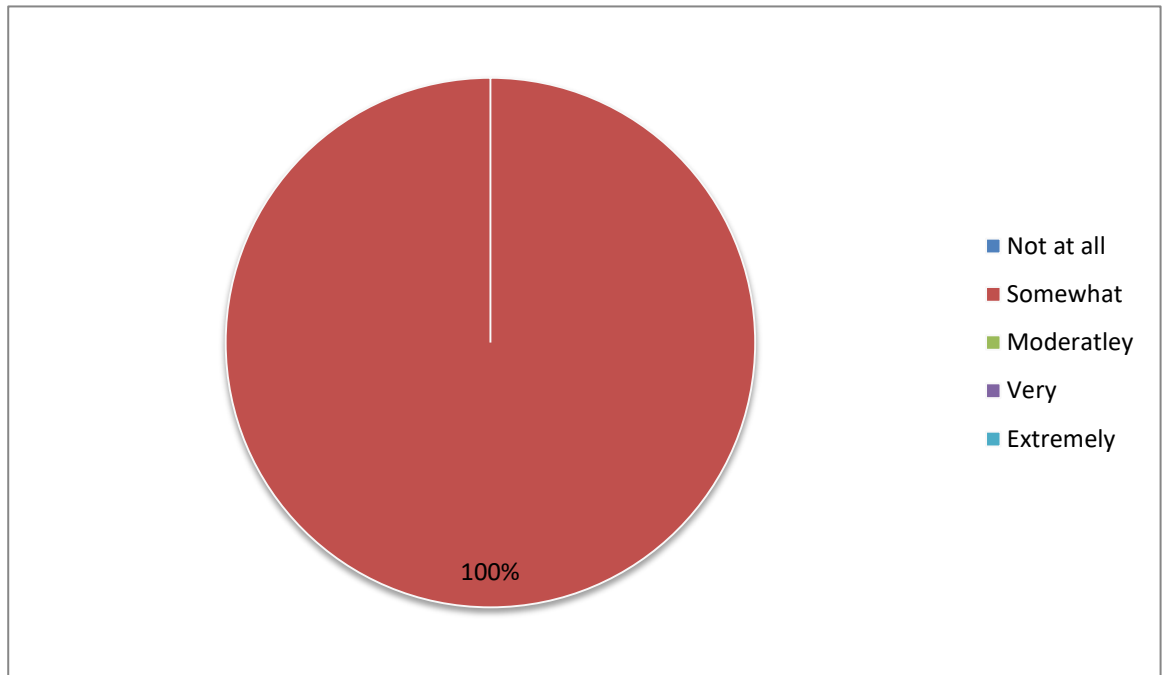
Figure 110, Question 8: How much damage to the structure is there? Phase Two 2014, BSc haptic group

Table 60, Phase Two (Haptic 2014), number of students in study per cadaver

Table number	Total in group	Total in study
14	4	1
15	3	1
17	4	2
18	4	1
19	4	1
21	4	1
22	4	3
23	4	1
27	4	2
30	4	1

Table 61, Phase Two (Haptic 2014), Dissection Evaluation results

	14: 5b	15: 17b	17: 6, 10b,	18: 4b	19: 9b	21: 11b	22: 13b, 14b, 16b	23: 7b	27: 8b, 15b	30: 6b	Total
Q1	4	4	2	4	2	3	3	3	4	4	33/50 (66%) median 3.5/mode 4
Q2	4	4	4	4	4	4	4	4	4	4	40/50 (80%) median 4/mode 4
Q3	3	3	3	4	3	3	3	3	3	3	31/50 (62%) median 3/mode 3
Q4	4	3	4	4	4	3	4	3	4	4	37/50 (74%) median 4/mode 4
Q5	4	4	3	3	3	3	4	3	3	3	33/50 (66%) median 3/mode 3
Q6	4	4	3	3	2	3	3	3	3	3	31/50 (62%) median 3/mode 3
Q7	4	4	4	4	4	4	4	4	5	4	41/50 (82%) median 4/mode 4
Q9	4	4	4	4	4	4	4	3	4	4	39/50 (78%) median 4/mode 4
Q10	4	3	3	4	3	2	3	3	4	3	32/50 (64%) median 3/mode 3
Q11	5	4	4	4	4	4	4	4	5	4	42/50 (84%) median 4/mode 4
Q12	4	4	4	4	4	3	4	4	4	3	38/50 (76%) median 4/mode 4
Q13	4	4	4	4	4	4	4	4	4	4	40/50 (80%) median 4/mode 4
Total	48/60 (80%)	45/60 (75%)	42/60 (70%)	46/60 (76.7%)	41/60 (68.3%)	40/60 (66.7%)	44/60 (73.3%)	41/60 (68.3%)	47/60 (78.3%)	43/60 (71.7%)	437/600 (72.8%) Median = 4/Mode = 4

Feedback Questionnaire 2014 (Haptic BSc)

The feedback questionnaire consisted of a total of fifteen questions. The first 9 of these were scored using a five-point Likert scale and asked questions such as how easy or enjoyable the software was to use or how the student felt it would improve their practical skills etc. where 1= 'not at all', 2 'somewhat', 3= 'moderately', 4= 'very', and 5= 'extremely'. For these questions therefore a higher score is preferable. Following this there were two 'closed' questions asking, 'how much time did you spend using the software?' And 'how many training sessions did you attend?' These were followed by three 'open' questions asking, 'if you used the keyboard and mouse interface how do you feel this affected your experience?' 'If you used the haptic interface how much do you feel this affected your experience?' And 'what improvements would you like to see made to the software?' Finally there was a space for 'any other comments?' The results for questions 1-9 can be found in the following Table (61) and Figures (111-119).

Table 62, Phase two (Haptic 2014), questionnaire results, questions 1-9

	4b	5b	6b	7b	8b	9b	10b	11b	12b	13b	14b	15b	16b	17b	Total
Q1	3	3	3	3	3	3	4	2	4	3	3	3	5	3	45/70 (64.3%) median 3/mode 3
Q2	5	4	4	3	4	5	4	5	4	4	4	5	5	4	60/70 (85.7%) median 4/mode 4
Q3	4	5	4	4	2	5	4	3	2	4	4	3	3	3	50/70 (71.4%) median 4/mode 4
Q4	5	5	2	3	5	4	5	4	5	4	4	5	5	4	60/70 (85.7%) median 4.5/mode 5
Q5	4	3	2	4	5	4	5	4	4	4	5	4	5	5	58/70 (82.9%) median 4/mode 4
Q6	5	4	4	4	3	4	5	5	4	4	4	3	5	5	59/70 (84.3%) median 4/mode 4
Q7	4	2	3	3	1	4	1	4	3	3	3	2	5	3	41/70 (58.6%) median 3/mode 3
Q8	5	2	4	4	4	3	4	4	3	3	5	3	5	3	52/70 (74.3%) median 4/mode 3*
Q9	3	1	3	3	1	3	2	3	4	2	3	2	5	3	38/70 (54.2%) median 3/mode 3
Total	38/45	29/45	29/45	31/45	28/45	35/45	34/45	34/45	33/45	31/45	35/45	30/45	43/45	33/45	463/630 (73.5%) Median = 4 Mode = 4

* Multiple modes exist. The smallest value is shown
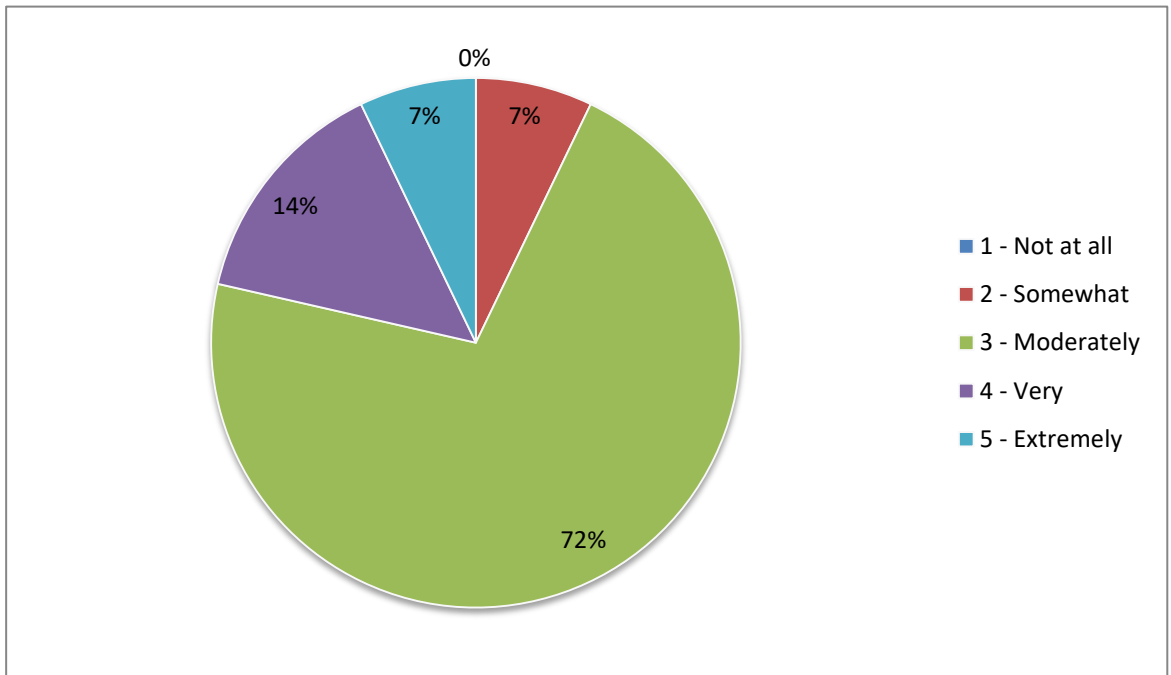
Figure 111, Question 1: How easy and intuitive was the software to use? Phase Two 2014, BSc haptic
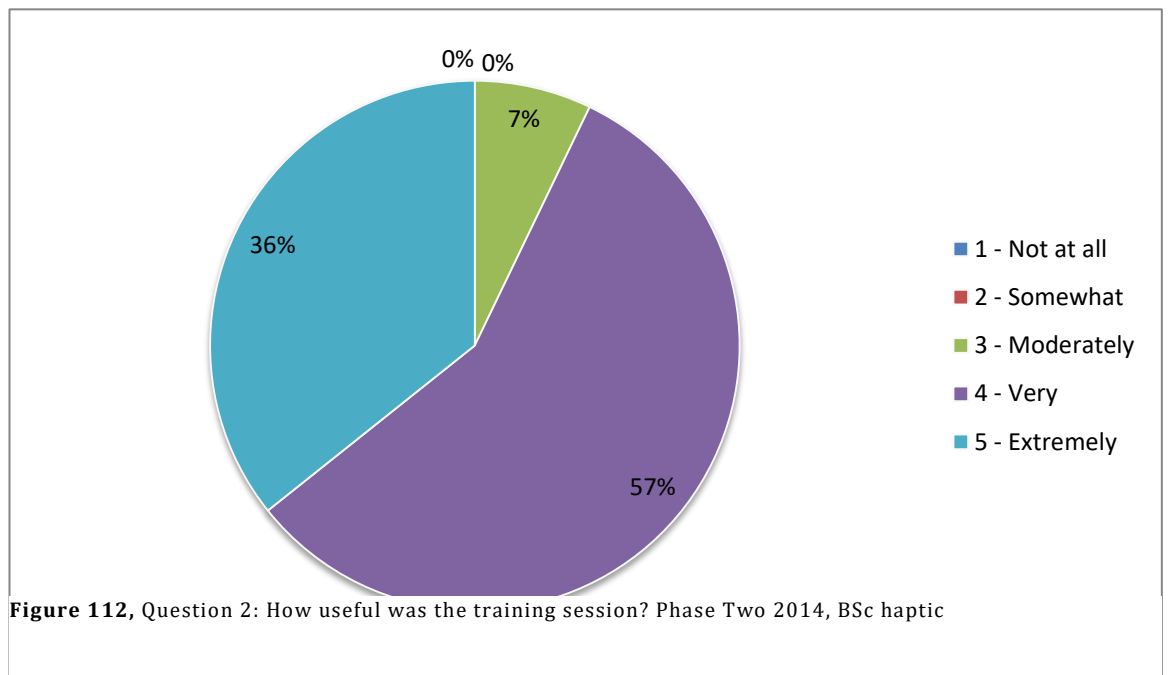
Figure 112, Question 2: How useful was the training session? Phase Two 2014, BSc haptic
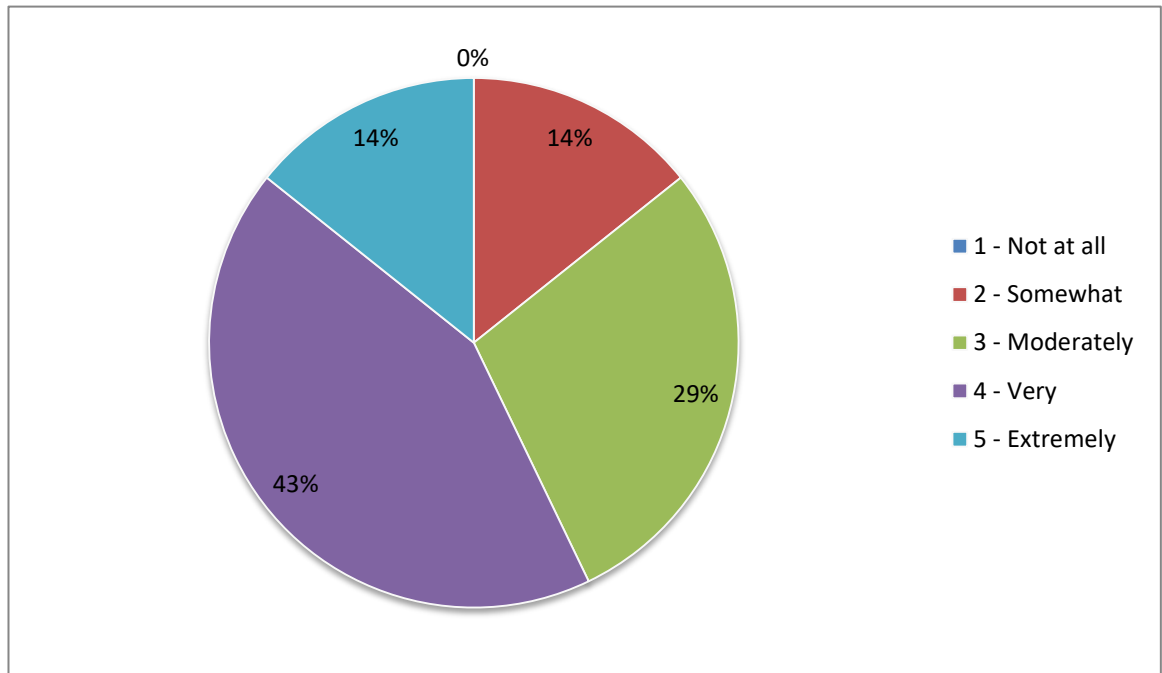
Figure 113, Question 3: How helpful was the dissection manual? Phase Two 2014, BSc haptic
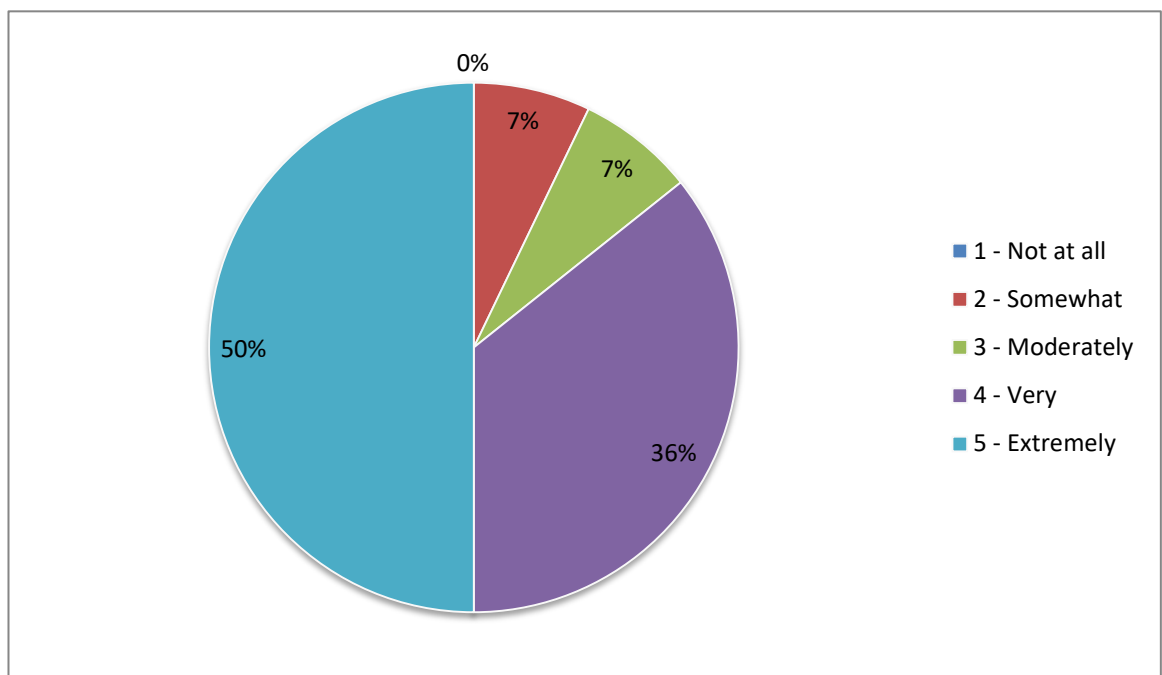
Figure 114, Question 4: Is the model anatomically accurate? Phase Two 2014, BSc haptic
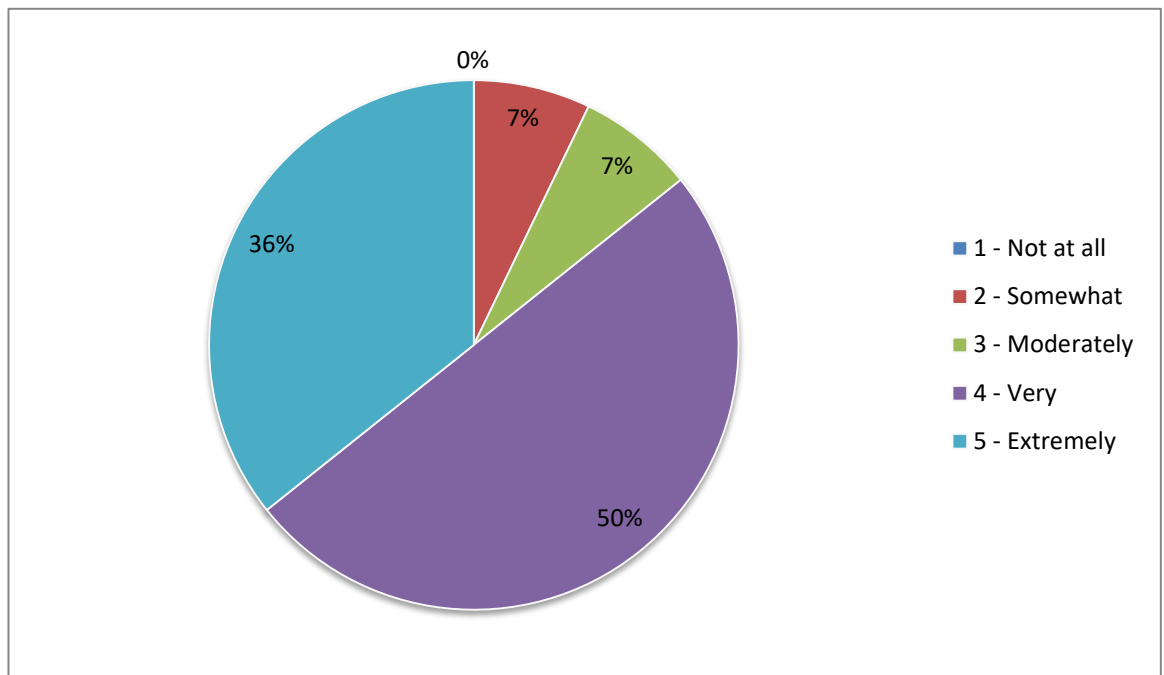
Figure 115, Question 5: How appropriate is the level of detail in the model? Phase Two 2014, BSc haptic
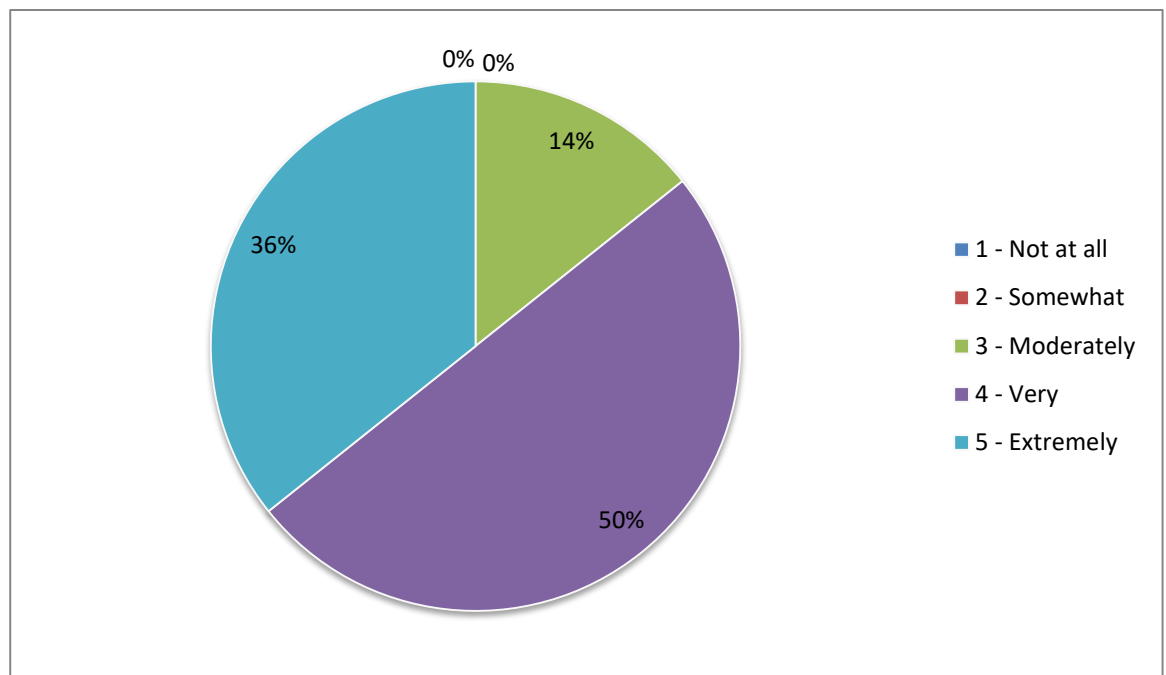
Figure 116, Question 6: Did you enjoy using the software? Phase Two 2014, BSc haptic
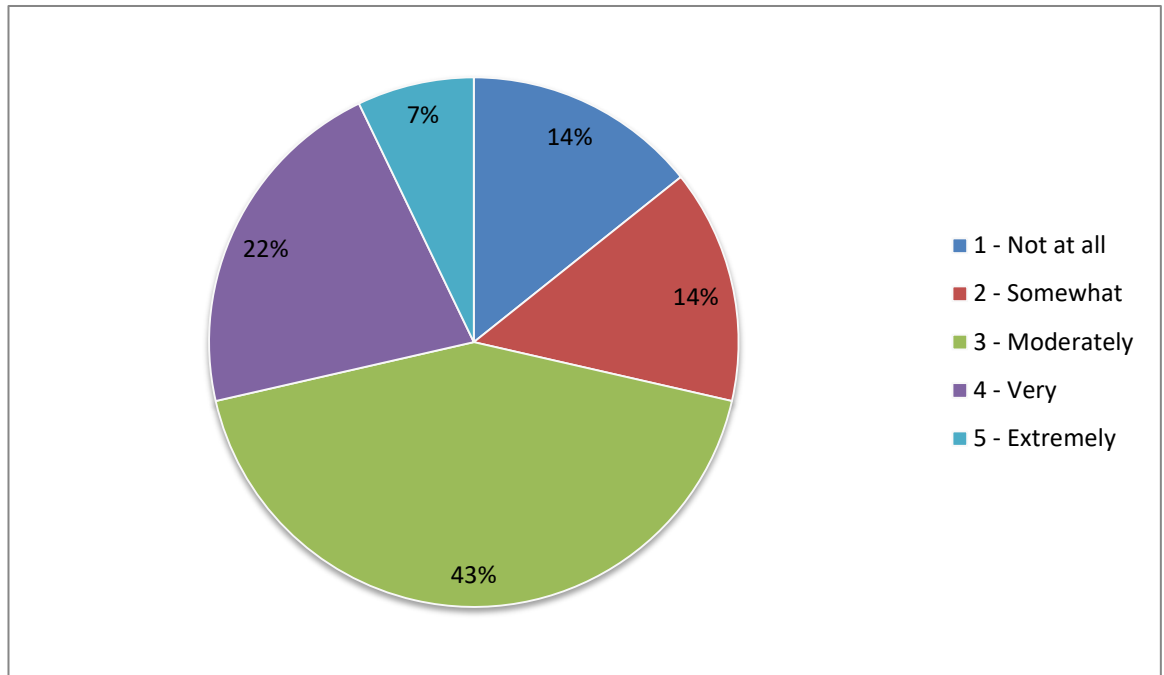
Figure 117, Question 7: Did the software improve your dissection skills? Phase Two 2014, BSc haptic
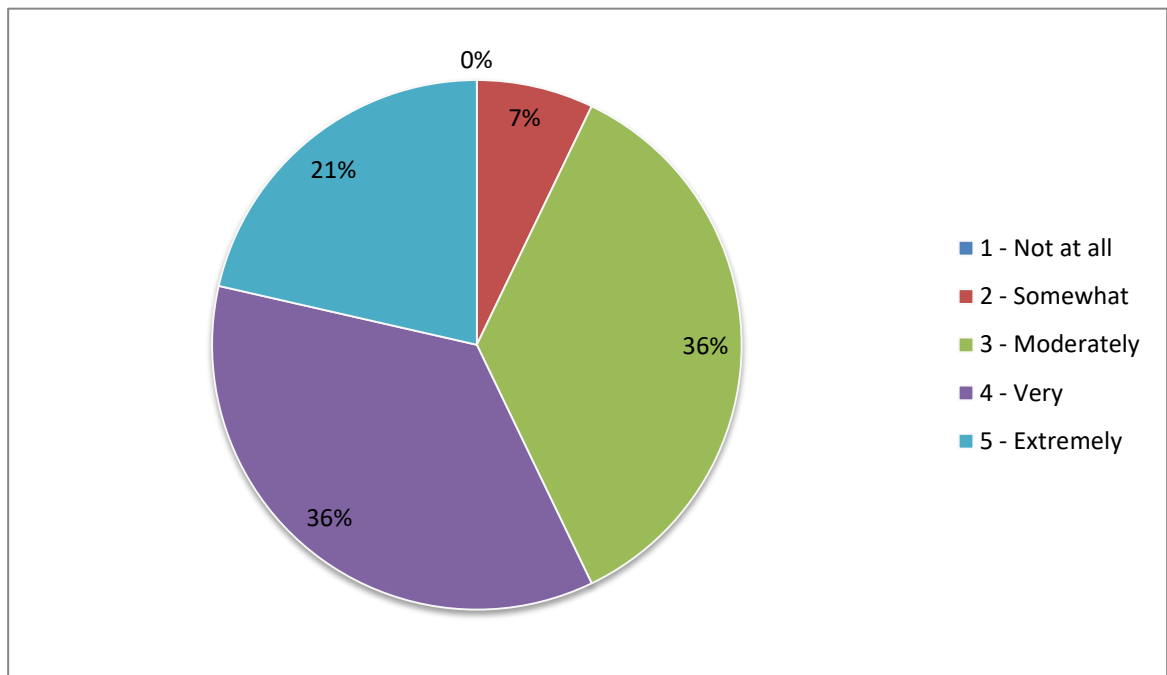
Figure 118, Question 8: Did use of the software improve your anatomical knowledge? Phase Two 2014, BSc haptic
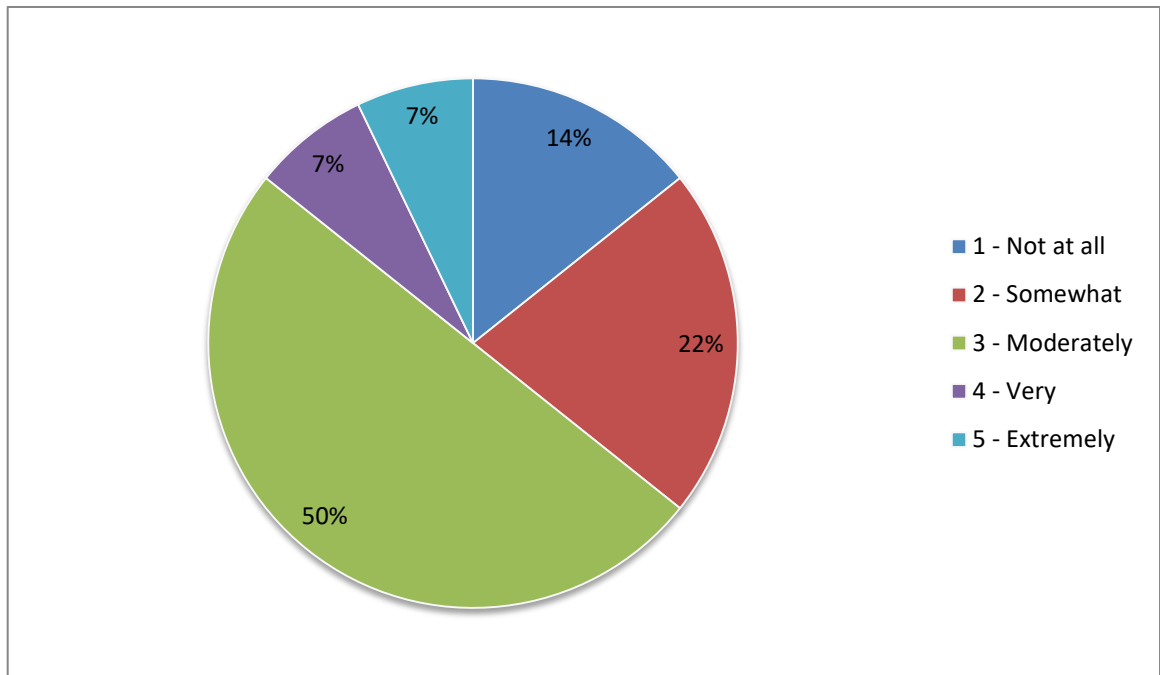
Figure 119, Question 9: Did you feel more confident doing cadaveric dissection after using the software? Phase Two 2014, BSc haptic

Questions 10 and 11 were 'closed' style questions asking, 'how much time did you spend using the software?' and 'how many training sessions did you attend?' Question 10 had five possible answers; 0 hours, 0-1 hour, 1-5 hours, 5-10 hours and 10+ hours. Question 11 had six possible answers; 0, 1, 2, 3, 4 and 5+. The results for questions 10 & 11 can be found in the following Table (62) and Figures (120-121).

Table 63, Questions 10 & 11 compared to anatomy test results. Phase Two 2014, BSc haptic

	4b	5b	6b	7b	8b	9b	10b	11b	12b	13b	14b	15b	16b	17b
Q10	1-5	1-5	0-1	0-1	1-5	0-1	0-1	1-5	0-1	0-1	1-5	1-5	1-5	1-5
Q11	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Total for anatomy test	63.3%	30%	66.7%	63.3%	73.3%	63.3%	66.7%	56.7%	80%	63.3%	86.7	36.7%	13.3%	26.7%
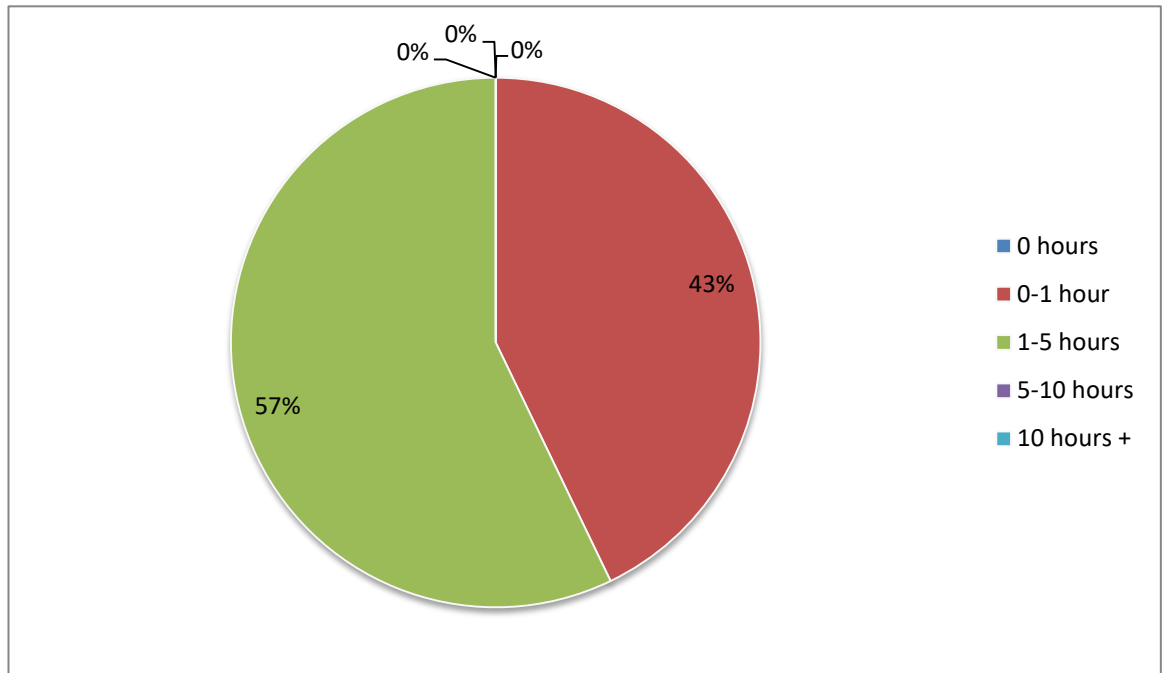
Figure 120, Question 10: How much time did you spend using the software? Phase Two 2014, BSc haptic
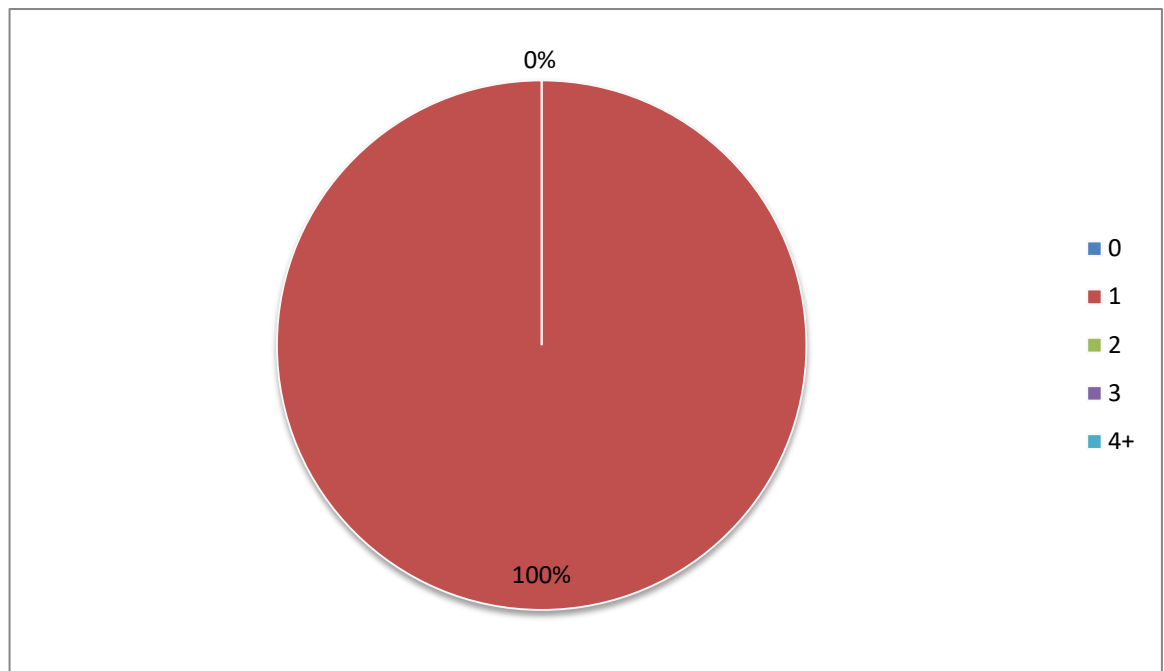
Figure 121, Question 11: How many training sessions did you attend? Phase two 2014, BSc haptic

Finally questions 12 through 15 were 'open' free text questions asking, 'if you used the keyboard and mouse interface how do you feel this affected your experience?' 'If you used the haptic interface how much do you feel this affected your experience?' 'What improvements would you like to see made to the software?' And finally there was a space for 'any other comments?' Question 12 which asked about the non-haptic version of the software was not applicable to this user group. For ease of reading, comments from questions 12-15 have been grouped into the following recurring themes: useful tool for revision, useful for learning structures, the haptic interface, keyboard and mouse interface, general ease of use, interactive labelling, and suggestions for improvements. The numbers relate to the student making the comment.

5b) I was helpful for exam revision, however with having exams for other modules before gross anatomy (I) didn't spend as much time using it as I'd have liked.

6b) I found it enjoyable to use and found it helped to reinforce my understanding of the hand anatomy. I think a few improvements could be made, but I do think it is a very valuable additional tool to normal dissection.

9b) I really liked the software and was a great revision aid that's in 3D. I would love to have a go at other dissections.

17b) I definitely think the haptic interface is a good thing however I think the layout of the classes didn't help, class on hand straight before dissection – so when you were using it before it was just seeing things and using the tolls, however afterwards it's a great revision tool. Id o think it's be a perfect tool to use between lecture and dissection.

8b) I think the software is very good and the idea behind it is great. If it was available for the other parts of the body, I would definitely use it a lot for my studying because it gives a very good understanding of where things are in a 3D structure.

12b) The tool is a very helpful revision aid however because of the structure of the course I was unable to use it to improve the dissection – the lecture on the hand was immediately followed by the dissection. However it did help with my revision and helped me to visualise the structure better than a 2D image would.

14b) It was interesting to get the feel of the structure but in terms of dissection, only the real structure in the DR give a proper understanding. It was incredibly helpful though for singling out individual structures – something which is impossible in the DR.

14b) I think the haptic device is incredibly useful for identifying he individual structures and their relationship to other structure.

4b) Very hands on experience, probably more fun than keyboard.

4b) Instead of struggling with the keyboard you could just go and 'do' without having to think much.

5b) It was good to physically feel the difference and where you were 'cutting'.

7b) Much more like dissection but a little confusing.

8b) I think it was more interesting to use, but when I was using it, one was not working perfectly and the other was not working at all, so it felt like the haptic interface was almost slowing everything down. However if everything was working smoothly I'm sure it would have been more useful than using just keyboard and mouse.

9b) The haptic interface was very useful as you could literally feel as you were dissecting, and different layers felt differently. This aided real life dissection.

10b) It was bizarre, but made the dissection more lifelike.

11b) I did try to use the haptic interface, but I feel I would need much more time with it in order to be quite confident using it.

11b) For me the tools that made the structure visible/invisible on a highlighted were extremely useful for studying purposes. It took a long time to get used to the haptic device.

12b) The haptic interface was useful in terms of 3D structure of the model, however I found it very easy to go through the hand – making it more difficult to dissect. I definitely think that using the haptic tool improved the software though.

15b) Sometimes difficult to control the haptic device. Was interesting to feel the different movements at first but when I wanted to really study the structures I found it quite frustrating using the device and returned to the keyboard.

16B) It was good to be able to 'feel' the cadaver and it probably helped my dissection skills.

8b) The only real downfall is that you cannot dissect through all the tissues, but only the one you have activated. Because of this it was more useful just taking layers off and looking at underlying structures.

9b) Making the activation of layers simpler/more user friendly

12b) I would also like to see the ability to select whole layers e.g. 'muscle' instead of each muscle individually.

15b) It was fun to try, I should have been less frustrated with it when it wouldn't do exactly what I wanted it to. More practice would probably have helped that though.

15b) I would like it to be easier to activate all the items in a folder.

17b) I think some of the tool functions are slightly awkward when trying to dissect small parts like nerves/vessels. I think it'd be nice to also be able to dissect all layers together as well as separately, or just a level of structures.

5b) A lot of time was spent trying to figure out relations/positions of different muscles. Although a text book was provided, would be helpful to see a muscle fact sheet (nerve innervations etc) on the screen, or for them to be highlighted when working with a particular section.

11b) It would be helpful if when clicked on a structure the name of the structure would appear.

12b) I would find it useful in the "?" mode to see the origin/insertionFx and innervation of each muscle.

4b) It would, in my opinion be a fantastic addition to our course if the whole body would be available to dissect virtually. This has helped me a lot in my understanding and having this way of virtual dissection could be a great additional tool to offer to students.

6b) A little more detail and more positions for the hand. Also the movement reaction when triggering a muscle or tendon.

7b) Tissues set to hardness they would not be in DR.

14b) I would be great to (see) the movements of individual structures. Something I found very interesting in the DR was being able to pick out a structure and see how it moved the wrist/digits. By showing a movement and showing the individual structures that caused that movement would be interesting if possible.

APPENDIX 8: PHASE THREE RESULTS (BSC, 2015)

During the fifth year (2015) 3rd year BSc Anatomy and BSc Forensic Anthropology students took part in the study. The aim of this phase was to compare haptic and non-haptic groups from the same student cohort.

In order to create a control group the returning 4th years were invited to complete the anatomy test, after being given a week to revise if they wished. The 3rd year students were given the opportunity to use the haptic software in addition to their normal tuition. The control group consisted of twenty students, the non-haptic group of seven, and the haptic group of five students.

The 3rd year BSc students were split at random into two groups. One group had access to the haptic version of the software and one to the non-haptic version in addition to their normal tuition from two weeks before to one week after cadaveric dissection of the hand and wrist took place. Use of the software was optional and tuition was provided at regular intervals during the time the software was available (5 tutorials, at least one per week). Within ten days of completing their dissection the students undertook an anatomy knowledge test consisting of eight questions; four 'spot tests' and five multiple choice on the anatomy of the hand and wrist. The quality of the cadaver dissections were evaluated by an anatomist within ten days of dissection being completed. During the time between completion of dissection and evaluation of the cadaver no further invasive procedures were performed. Students were also asked to complete a feedback questionnaire on how on how useful they felt the software to be.

Anatomy Test 2015 (Control BSc)

The individual results of the anatomy test are broken down in to four tables (Tables 64-67); three for each of the spot tests (multiple answers) and one for the multiple choice (single correct answer) questions. Five students (numbers 4b, 8b, 10b, 19b, and 20b) have been omitted from the results as they left over 40% of the answers blank.

Table 64, Phase Three (Control 2015), anatomy test question 1 results

Q1	1b	2b	3b	5b	6b	7b	9b	11b	12b	13b	14b	15b	16b	17b	18b	21b	22b	23b	24b	25b	Total
A	0	0	0	1	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	3/20 15%
B	0	0	0	0	0	0	1	0	0	0	1	0	0	1	0	1	0	0	0	1	4/20 20%
C	0	0	0	0	1	0	0	0	0	1	0	1	0	1	0	0	0	0	0	0	3/20 15%
D	1	0	0	0	0	0	1	0	0	0	1	0	1	0	0	1	1	0	0	0	6/20 30%
E	1	0	0	0	0	0	1	0	0	0	1	1	1	0	0	1	1	1	0	0	8/20 40%
F	0	1	0	0	0	0	0	1	0	0	1	1	0	0	0	1	0	1	0	0	6/20 30%
G	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1/20 5%
H	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	1	0	0	0	0	4/20 20%
I	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	1	0	0	0	0	4/20 20%
Total	2/9 22.2%	1/9 11.1%	0/9 0%	1/9 11.1%	1/9 11.1%	0/9 0%	3/9 33.3%	2/9 22.2%	0/9 0%	1/9 11.1%	7/9 77.7%	4/9 44.4%	4/9 44.4%	2/9 22.2%	0/9 0%	6/9 66.6%	2/9 22.2%	2/9 22.2%	0/9 0%	1/9 11.1%	**39/180** **21.6%**

Table 65, Phase Three (Control 2015), anatomy test question 2 results

Q2	1b	2b	3b	5b	6b	7b	9b	11b	12b	13b	14b	15b	16b	17b	18b	21b	22b	23b	24b	25b	Total
A	1	1	0	0	0	0	1	1	1	0	1	1	1	0	1	0	0	0	0	1	10/20 50%
B	1	0	0	0	0	0	1	1	0	0	1	1	0	0	1	1	0	0	0	0	7/20 35%
C	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1/20 5%
D	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1	0	0	0	0	4/20 20%
E	1	0	0	1	0	0	1	1	0	0	1	1	1	0	0	1	0	0	1	0	9/20 45%
F	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	3/20 15%
Total	3/6	1/6	0/6	1/6	0/6	0/6	4/6	5/6	1/6	0/6	4/6	4/6	3/6	0/6	3/6	3/6	0/6	0/6	1/6	1/6	**34/120**
	50%	16.6%	0%	16.6%	0%	0%	66.6%	83.3%	16.6%	0%	66.6%	66.6%	50%	0%	50%	50%	0%	0%	16.6%	16.6%	**28.3%**

Table 66, Phase Three (Control 2015), anatomy test question 3 results

Q3	1b	2b	3b	5b	6b	7b	9b	11b	12b	13b	14b	15b	16b	17b	18b	21b	22b	23b	24b	25b	Total
1	1	1	0	1	0	0	1	1	0	0	1	1	1	0	0	0	0	0	0	1	9/20 45%
2	1	0	0	0	0	0	1	1	0	0	0	0	1	0	0	0	0	0	0	1	5/20 25%
5	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1/20 5%
6	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	2/20 10%
8	1	1	0	0	0	1	0	0	0	0	1	1	1	1	1	0	0	0	0	0	8/20 40%
9	0	0	0	1	0	0	1	0	1	1	1	1	1	1	0	0	1	0	1	0	10/20 50%
10	0	0	0	0	0	0	1	1	1	0	1	1	1	0	0	0	0	0	0	0	6/20 30%
11	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	2/20 10%
12	1	0	1	0	0	0	0	1	0	0	0	0	1	0	1	0	0	0	0	0	5/20 25%
13	1	0	1	1	1	1	0	1	0	1	1	1	1	0	1	1	1	1	1	1	16/20 80%
Total	6/10 60%	2/10 20%	2/10 20%	3/10 30%	1/10 10%	2/10 20%	4/10 40%	5/10 50%	2/10 20%	3/10 30%	5/10 50%	5/10 50%	9/10 90%	2/10 20%	4/10 40%	1/10 10%	2/10 20%	1/10 10%	2/10 20%	3/10 30%	**64/200** **32%**

Table 67, Phase Three (Control 2015), anatomy test question 4-8 results

	1b	2b	3b	5b	6b	7b	9b	11b	12b	13b	14b	15b	16b	17b	18b	21b	22b	23b	24b	25b	Total
Q4	1	1	1	0	1	1	1	0	1	1	1	1	1	0	1	1	1	1	0	1	16/20 80%
Q5	0	0	0	0	1	0	0	0	0	0	0	1	0	1	1	1	1	0	1	1	8/20 40%
Q6	0	0	0	1	1	0	1	0	0	0	1	1	1	1	0	1	1	1	0	0	10/20 50%
Q7	1	1	1	1	1	1	0	1	1	1	1	1	0	1	1	0	0	1	1	1	16/20 80%
Q8	1	1	0	0	0	1	0	0	1	0	1	0	0	0	1	0	1	0	1	0	8/20 40%
Total	3/5 60%	3/5 60%	2/5 40%	2/5 40%	4/5 80%	3/5 60%	2/5 40%	1/5 20%	3/5 60%	2/5 40%	4/5 80%	4/5 80%	2/5 40%	3/5 60%	4/5 80%	3/5 60%	4/5 80%	3/5 60%	3/5 60%	3/5 60%	**58/100 58%**

Question one consisted of nine elements: the group scored a total of 35 out of 180 (19.4%), (Table 64). Question two consisted of six elements: the group scored a total of 34 out of 120 (28.3%) (Table 65). Question three consisted of ten elements: the group scored a total of 64 out of 200 (32%) (Table 66). Question four scored a total of 16 out of 20 (80%). Question five scored a total of 8 out of 20 (40%), Question six scored a total of 10 out of 20 (50%). Question seven scored a total 16 out of 20 (80%). Finally question eight scored a total 8 out of 20 (40%) (Table 83). The total for this section being 58 out of a possible 100 (58%) (Table 67).

Anatomy Test 2015 (Non-Haptic BSc)

The results of the anatomy test are broken down in to four tables (Tables 68-71); three for each of the spot tests (multiple answers) and one for the multiple choice (single correct answer) questions.   One student (number 9) has been omitted from the results as they left over 40% of the answers blank.

Table 68, Phase Three (Non-haptic 2015), anatomy test question 1 results

Q1	1	2	4	7	8	Total
A	1	0	0	1	1	3/5 60%
B	1	0	0	0	0	1/5 20%
C	0	0	0	0	1	1/5 20%
D	0	1	0	0	1	2/5 40%
E	0	1	0	1	1	3/5 60%
F	1	1	1	1	1	6/5 100%
G	0	0	0	0	1	1/5 20%
H	0	0	0	1	1	2/5 40%
I	0	0	0	1	1	2/5 40%
Total	3/9 33.3%	3/9 33.3%	1/9 11.1%	5/9 55.5%	8/9 88.8%	**21/45 46.6%**

Table 69, Phase Three (Non-haptic 2015), anatomy test question 2 results

Q2	1	2	4	7	8	Total
A	0	0	1	0	0	1/5 20%
B	0	0	0	1	1	2/5 40%
C	1	1	0	1	1	4/5 80%
D	0	0	0	1	1	2/5 40%
E	1	0	1	1	1	4/5 80%
F	0	0	1	1	1	3/5 60%
Total	2/6 33.3%	1/6 16.6%	3/6 50%	5/6 83.3%	5/6 83.3%	**16/30 53.3%**

Table 70, Phase Three (Non-haptic 2015), anatomy test question 3 results

Q3	1	2	4	7	8	Total
1	0	0	1	0	0	1/5 20%
2	0	0	1	0	0	1/5 20%
5	0	0	0	1	1	2/5 40%
6	0	0	0	1	1	2/5 40%
8	1	1	1	1	1	5/5 100%
9	0	1	1	0	1	3/5 60%
10	0	1	1	1	1	4/5 80%
11	0	0	0	0	1	1/5 20%
12	0	0	0	0	0	0/5 0%
13	0	1	1	1	1	4/5 80%
Total	1/10 10%	4/10 40%	6/10 60%	5/10 50%	7/10 70%	**23/50 46%**

Table 71, Phase Three (Non-haptic 2015), anatomy test questions 4-8 results

	1	2	4	7	8	Total
Q4	1	1	0	1	1	4/5 80%
Q5	1	1	1	1	1	5/5 100%
Q6	1	1	0	1	1	4/5 80%
Q7	1	1	1	1	1	5/5 100%
Q8	1	1	1	0	1	4/5 80%
Total	5/5 100%	5/5 100%	3/5 60%	4/5 80%	5/5 100%	**22/25 88%**

Question one consisted of nine elements: the group scored a total of 21 out of 45 (46.6%) (Table 68). Question two consisted of six elements: the group scored a total of 16 out of 30 (53.3%) (Table 69). Question three consisted of ten elements: the group scored a total of 23 out of 50 (46%) (Table 70). Question four scored a total of 4 out of 5 (80%). Question five scored a total of 5 out of 5 (100%), Question six scored a total of 4 out of 5 (80%). Question seven scored a total 5 out of 5 (100%). Finally question eight scored a total 4 out of 5 (80%). The total for this section being 22 out of a possible 25 (88%) (Table 71).

Anatomy Test 2015 (Haptic BSc)

The results of the anatomy test are broken down in to four tables (Tables 72-75); three for each of the spot tests (multiple answers) and one for the multiple choice (single correct answer) questions.

Table 72, Phase Three (Haptic 2015), anatomy test question 1 results

Q1	1a	2a	4a	5a	7a	9a	Total
A	0	1	0	1	1	1	4/6 66.6%
B	0	0	0	1	0	1	2/6 33.3%
C	0	0	0	0	0	0	0/6 0%
D	0	0	1	0	1	0	2/6 33.3%
E	0	1	1	0	1	0	3/6 50%
F	0	1	1	1	1	0	4/6 66.6%
G	0	1	0	0	0	1	2/6 33.3%
H	0	0	0	1	1	1	3/6 50%
I	0	1	0	1	1	1	4/6 66.6%
Total	0/9	5/9	3/9	5/9	6/9	5/9	**24/54**
	0%	55.5%	33.3%	55.5%	66.6%	55.5%	**44.4%**

Table 73, Phase Three (Haptic 2015), anatomy test question 2 results

Q2	1a	2a	4a	5a	7a	9a	Total
A	0	1	0	0	1	1	3/6 50%
B	0	1	1	1	1	1	5/6 83.3%
C	0	1	0	1	0	0	2/6 33.3%
D	0	0	1	1	1	1	4/6 66.6%
E	0	1	1	1	0	1	4/6 66.6%
F	0	0	1	1	0	0	2/6 33.3%
Total	0/6 0%	4/6 66.6%	4/6 66.6%	5/6 83.3%	3/6 50%	4/6 66.6%	**20/30 66.6%**

Table 74, Phase Three (Haptic 2015), anatomy test question 3 results

Q3	1a	2a	4a	5a	7a	9a	Total
1	0	1	0	1	1	1	4/6 66.6%
2	0	1	1	0	0	1	3/6 50%
5	0	0	0	0	0	0	0/6 0%
6	0	0	0	0	1	0	1/6 16.6%
8	0	1	1	1	1	1	5/6 83.3%
9	0	1	1	1	0	1	4/6 66.6%
10	0	1	1	1	0	1	4/6 66.6%
11	0	0	0	0	0	1	1/6 16.6%
12	0	0	1	0	0	1	2/6 33.3%
13	0	1	1	1	1	1	5/6 83.3%
Total	0/10 0%	6/10 60%	6/9 60%	5/10 50%	4/10 40%	8/10 80%	**29/60** **48.3%**

Table 75, Phase Three (Haptic 2015), anatomy test questions 4-8 results

	1a	2a	4a	5a	7a	9a	Total
Q4	1	1	1	1	1	1	6/6 100%
Q5	1	1	0	0	0	1	3/6 50%
Q6	1	1	1	1	1	1	6/6 100%
Q7	0	0	1	1	1	1	4/6 66.6%
Q8	1	0	0	0	1	1	3/6 50%
Total	4/5	3/5	3/5	3/5	4/5	5/5	**22/30**
	80%	60%	60%	60%	80%	100%	**73.3%**

Question one consisted of nine elements: the group scored a total of 24 out of 54 (44.4%) (Table 68). Question two consisted of six elements: the group scored a total of 20 out of 30 (66.6%) (Table 73). Question three consisted of ten elements: the group scored a total of 29 out of 60 (48.3%) (Table 74). Question four scored a total of 6 out of 6 (100%). Question five scored a total of 3 out of 6 (50%), Question six scored a total of 6 out of 6 (100%). Question seven scored a total 4 out of 6 (66.6%). Finally question eight scored a total 3 out of 6 (50%). The total for this section being 22 out of a possible 25 (88%) (Table 75).

Dissection Evaluation 2015 (All BSc)

Eleven cadavers were dissected between both the non-haptic and haptic groups. Some students dissected the same cadaver as one another, while others dissected different cadavers with students who were not taking part in the study. Each group consisted of

four students per cadaver. Thirteen questions were asked regarding 'how well' different aspects of the dissection had been performed and were scored using a five-point Likert scale, where 1= 'not at all', 2 'somewhat', 3= 'moderately', 4= 'very', and 5= 'extremely'. For these questions therefore a higher score is preferable. One exception to this format is question 8, which asked, 'How much damage to the structure is there?' In this instance a lower score would be preferable. For this reason, this question is looked at in isolation from the others (Figure 122). For the Likert scale questions, cadaver 12 scored 38 out 60 (63.3%), cadaver 14 scored 35 out of 60 (58.3%), cadaver 15 scored 49 out of 60 (81.6%), cadaver 17 scored 45 out of 60 (75%), cadaver 19 scored 38 out of 60 (63.3%), cadaver 21 scored 42 out of 60 (70%), cadaver 22 scored 48 out of 60 (80%), cadaver 23 scored 42 out of 60 (70%), cadaver 25 scored 42 out of 60 (70%) cadaver 27 scored 50 out of 60 (83.3%) and finally cadaver 30 scored 43 out of 60 (71.7%). Adding together the nine totals of for the likert scale questions gave a score of 472 out of a possible 660 points (71.5%) (Table 77).

For question 8 'how much damage to the structures is there?' all tables scored 2 - 'somewhat', with the exception of table 22 which scored 3 'moderately' (Figure 122).
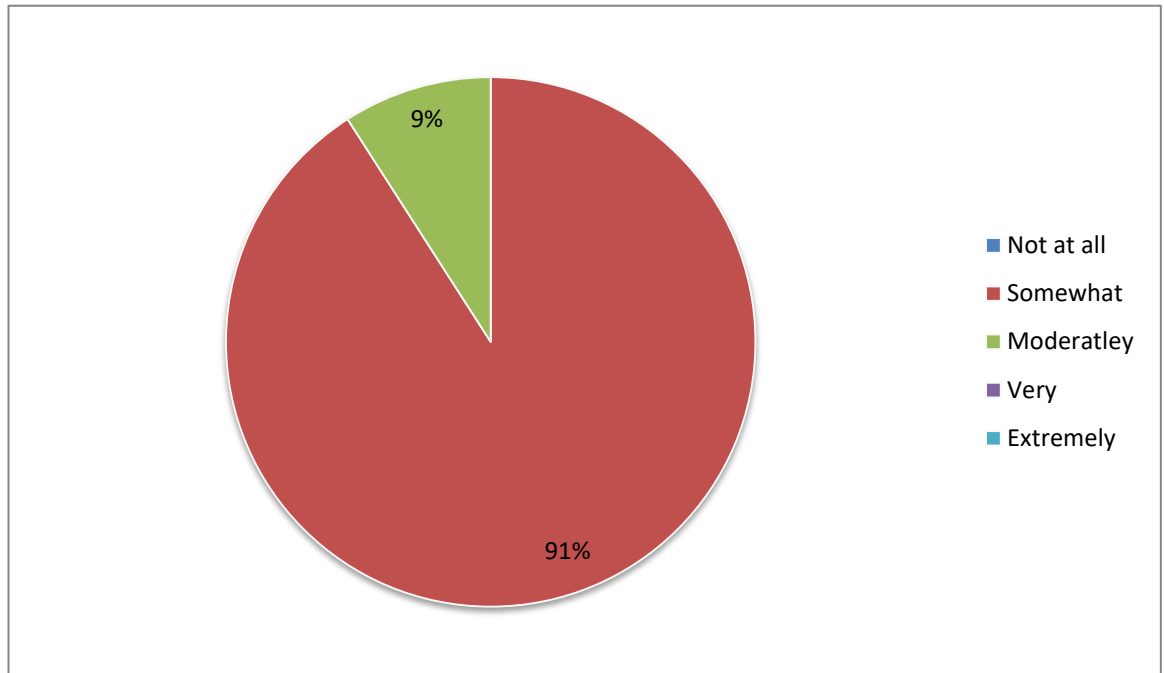
Figure 122, Question 8: How much damage to the structure is there? Phase three 2015, all groups

Table 76, Phase three (2015), number of students in study per cadaver

Table number	Total in group	Total in non-haptic study	Total in haptic study
12	3	1	1
14	4	1	0
15	4	1	2
17	4	1	1
19	4	1	1
21	3	2	0
22	4	0	2
23	4	2	0
25	4	0	1
27	4	0	2
30	3	0	1

Table 77, Phase Three (2015), Dissection Evaluation results

	12:	14: 7, 9a	15: 3, 1a, 6a	17: 8, 10a	19: 5a, 11a	21: 2, 6	22: 4a, 5a	23: 1, 4	25: 2a	27: 3a, 8a	30: 7a	Total
Q1	4	4	5	3	4	4	4	4	5	4	4	45/55 (81.8%) median 4/mode 4
Q2	3	4	5	4	3	4	4	4	5	5	4	45/55 (81.8%) median 4/mode 4
Q3	3	1	4	4	4	3	4	3	2	4	3	35/55 (63.6%) median 3/mode 4
Q4	4	4	4	4	4	4	4	4	4	4	4	44/55 (80%) median 4/mode 4
Q5	4	4	4	4	4	4	4	4	4	4	4	44/55 (80%) median 4/mode 4
Q6	2	1	3	3	1	1	4	1	1	4	2	23/55 (41.8%) median 2/mode 1
Q7	3	4	4	4	4	4	4	4	4	5	4	44/55 (80%) median 4/mode 4
Q9	3	4	4	4	3	4	4	4	4	4	4	42/55 (76.3%) median 4/mode 4
Q10	3	3	4	3	1	3	4	3	4	3	4	35/55 (63.6%) median 3/mode 3
Q11	3	4	4	4	2	3	4	4	5	5	4	42/55 (76.3%) median 4/mode 4
Q12	3	1	4	4	4	4	4	4	2	4	3	37/55 (67.2%) median 4/mode 4
Q13	3	1	4	4	4	4	4	3	2	4	3	36/55 (65.4%) median 4/mode 4
Total	38/60 63.3%	35/60 58.3%	49/60 81.6%	45/60 75%	38/60 63.3%	42/60 70%	48/60 80%	42/60 70%	42/60 70%	50/60 83.3%	43/60 71.6%	472/660 (71.5%) Mean =4 Mode = 4

Feedback Questionnaire 2015 (Non-Haptic BSc)

The feedback questionnaire consisted of a total of fifteen questions. The first 9 of these were scored using a five-point Likert scale and asked questions such as how easy or enjoyable the software was to use or how the student felt it would improve their practical skills etc. where 1= 'not at all', 2 'somewhat', 3= 'moderately', 4= 'very', and 5= 'extremely'. For these questions therefore a higher score is preferable. Following this there were two 'closed' questions asking, 'how much time did you spend using the software?' And 'how many training sessions did you attend?' These were followed by three 'open' questions asking, 'if you used the keyboard and mouse interface how do you feel this affected your experience?' 'If you used the haptic interface how much do you feel this affected your experience?' And 'what improvements would you like to see made to the software?' Finally there was a space for 'any other comments?' The results for questions 1-9 can be found in the following Table (77) and Figures (123-131).

Table 78, Phase Three (Non-haptic 2015), questionnaire results, questions 1-9

	1	2	4	7	8	9	Total
Q1	4	3	4	3	3	3	20/30 (66.6%) median 3/mode 3
Q2	3	4	4	5	4	4	24/30 (80%) median 4/mode 4
Q3	4	3	3	4	5	3	22/30 (73.3%) median 3.5/mode 3
Q4	5	5	4	4	5	4	27/30 (90%) median 4.5/mode 4*
Q5	5	5	4	4	5	4	27/30 (90%) median 4.5/mode 4*
Q6	3	4	3	4	5	5	24/30 (80%) median 4/mode 3*
Q7	1	3	2	1	4	3	14/30 (46.6%) median 2.5/mode 1*
Q8	3	3	4	3	4	3	20/30 (66.6%) median 3/mode 3
Q9	1	1	2	1	3	3	11/30 (36.6%) median 1.5/mode 1
Total	**29/45**	**31/45**	**30/45**	**29/45**	**38/45**	**32/45**	**189/270 (70%)** **Median = 4** **Mode = 4**

* Multiple modes exist. The smallest value is shown

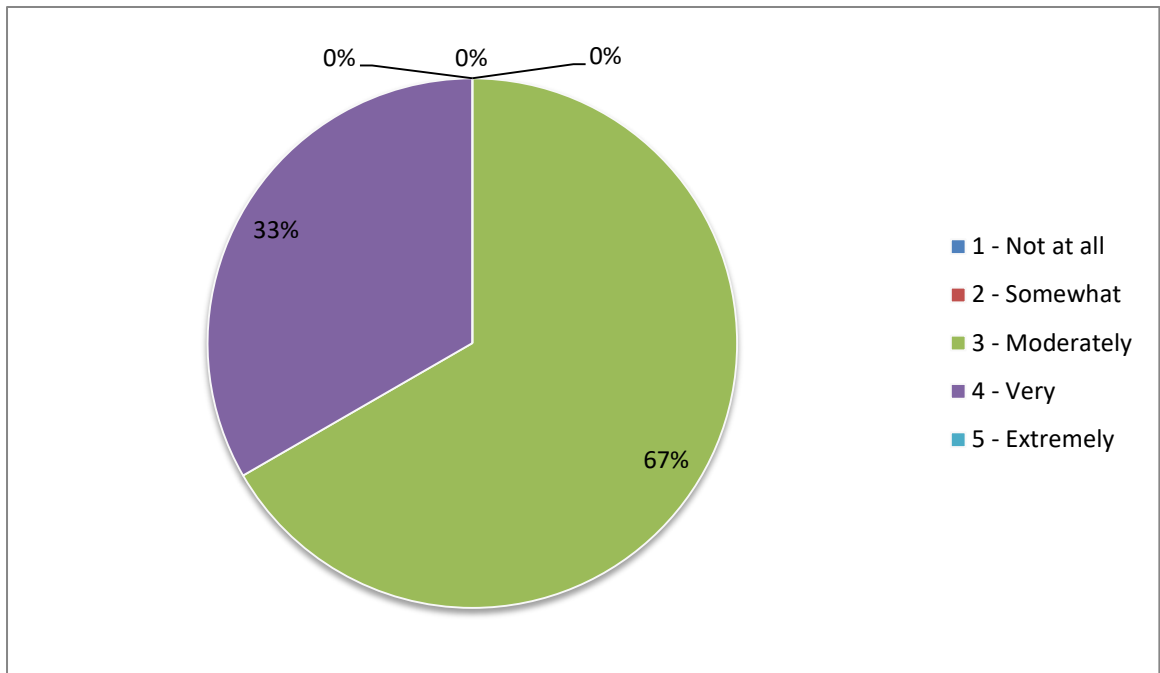**Figure 123,** Question 1: How easy and intuitive was the software to use? Phase Three 2015, BSc non-haptic
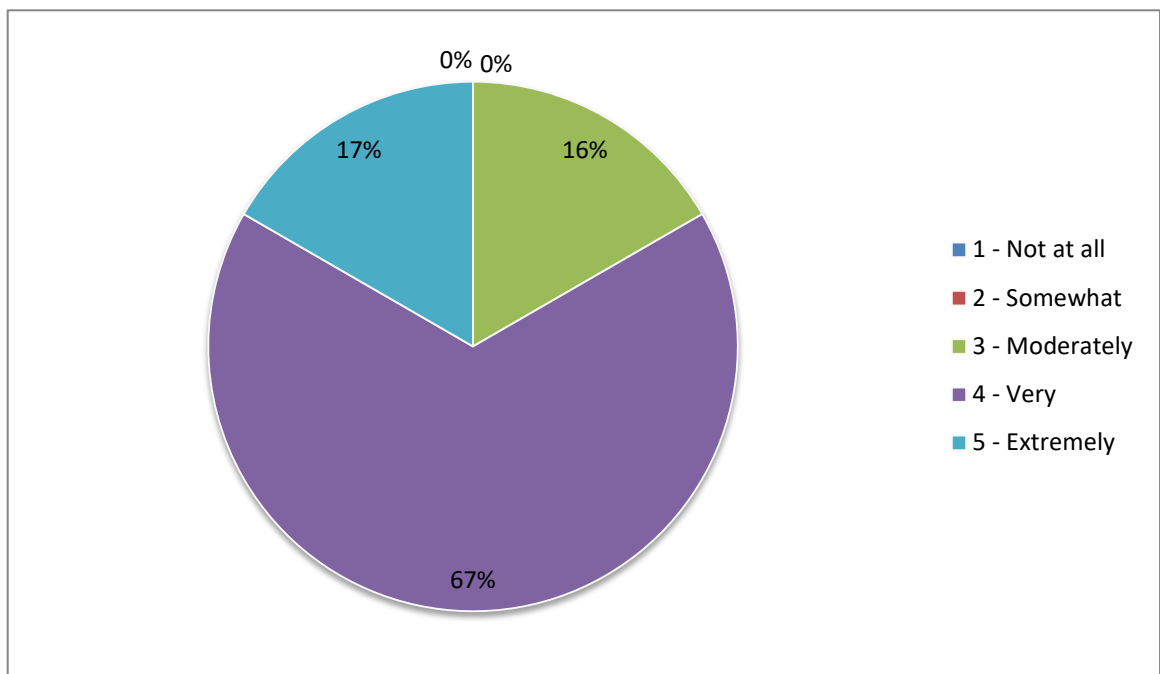
Figure 124, Question 2: How useful was the training session? Phase Three 2015, BSc non-haptic
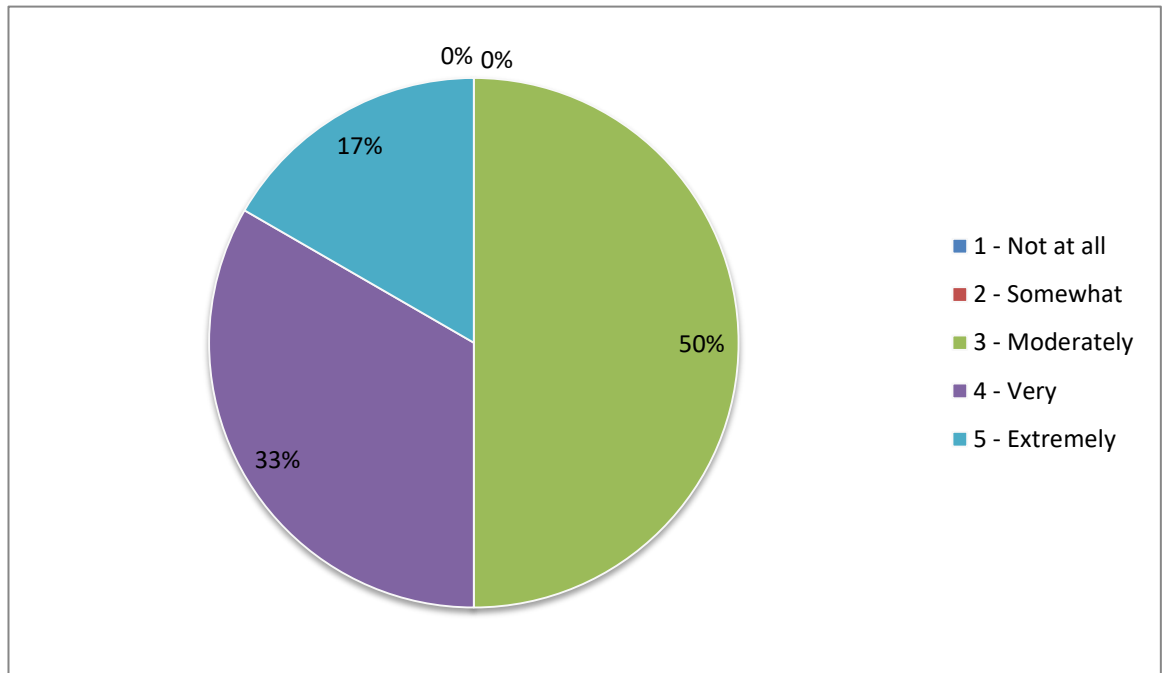
Figure 125, Question 3: How helpful was the dissection manual? Phase Three 2015, BSc non-haptic
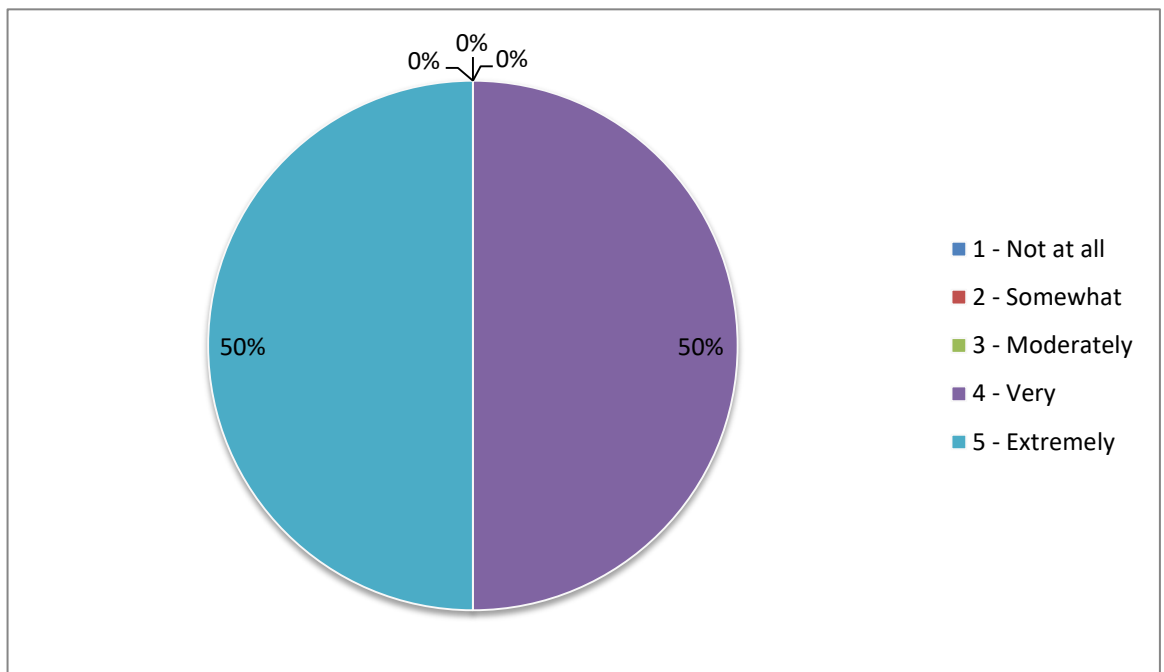
Figure 126, Question 4: Is the model anatomically accurate? Phase Three 2015, BSc non-haptic
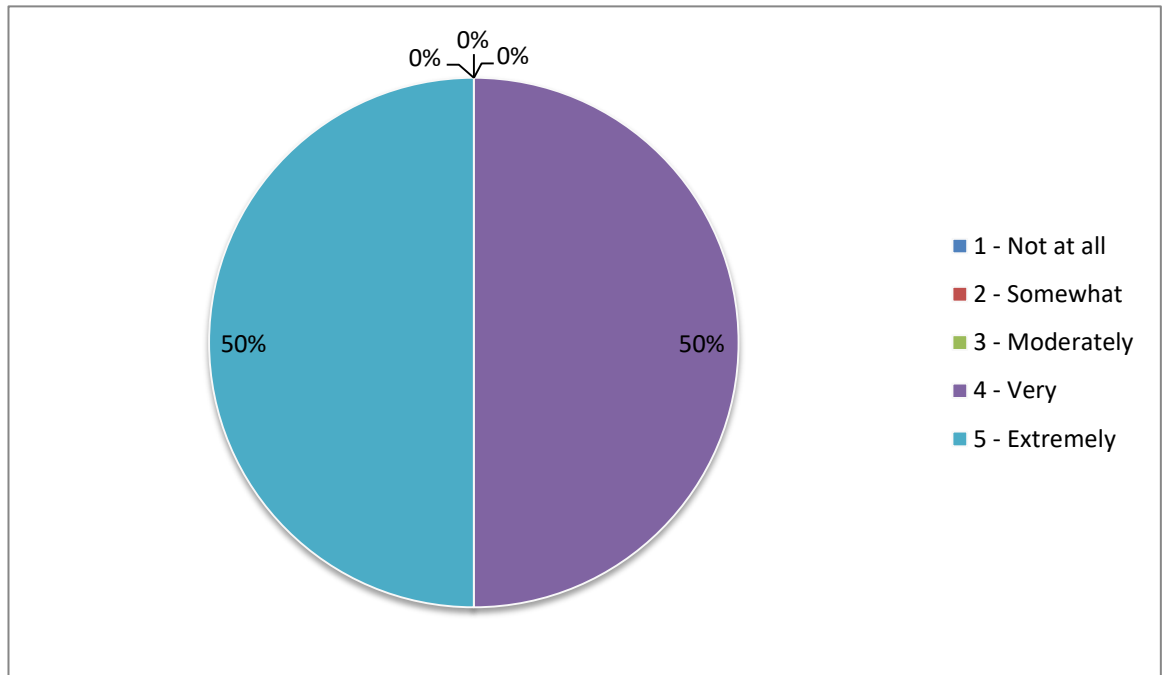
Figure 127, Question 5: How appropriate is the level of detail in the model? Phase Three 2015, BSc non-haptic
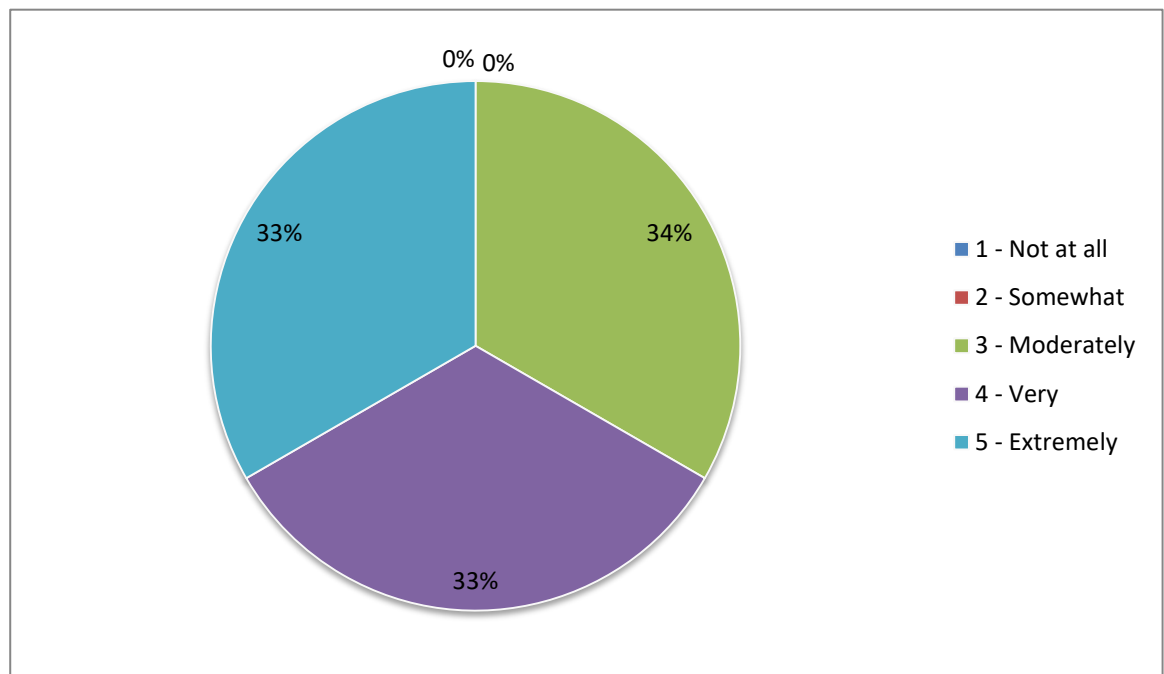
Figure 128, Question 6: Did you enjoy using the software? Phase Three 2015, BSc non-haptic
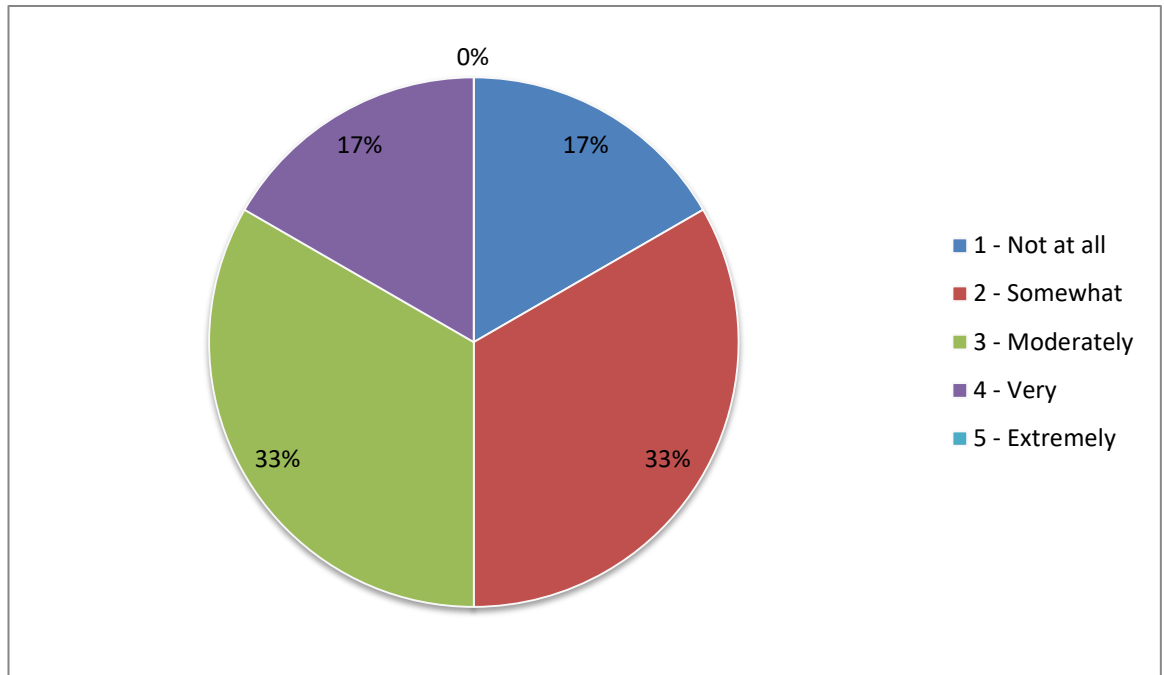
Figure 129, Question 7: Did the software improve your dissection skills? Phase Three 2015, BSc non-haptic
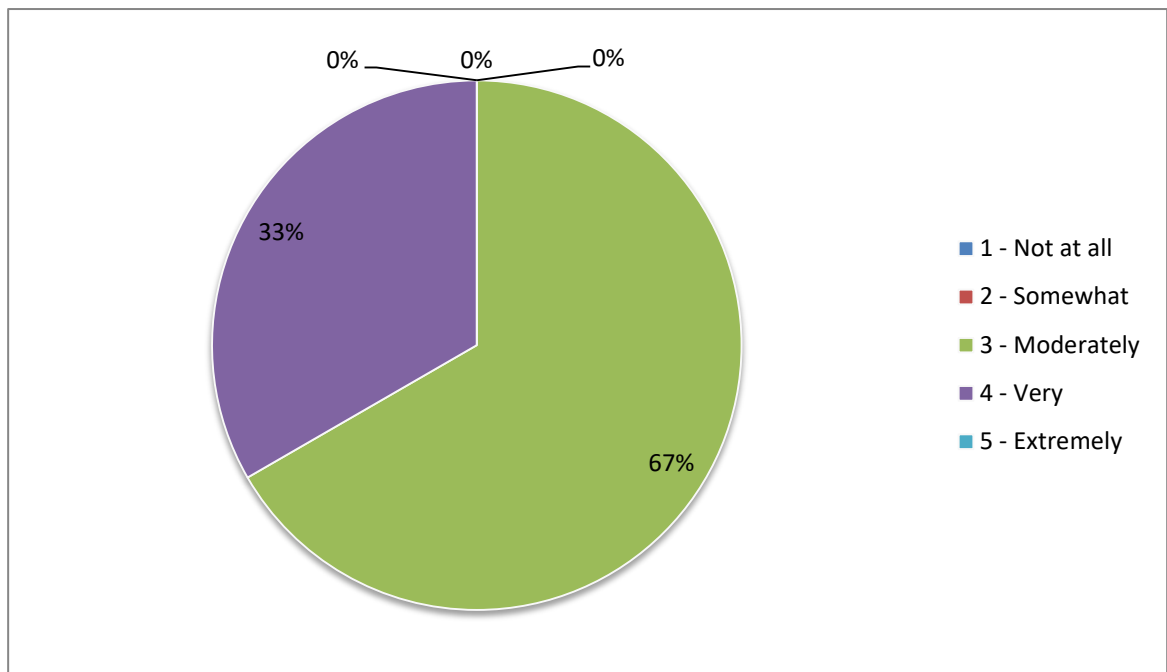
Figure 130, Question 8: Did use of the software improve your anatomical knowledge? Phase Three 2015, BSc non-haptic
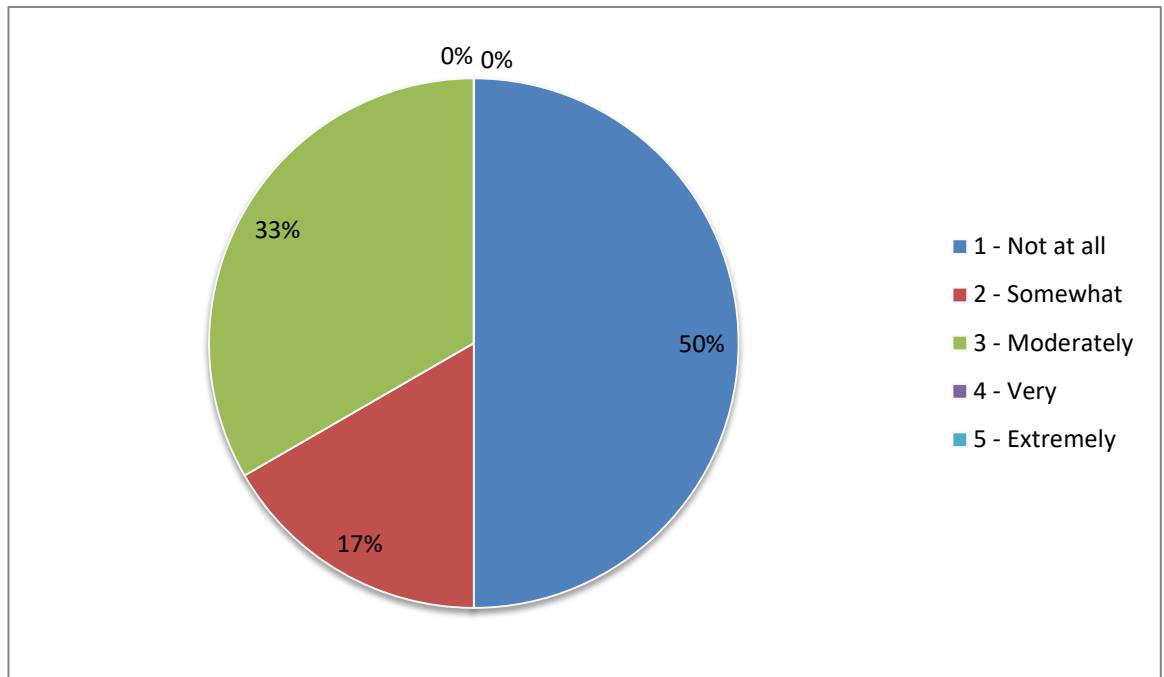
Figure 131, Question 9: Did you feel more confident doing cadaveric dissection after using the software? Phase Three 2015, BSc non-haptic

Questions 10 and 11 were 'closed' style questions asking, 'how much time did you spend using the software?' and 'how many training sessions did you attend?' Question 10 had six possible answers; 0-1 hour, 1-2 hours, 2-3 hours, 3-4 hours, 4-5 hours, and 5+ hours. Question 11 also had six possible answers; 0, 1, 2, 3, 4 and 5+. The results for questions 10 & 11 can be found in the following Table (78) and Figures (132-133).

Table 79, Questions 10 & 11 compared to anatomy test results. Phase Three 2015, BSc non-haptic

	1	2	4	7	8
Q10	0-1	0-1	0-1	0-1	1-2
Q11	1	1	1	1	1
Total for anatomy test	33.3%	43.3%	43.3%	63.3%	80%
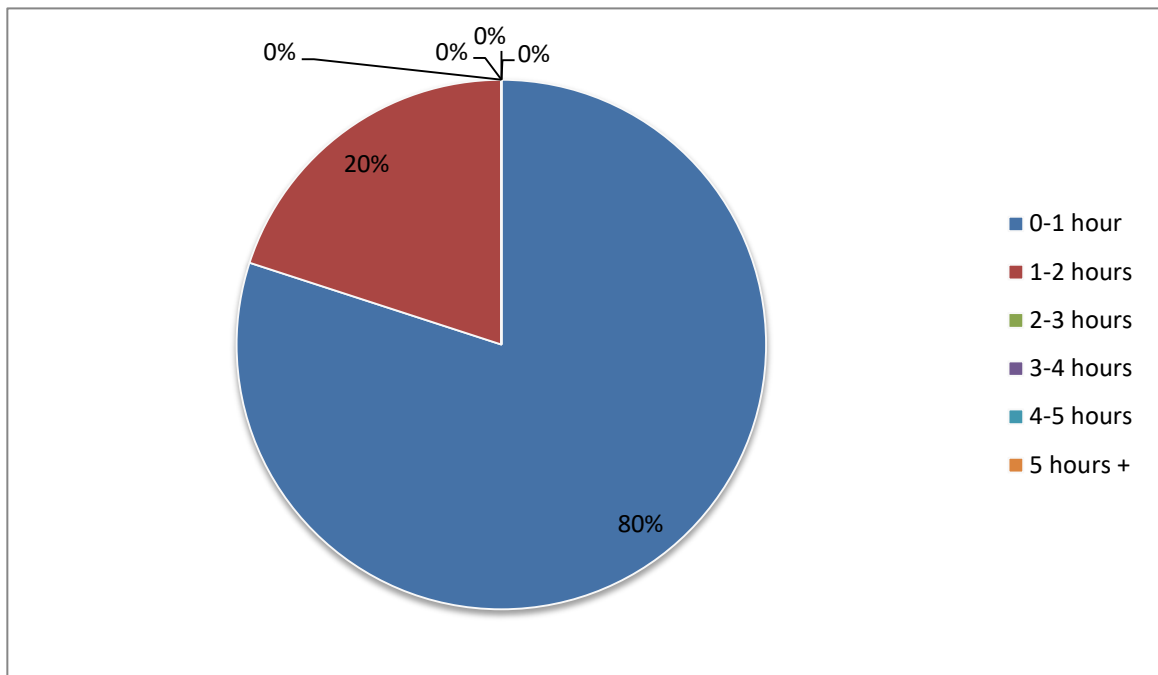
Figure 132, Question 10: How much time did you spend using the software? Phase Three 2015, BSc non-haptic
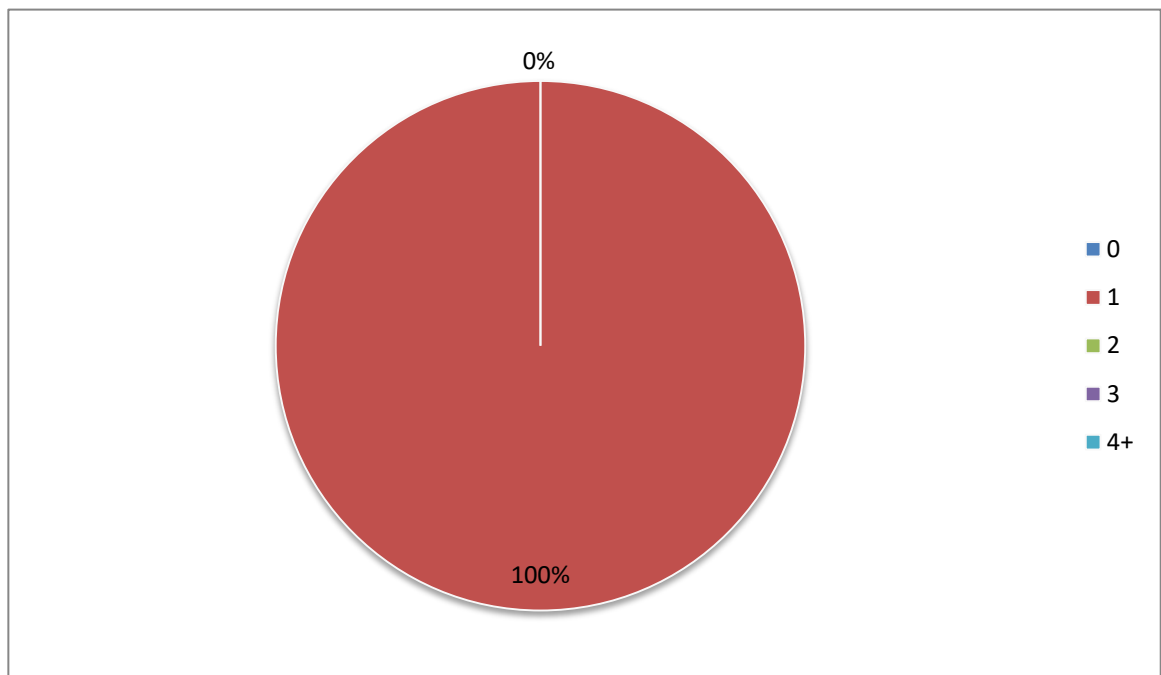
Figure 133, Question 11: How many training sessions did you attend? Phase three 2015, BSc non-haptic

Finally questions 12 through 15 were 'open' free text questions asking, 'if you used the keyboard and mouse interface how do you feel this affected your experience?' 'If you used the haptic interface how much do you feel this affected your experience?' 'What improvements would you like to see made to the software?' And finally there was a space for 'any other comments?' Question 13 which asked about the haptic version of the software was not applicable to this user group. For ease of reading, comments from questions 12-15 have been grouped into the following recurring themes: useful tool for revision, useful for learning structures, keyboard and mouse interface, general ease of use, lack of interactive labelling, and suggestions for improvements. The numbers relate to the student making the comment.

1) It was a good experience and the software was effective. Non haptic would be suitable for revision, but I feel haptic would be better for dissection practice.

4) It was good for seeing the entire structure, more of a revision aid than for dissection.

8) Software like this would be extremely useful when revising and t have this software for the entire body could be very helpful.

9) With keyboard and mouse it feels like going through lecture slides.

2) It was more engaging than I imagined a mouse would be.

7) It was easy to use the mouse and I just focused on the dissection, I didn't waste time learning how to use the haptic.

8) It was easier to remove the layers all at once but no dissection experience was available.

4) Being able to click on or hover over a structure and have a box come up to tell you what it is.

9) It would be great if when clicked on a structure, the name would appear.

9) Increase the speed of rotation.

9) I feel like I could do with extra time.

Feedback Questionnaire 2015 (Haptic BSc)

The feedback questionnaire consisted of a total of fifteen questions. The first 9 of these were scored using a five-point Likert scale and asked questions such as how easy or enjoyable the software was to use or how the student felt it would improve their practical skills etc. where 1= 'not at all', 2 'somewhat', 3= 'moderately', 4= 'very', and 5= 'extremely'. For these questions therefore a higher score is preferable. Following this there were two 'closed' questions asking, 'how much time did you spend using the software?' And 'how many training sessions did you attend?' These were followed by three 'open' questions asking, 'if you used the keyboard and mouse interface how do

you feel this affected your experience?' 'If you used the haptic interface how much do you feel this affected your experience?' And 'what improvements would you like to see made to the software?' Finally there was a space for 'any other comments?' The results for questions 1-9 can be found in the following Table (79) and Figures (134-142).

Table 80, Phase three (Haptic 2015), questionnaire results, questions 1-9

	1a	2a	4a	5a	7a	9a	Total
Q1	3	4	4	3	3	4	21/30 (70%) median 3.5/mode 3*
Q2	4	4	4	5	4	5	26/30 (86.6%) median 4/mode 4
Q3	3	3	4	4	5	5	24/30 (80%) median 4/mode 3*
Q4	5	5	5	4	4	4	27/30 (90%) median 4.5/mode 4*
Q5	5	5	4	4	5	4	27/30 (90%) median 4.5/mode 4
Q6	5	5	5	5	5	5	30/30 (100%) median 5/mode 5
Q7	2	2	3	2	1	4	14/30 (46.6%) median 2/mode 2
Q8	4	4	2	3	5	5	23/30 (76.6%) median 4/mode 4*
Q9	2	4	3	3	3	5	20/30 (66.6%) median 3/mode 3
Total	**33/45**	**36/45**	**34/45**	**33/45**	**35/45**	**41/45**	**212/270 (78.5%)** **Median 4** **Mode 4***

* Multiple modes exist. The smallest value is shown
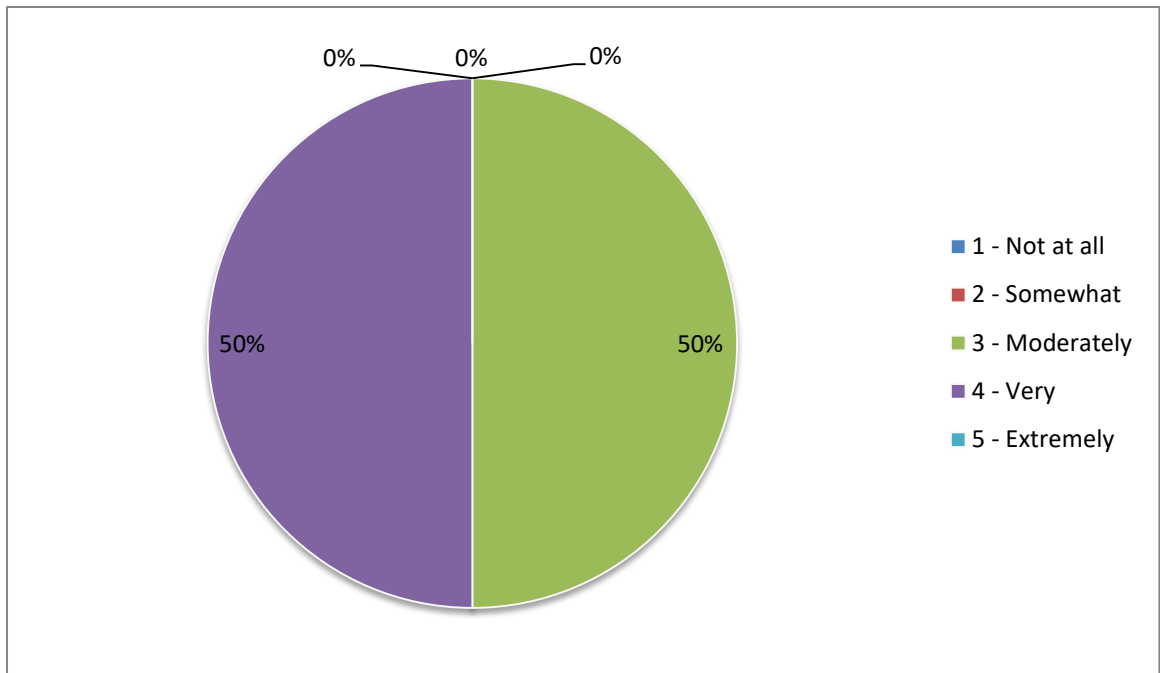
Figure 134, Question 1: How easy and intuitive was the software to use? Phase Three 2015, BSc haptic
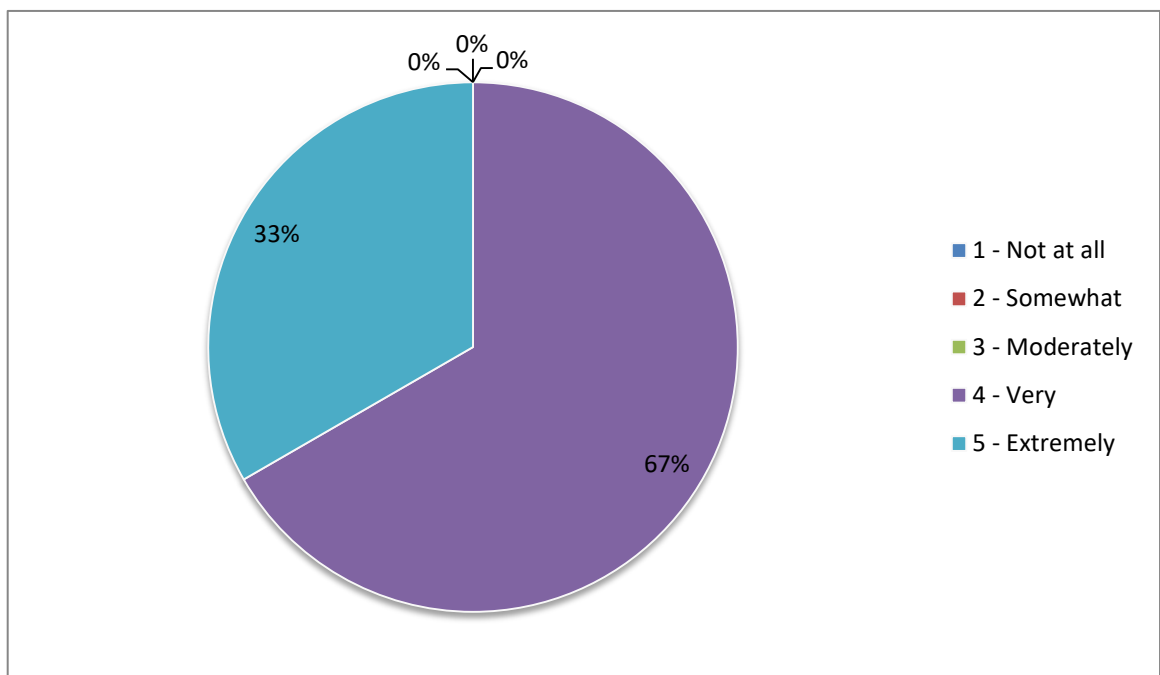
Figure 135, Question 2: How useful was the training session? Phase Three 2015, BSc haptic
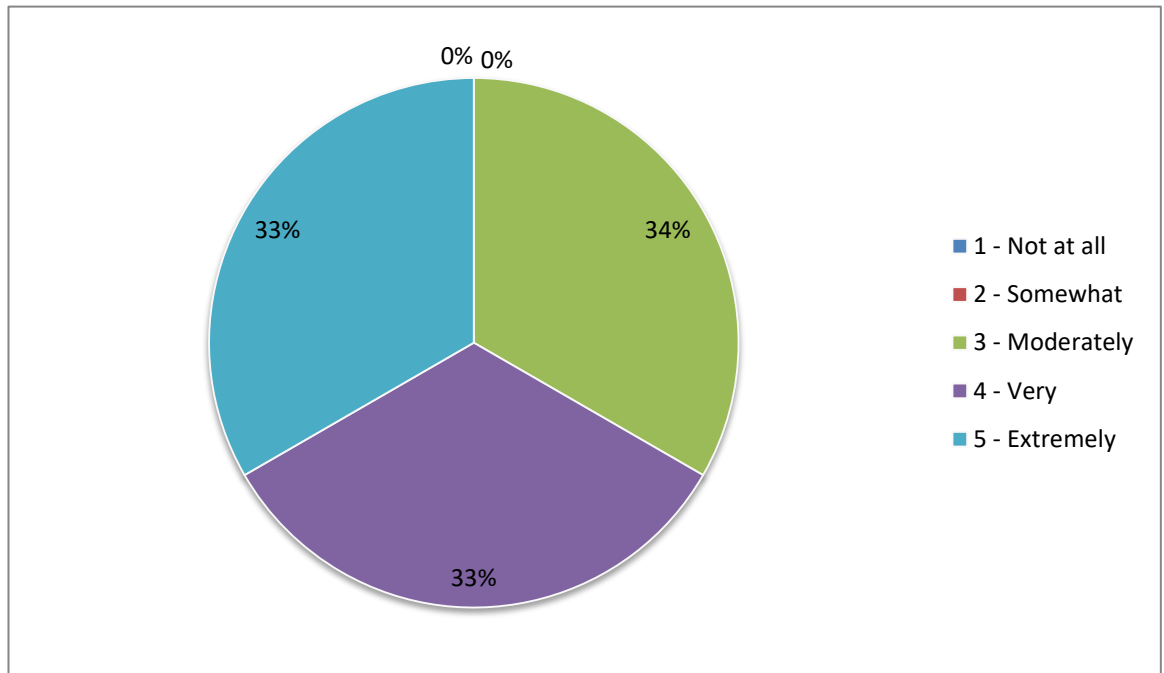
Figure 136, Question 3: How helpful was the dissection manual? Phase Three 2015, BSc haptic
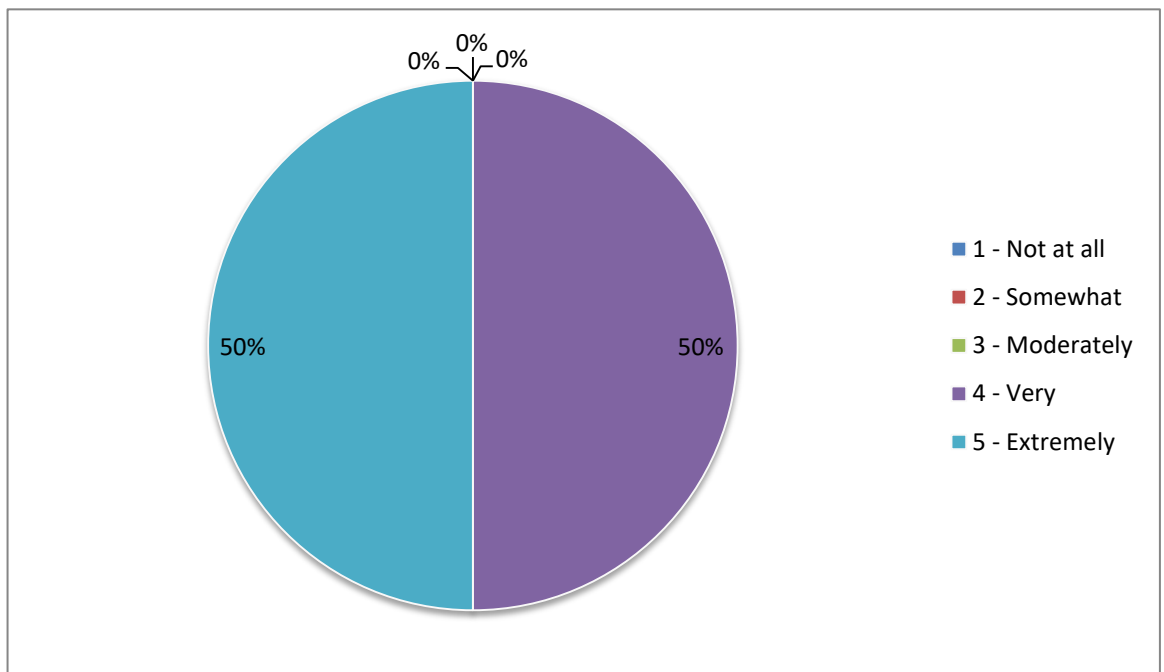
Figure 137, Question 4: Is the model anatomically accurate? Phase Three 2015, BSc haptic
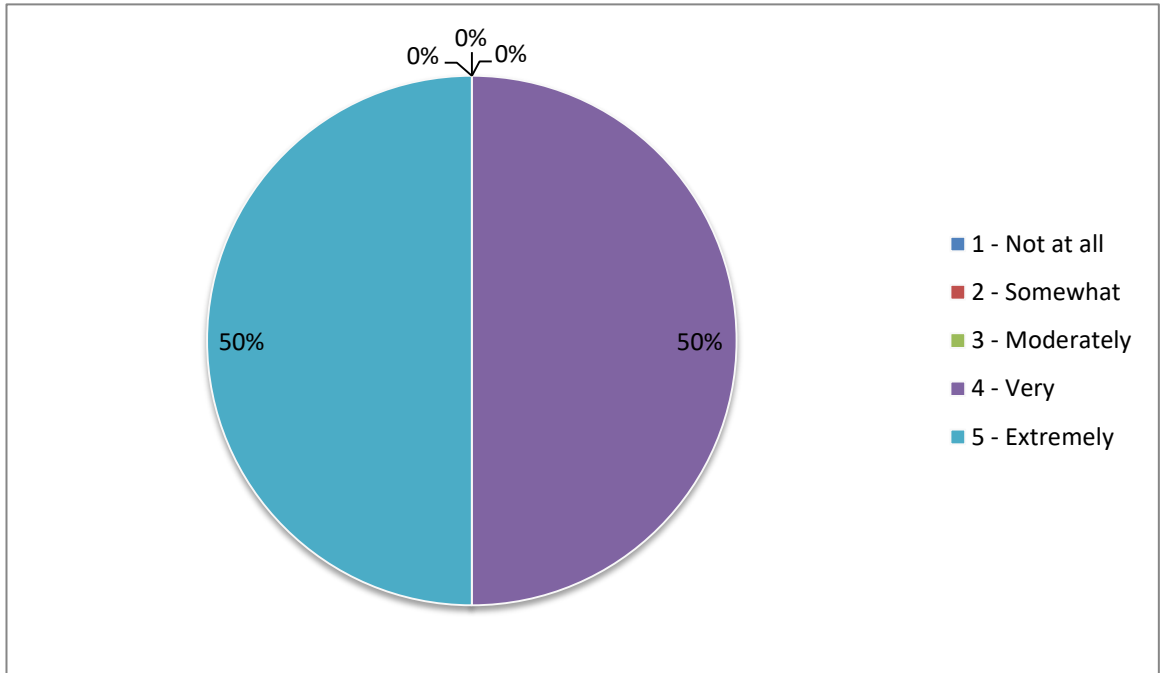
Figure 138, Question 5: How appropriate is the level of detail in the model? Phase Three 2015, BSc haptic
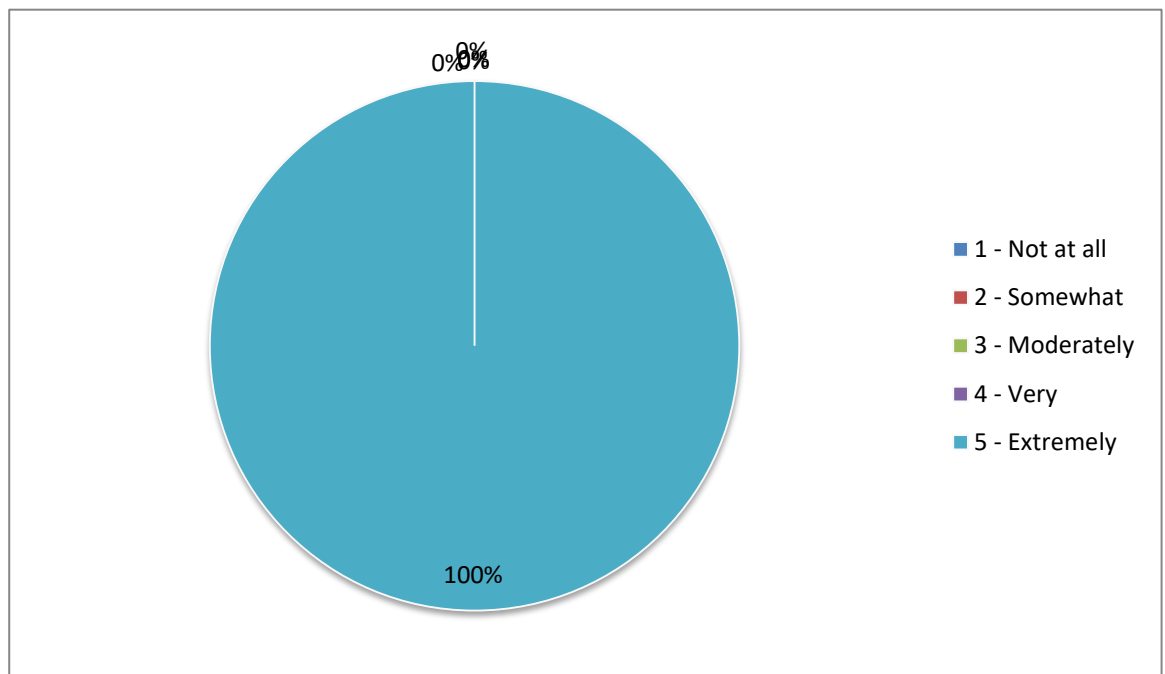
Figure 139, Question 6: Did you enjoy using the software? Phase Three 2015, BSc haptic
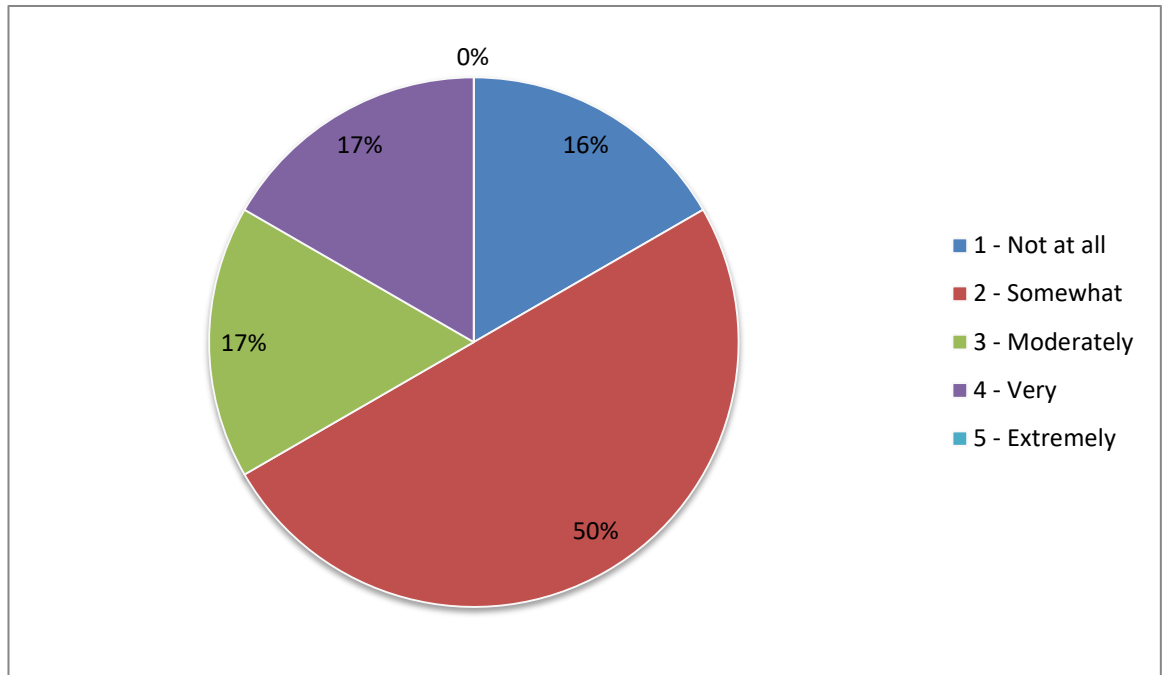
Figure 140, Question 7: Did the software improve your dissection skills? Phase Three 2015, BSc haptic
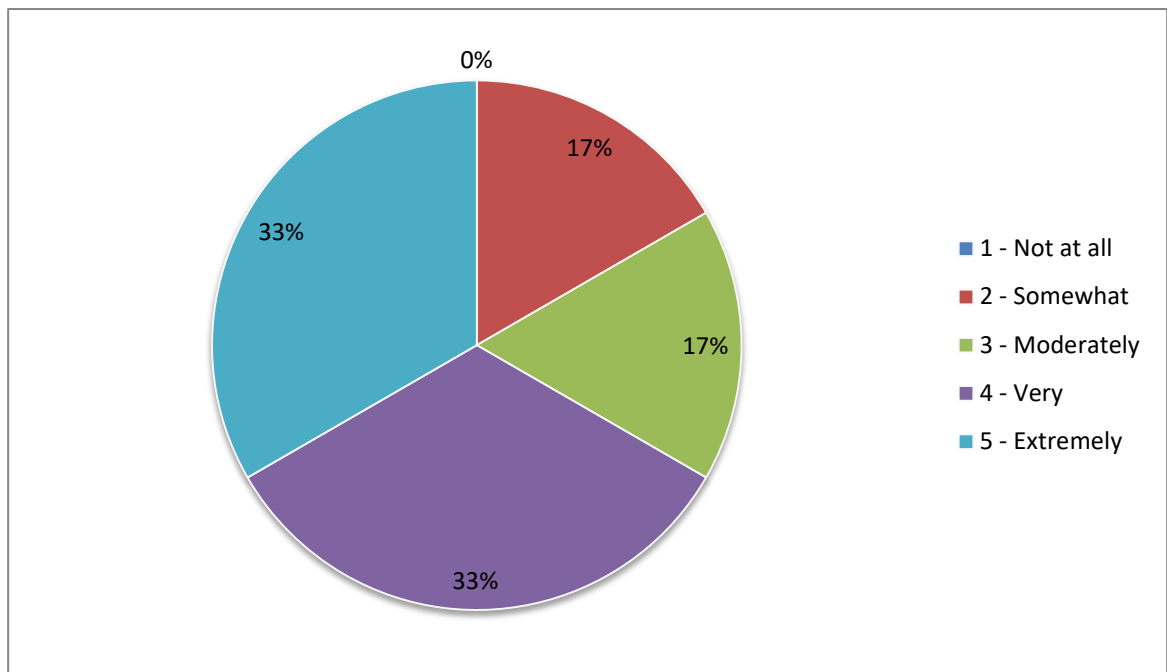
Figure 141, Question 8: Did use of the software improve your anatomical knowledge? Phase Three 2015, BSc haptic
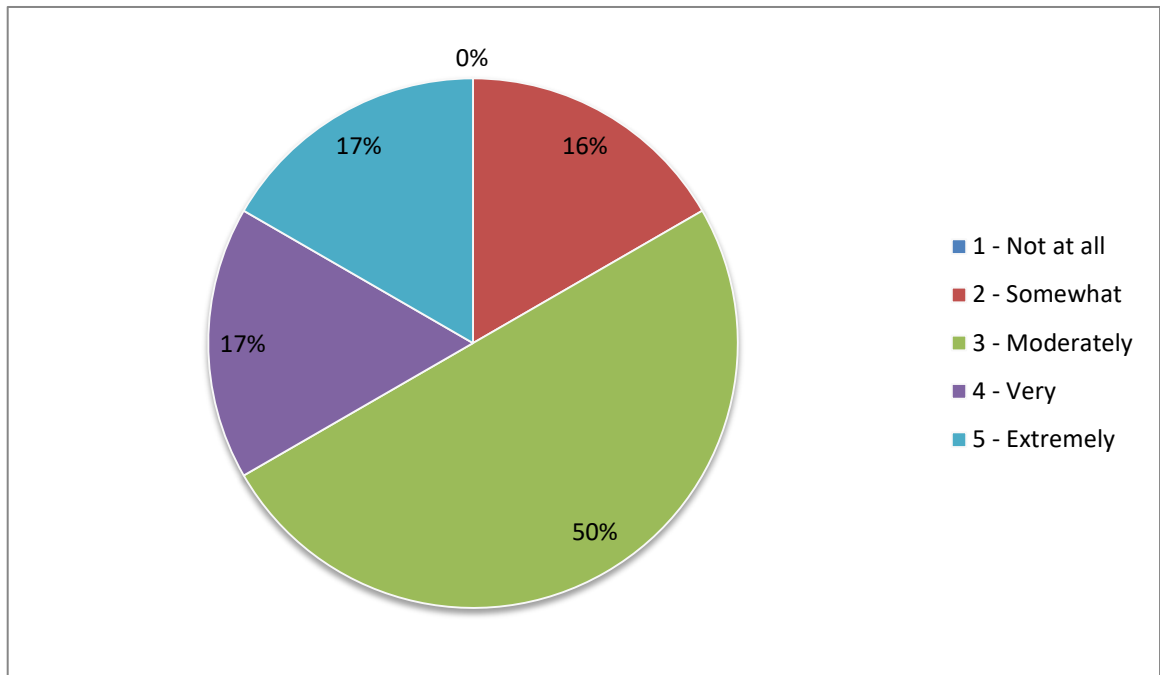
Figure 142, Question 9: Did you feel more confident doing cadaveric dissection after using the software? Phase Three 2015, BSc haptic

Questions 10 and 11 were 'closed' style questions asking, 'how much time did you spend using the software?' and 'how many training sessions did you attend?' Question 10 had six possible answers; 0-1 hour, 1-2 hours, 2-3 hours, 3-4 hours, 4-5 hours, and 5+ hours. Question 11 also had six possible answers; 0, 1, 2, 3, 4 and 5+. The results for questions 10 & 11 can be found in the following Table (80) and Figures (143-144).

Table 81, Questions 10 & 11 compared to anatomy test results. Phase Three 2015, BSc haptic

	1a	2a	4a	5a	7a	9a
Q10	0-1	1-2	1-2	2-3	1-2	1-2
Q11	1	1	1	1	1	1
Total for anatomy test	13.3%	60%	53%	56.6%	56.6%	70%
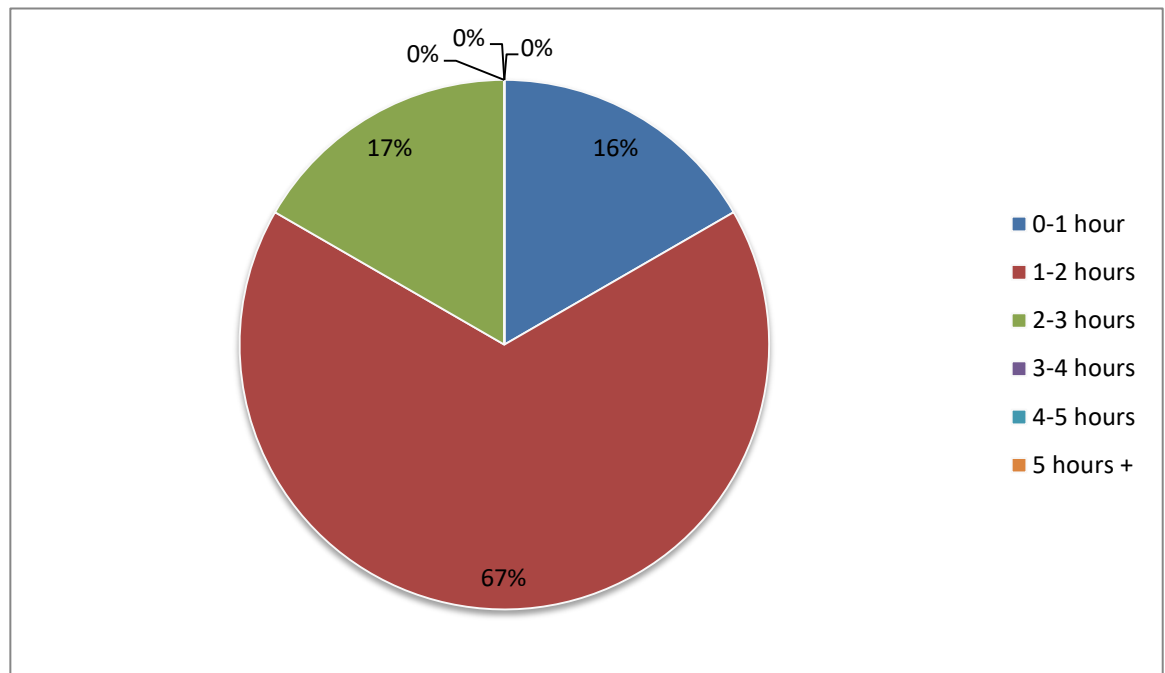
Figure 143, Question 10: How much time did you spend using the software? Phase Three 2015, BSc haptic
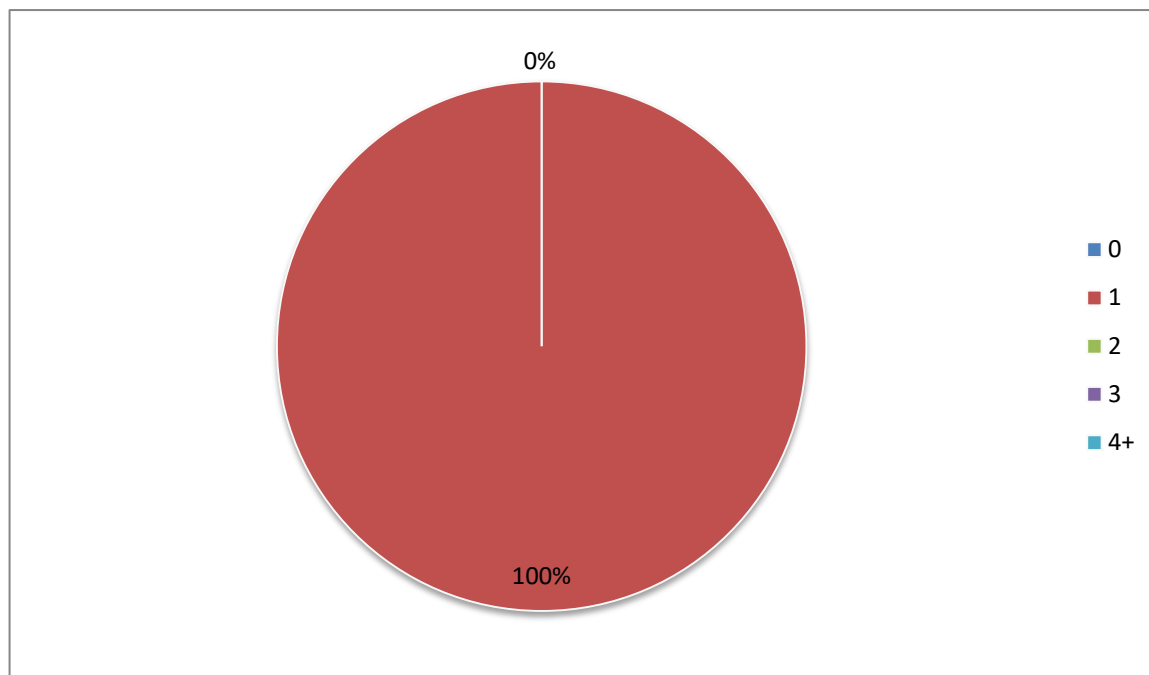
Figure 144, Question 11: How many training sessions did you attend? Phase three 2015, BSc haptic

Finally questions 12 through 15 were 'open' free text questions asking, 'if you used the keyboard and mouse interface how do you feel this affected your experience?' 'If you used the haptic interface how much do you feel this affected your experience?' 'What improvements would you like to see made to the software?' And finally there was a space for 'any other comments?' Question 12 which asked about the non-haptic version of the software was not applicable to this user group. For ease of reading, comments from questions 12-15 have been grouped into the following recurring themes: useful tool for revision, useful for learning structures, the haptic interface, keyboard and mouse interface, general ease of use, interactive labelling, and suggestions for improvements. The numbers relate to the student making the comment.

7a) It was great to clearly see all the structures and be able to cut away just one structure without damaging the others.

1a) It made it far more enjoyable and engaging

2a) Felt more realistic and allowed me to dissect one muscle at a time which I found helpful. More engaging

4a) Improved patience in Dissection. Good to go through layer by layer.

5a) I personally learn more easily by interaction so the haptic component makes it better than other online or virtual things I've tried. Also, it was fun which I'm pretty sure made it more easy to spend time on it. The second time I came down to do it I passed 2 hours there and barely saw the time pass.

7a) Slowed it (the experience) down at first but it got better with time.

9a) It was helpful to focus on what I was doing. I probably wouldn't have stayed as long if it were just mouse and keyboard. And focus helps remembering things.

7a) The highlighting and ? (interactive labelling) options were extremely helpful and precise.

4a) Higher picture quality, faster and more efficient software.

4a) If a tool like this was combined with something like 'Essential Anatomy' software would very much help dissection plus knowledge.

5a) Maybe more different textures between different types of structures like muscle and tendon for example.

5a) Being able to activate muscle and tendon of the same structures together.

5a) An option to reset elements that have already been dissected other than ctrl+z, like select skin/fascia – restore.

5a) Maybe add a quiz mode?

5a) Possibility of activating more than one element.

9a) Sections through the model would be nice.

APPENDIX 9: THEMATIC ANALYSIS

Coding

Non-Haptic Phase 1 Non-Haptic Phase3 Haptic Phase 1 Haptic Phase 2 Haptic Phase 3

Table 82, Thematic analysis: transcription of data extracts with initial coding.

It helped you to know where the structures are, by highlighting in green as sometimes in dissection it is hard to know what you are looking at and helps you to see where structures lie relative to each other.	*Helps to ID structures *Helps to understand 3d structural relationships
I would have liked to virtually dissect, but this was not our year for it.	*NH- would have liked to have tried haptic
Very helpful in learning structures. I found it best to use after lectures/dissection not before.	*Helps to ID structures *Used after lectures & dissection
At the moment you click on a name and it highlights the structure. It would be helpful if you could click on the structure and it highlight the name.	*ID mode in NH
Very useful software, I would be happy to use it again especially if it extended into the arm.	*Useful *Extend to arm
Fine – a useful revision tool but no improvement on dissection skill.	*Useful for revision *Not useful for dissection
Scroll mouse button may be better for zoom function.	*Scroll for zoom
Useful tool but perhaps not for primary learning.	*Useful for revision
The mouse worked well but I found it restrictive.	*Mouse restrictive
I found the 'visible/see through' not very helpful worked best removing the structures all together to properly view what the underlying structures were.	*See through unhelpful *Visible/invisible very useful *Prefer to remove entire structures
Very helpful in terms of revision.	*Useful for revision
Very useful – facilitates learning of the anatomy of the hand.	*Useful
Thanks for this experience, wish you best of luck.	*Thanks
It was quicker than the real dissection as didn't have to 'play' with removing the skin etc. But on the other hand it removed the whole structure 'perfectly'. Good because less hard. Bad because in reality we had only a small window to see the deeper structures.	*Quicker than real dissection *Easier than dissection *Dissection unrealistic
Maybe to have the option to click on a structure and see what it is. In that way the user not only sees the structure in place, but learns the name at the same time.	*ID mode in NH
Relatively time consuming to have to click through everything to find the muscles. The dissection itself was not very realistic to an actual dissection, although being able to see everything was nice.	*Time consuming to search for structures *Dissection unrealistic *Nice to see everything

To be able to click on a muscle/object and it labelled.	*ID mode in NH
It was a good experience and the software was effective. Non haptic would be suitable for revision, but I feel haptic would be better for dissection practice.	*Good experience *Useful for revision *Thinks haptic might be better
It was good for seeing the entire structure, more of a revision aid than a dissection.	*Useful for revision
Using mouse and keyboard – being able to click on a structure or hover over a structure and have a box come up to tell you what it is.	*ID mode in NH
It was easy to use the mouse and I just focussed on the dissection, I didn't waste time learning to use the haptic.	*Easy to use *Time to learn haptic
It was easier to remove the layers all at once but no dissection experience was available.	*Easy to use *Visible/invisible very useful *Not useful for dissection
Software like this would be extremely useful when revising and to have this software for the entire body would be very helpful.	*Useful for revision *Extend to entire body
I feel like I could use extra time using the software. With keyboard and mouse it feels like going through lecture slides.	*Need more time *Like lecture slides
It would be great, if when clicked on a structure the name would appear.	*ID mode in NH
Increase the speed of rotation.	*Rotation
Thank you, I had a great experience and would recommend to everyone.	*Thank you *Great experience
Easier rotation	*Rotation
I used the mouse and keyboard when I was having difficulties with the haptic interface. This improved my experience and made using the software easier.	*Reverted to K&M
I think the haptic interface was interesting to use, but I don't this it is valuable in its 'dissection' actions. You hold it like a pen rather than a scalpel; and the movement's resistance I don't think was realistic.	*Interesting *Haptics not helpful for dissection *Dissection unrealistic
I think the software was fine.	
I do not think this software is useful in terms of training or practicing dissection techniques. It is however useful for studying/revising hand anatomy.	*Haptics not helpful for dissection *Useful for revising
It was useful to be able to feel what was being dissected. Also felt more like using the dissection tools.	*Haptics helpful for dissection *Felt more like dissection
I used the tool after doing the dissection.	*Used after dissection
I found the haptic device difficult to use, the tool kept getting stuck inside the hand and the resistance me tire quickly and my wrist sore. After a short time with the device I resorted to using the keyboard and mouse an clicking through the layers.	*Haptics difficult *Physically tiring *Reverted to K&M
Less –resistance – enough to feel the hand is there but not enough to make it strenuous to use. Also fix the sticking problem.	*Physically tiring

Feedback	Codes
Overall the software is good, I enjoyed clicking through the layers and seeing the overall picture. I would love to see it for the whole body, I have trouble with memorising isolated facts but being able to put it in such context would really help, 3D is very good.	*Extend to whole body *Context *3D is useful
I like the haptic interface. Good for learning dissection experience.	*Haptics helpful for dissection
A list of hot keys would be good and add to the ease of use.	*Hot keys
Useful as you can dissect only a small part and try to identify the structures. You can 'feel' the 'tissue'.	*Haptics helpful for dissection *Feel tissue
Very useful for revision and understanding the relationship of each structure.	*Useful for revision *Helps to understand 3d structural relationships
The haptic interface took some getting used to, but was quite helpful.	*Time to learn haptics *Haptics helpful
Easy to use, very enjoyable.	*Easy to use *Enjoyable
The dissection manual is a little bit confusing on how to operate the software.	*Manual is confusing
Thank you for giving me an opportunity to use it.	*Thank you
It was odd to get used to the resistance and being able to feel the surfaces, but it helped to make me realise it was 3D and that thumb structures would be more anteriorly placed.	*Helps to understand 3d structural relationships
Maybe as there is so much in the hand an easier way to find different muscles and tendons to be able to make them active or remove them. Took time just scrolling through the list.	*Forgot about ID mode
Although it can be frustrating having to find every muscle and tendon to be able to dissect it, it does help with identifying as you have to identify a muscle you want to remove.	*Helps to ID structures
I definitely think the haptic interface is a good thing, however I think the layout of our classes didn't help – class on hand straight before dissection – so when you were using it before it was very much just seeing things and using the tool, however afterwards it's a great revision tool. I do think it's be a perfect tool to use between the lecture and dissection.	*Haptics helpful *Module structure
I think some of the tool functions are slightly awkward when trying to dissect small parts like nerves/vessels. I think it's be nice to also be able to dissect all layers together as well as separately, or just a level of structures such as all muscles.	*Haptics difficult *Dissect all layers
It was good to be able to 'feel' the cadaver and it probably improved my dissection.	*Haptics helpful for dissection
Thank you.	*Thank you
Sometimes difficult to control haptic device. Was interesting to feel the different movements at first but when I wanted to really study the structures I found it quite frustrating moving the device and returned to the keyboard.	*Haptics difficult *Haptics interesting *Reverted to K&M
(Make it) easier to change between items and when looking at a specific item from a folder, I would like it to be easier to activate all the items in a folder.	*Activate all structures

Was a fun thing to try. I should have been less frustrated with it when it wouldn't do exactly what I wanted it to. More practice would probably have helped that.	*Fun *More time/practice
It was interesting to get the feel of the structures, but in terms of dissection, only the real structures in the DR give a proper understanding. It was incredibly helpful though for singling out and identifying individual structures, something which is impossible in the DR.	*Haptics interesting *Haptics not helpful for dissection *Helps to ID structures
It would be great to (see) the movement of the individual structures. Something I found very interesting in the DR was being able to pick out a structure and see how it moved the wrist/digits. By showing a movement and showing the individual structures that caused that movement wold be interesting if possible.	*Movement
It would be great to have access to the program at other times as well for revision.	*Access *Useful for revision
I think the haptic device is incredibly useful identifying the individual structures and their relationships to other structures.	*Helps to ID structures *Helps to understand 3d structural relationships
The haptic interface was useful in terms of 3D structure of the model. However I found it very easy to go through the hand, making it more difficult to dissect. I definitely think that using the haptic tool improved the software through.	*Haptics useful *Haptics difficult
I would find it useful if the "?" mode to see the origin/insertion, function and innervation for each muscle. I would also like to see the ability to select whole layers e.g. 'muscles' instead of each muscle individually.	*More textual information *Select multiple structures
The tool is very helpful as a revision aid however because of the structuring of the course I was unable to use it to improve my dissection. The lecture on the hand was immediately followed by the dissection. However it did help with my revision and helped me to visualise the structures better than a 2D image would.	*Useful for revision *Module structure
I did try to use the haptic interface, but I felt I would need much more time with it in order to be quite confident using it.	*Time to learn haptic *Haptics difficult
It would be helpful if when clicked on a structure the name of the structure would appear.	*Forgot about ID mode
For me the tools that made the structures visible/invisible or highlighted were extremely useful for studying purposes. It took a long time to get used to the haptic device.	*Visible/invisible very useful *Haptic difficult to use
It was bizarre, but made the dissection more lifelike.	*Haptics more realistic
When you finally dissected something it was difficult to retrieve it back later.	*Difficult to undo
The haptic interface was very useful as you could literally feel as you were dissecting, and different layers felt differently. This aided with the real life dissection.	*Haptics useful for dissection
Make it so the cutting tool wouldn't get stuck in the hand itself. Maybe making the activation of layers simpler/more user friendly.	*Haptics difficult

	*Easier activation
I really liked the software and it was a great revision aid that's in 3D. I would love to have a go at other dissections. But as the lecture on the hand was the last one, I didn't feel it helpful to use until the last week, so I didn't end up spending much time on it. Which I would have if it was something covered earlier in the semester.	*Useful for revision *Extend to other parts of the body *Module structure *Time
I think it was more interesting to use, but when I was using it, one was not working perfectly and the other was not working at all. So it feels like the haptic interface was almost slowing everything down. However, if everything was working smoothly I'm sure it would have been more useful than using just the keyboard and mouse.	*Haptics interesting *Haptics not working properly
The only real downfall is that you cannot dissect through all of the tissues but only the one you have activated. Because of this it was more useful to just take layers off and look at underlying structures.	*Select multiple structures *Visible/invisible very useful
I think the software is very good and the idea behind it is great. If it was available for the other parts of the body I would definitely use it a lot for my studying because it gives a very good understanding of where things are in a 3D structure.	*Extend to other parts of the body *Helps to understand 3d structural relationships
Much more like dissection but a little confusing.	
Tissues set to hardness they would be in the DR.	*Haptics more realistic *Confusing *More accurate tissue properties
A little more detail and more positions for the hand (would be good). Also the movement reaction when triggering a muscle or tendon.	*More positions *Movement
I found it enjoyable to use and I found it helped to reinforce my understanding of the hand anatomy. I think a few of improvements could be made, but I do think it's a very valuable additional tool to normal dissection.	*Enjoyable to use *Useful for revision
It was good to physically feel the difference and where you were cutting.	*Haptics useful
A lot of time was spent trying to figure out relations/positions of different muscles. Although a text book was provide, it would be helpful to see a muscle fact sheet (nerve innervations etc) on the screen, or for them to be highlighted when working with a particular section.	*More textual information
It was helpful for exam revision, however with having exams for other modules before gross anatomy didn't spend as much time using it as I'd have liked.	*Useful for revision *Module structure *Time
Very hands on experience. Probably more fun than keyboard. Instead of struggling with keyboard you could just go and 'do' without having to think much.	*Fun *Haptics useful
It would in my opinion be a fantastic addition to our course if the whole body would be available to dissect virtually. This has helped me a lot in my understanding and having this way of virtual dissection could be a great additional tool to offer students.	*Extend to other body parts
It helped me focus on what I was doing. I probably couldn't have stayed as long if it were just mouse and keyboard. And focus helps me remember things.	*Haptics useful
Sections through the model would be nice	

Comment	Code
I don't feel being able to cut through different things at the same time would be interesting, unless it would be to make a section.	*Sections *Sections
It made it far more enjoyable and engaging	*Enjoyable and engaging
(Would like to see) more body parts	*Extend to other body parts
(The haptic device) slowed it down at first, but it got better with time.	*Time to learn haptic
It was great to clearly see all the structures and be able to cut away just one structure without damaging the others. The highlighting and "?" options also were extremely helpful and precise.	*Helps to ID structures
Improved performance in dissection. (It was) good to go through layer by layer.	*Haptics helped dissection
(Would like) higher picture quality, faster more efficient software.	*Better faster graphics
If a tool like this was combined with something like 'Essential Anatomy' software it would very much help dissection and knowledge.	*Extend to more body parts
Felt more realistic and allowed me to dissect one muscle at a time which I found helpful. More engaging.	*Haptics more realistic *Engaging
It was more engaging than I imagine the keyboard would be.	*Engaging
I need to use the software more.	*Time/practice
I personally learn more easily be interactions so the haptic component makes it better than other online or virtual things I have tried. Also, it was fun which I'm pretty sure made it more easy to spend time on it. The second time I came down to it I passed 2 hours there and barley saw the time pass.	*Haptics useful (kinaesthetic) *Fun
Maybe more difference in textures between different types of structures like muscle and tendon for example.	*More accurate tissue properties
Being able to activate a muscle and tendon together.	*Activating multiple structures
An option to reset all elements that have already been dissected other than contr+z, like a select skin/fascia – restore.	*Difficult to undo
Program crashed at one point. No idea how or why. I closed everything and opened it back again. It crashed again but worked the 3rd time.	*Haptics not working properly
Maybe add a quiz mode.	*More textual information
Possibility of activating more than one element.	*Activating multiple structures

Initial Themes

Identification/Revision

*Helps to ID structures (6)

*Useful for revision (13)

*Useful (2)

3D structural Relationships

*Helps to understand 3d structural relationships (7)

Improvements

*ID mode in NH (6)

*Easier activation

*Scroll for zoom

*Rotation

*Better faster graphics

*Hot keys

*Movement (2)

*More hand positions

*More textual information (3)

*Difficult to undo (3)

*More accurate tissue properties (2)

*Dissect/activate multiple structures (6)

*Extend to more body part (8)

Dissection

*Non-Haptic not useful for dissection (2)

*Haptics not helpful for dissection (3)

*Dissection unrealistic (3)

*Haptics helpful for dissection (5)

*Quicker/easier than real dissection (2)

Haptics

*Haptics difficult (7)

*Haptics not working properly (2)

*Haptics helpful (9)

*Haptics more realistic (than NH) (4)

*Non-haptic would like to have tried haptic (2)

*Physically tiring (2)

Keyboards and mouse

*Mouse restrictive

*See-through unhelpful

*Visible/invisible very useful (5)

*Nice to see everything

*Reverted to keyboard and mouse (3)

Ease of Use

*Easy to use (3)

*Good experience (2)

*Enjoyable/fun/interesting/engaging (12)

*Thank you (4)

Module Structure and Time

*Module structure (7)

*Time/practice (9)

Miscellaneous

*Like lecture slides

*Manual is confusing

*Forgot about ID mode (2)

*Sections (2)

*Confusing
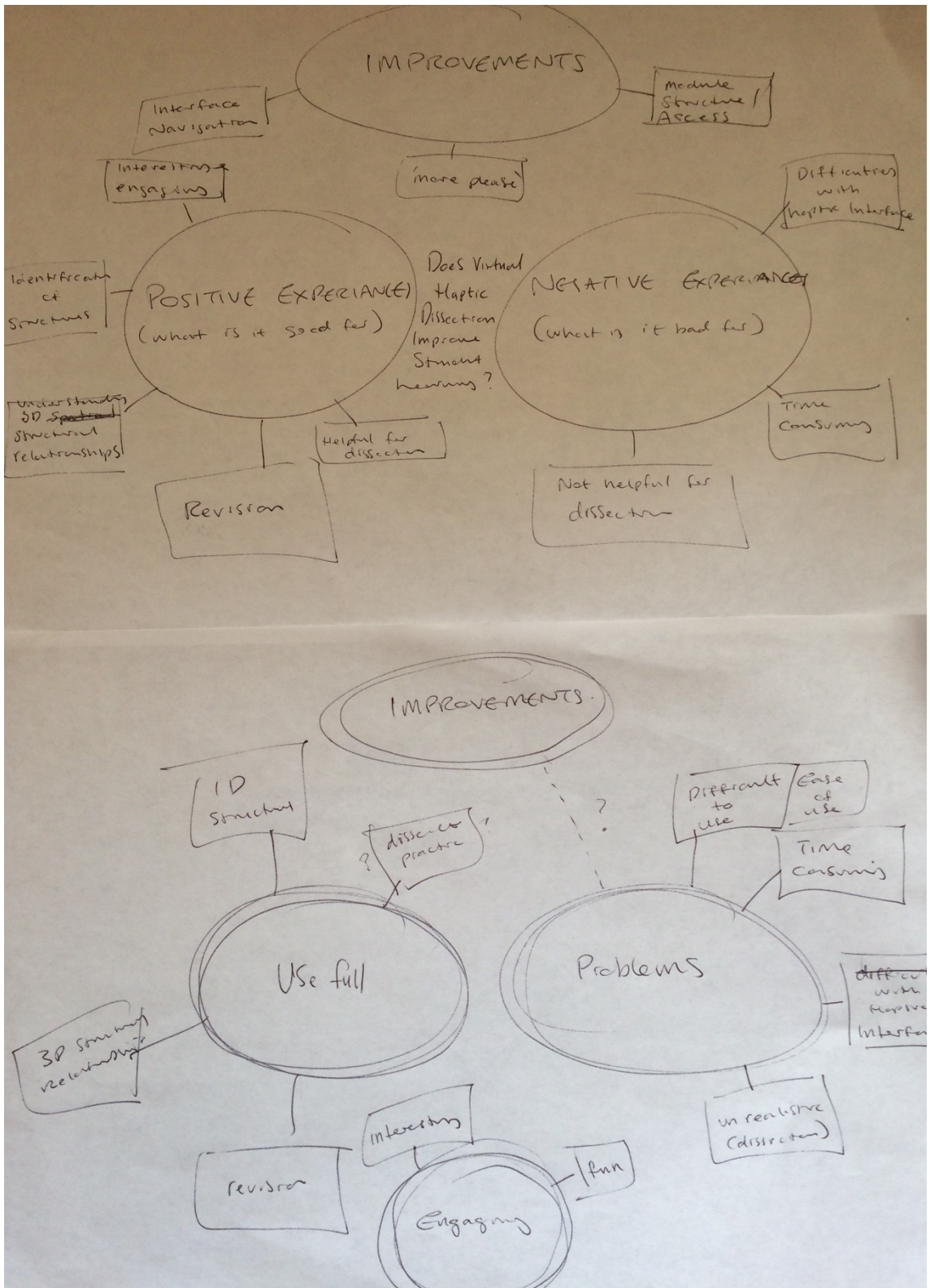
Figure 145, Examples of thematic analysis mind-maps by the author.

APPENDIX 10: ETHICAL APPROVAL

School of Psychology

University of Dundee Research Ethics Committee

Caroline Needham,
CAHID,
College of Life Sciences,
University of Dundee,
Dundee,
DD1 5EH.

23 June 2010

Dear Ms Needham,

Application Number: UREC 10034

Title: Virtual Reality Haptic Dissection

Your application has been reviewed by the University Research Ethics Committee, and there are no ethical concerns with the proposed research. I am pleased to confirm that the above application has now been formally approved.

You submitted the following documents:

1. ethics form2
2. ethics form2 (amended)

Yours sincerely,

Dr Peter Willatts
Chair, University of Dundee Research Ethics Committee

ANATOMY TEST

(This test is optional and does NOT count towards your final grade. It is for research purposes ONLY)

Q1, Please identify the structures a-i on the image below

a)

b)

c)

d)

e)

f)

g)

h)

i)

Q2, Please identify the structures a-f on the image below

a)

b)

c)

d)

e)

f)

Q3, Please identify the structures 1-13 on the image below
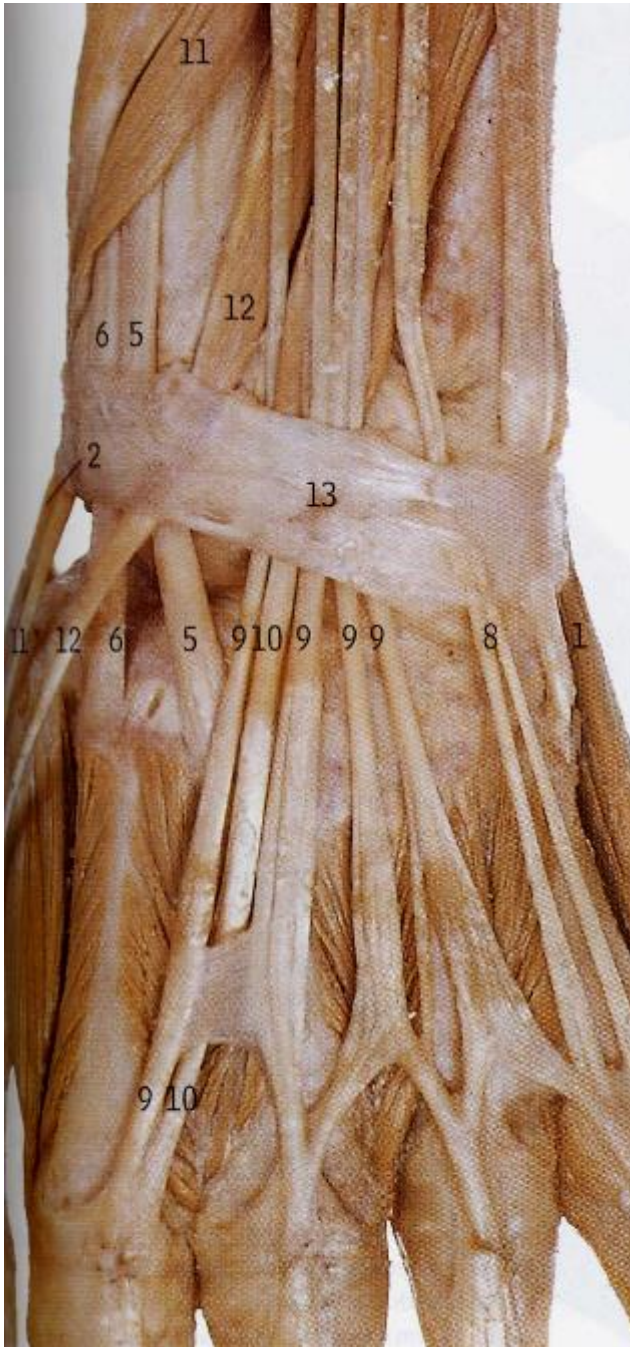
1)

2)

5)

6)

8)

9)

10)

11)

12)

13)

Q4, Which muscle is deeper?

    a) Abductor pollicis brevis
    b) Opponens pollicis

Q5, What muscle lies directly lateral of Flexor digitorum profundus?

    a) Palmaris longus
    b) Flexor pollicis longus
    c) Flexor carpi ulnaris
    d) Flexor carpi radialis

Q6, Which head of Adductor pollicis is the largest?

    a) Transverse head
    b) Oblique head

Q7, What nerve innervates Abductor digit minimi?

    a) Ulnar n.
    b) Radial n.
    c) Median n.

Q8, What nerve innervates the 1st and 2nd lumbricals?

    a) Ulnar n.
    b) Radial n.
    c) Median n.

ANATOMY TEST ANSWERS

Q1

a) Abductor pollicis brevis

b) Flexor pollicis brevis (superficial head)

c) Flexor pollicis brevis (deep head)

d) Flexor digitorum superficialis tendon

e) Flexor digitorum profundus tendon

f) Pronator quadratus

g) Common palmar digital aa.

h) Adductor pollicis (transverse head)

i) Adductor pollicis (oblique head)

Q2

a) Abductor digiti minimi

b) Dorsal interosseus (4th)

c) 2nd metacarpal

d) Dorsal interosseus (1st)

e) Extensor digitorum tendon

f) Abductor pollicis longus

Q3

1) Abductor digiti minimi

2) Abductor pollicis longus

5) Extensor carpi radalis brevis

6) Extensor carpi radalis longus

8) Extensor digiti minimi

9) Extensor digitorum

10) Extensor indicis

11) Extensor pollicis brevis

12) Extensor pollisis longus

13) Extensor retinaculum

Q4, b) Opponens pollicis

Q5, b) Flexor pollicis longus

Q6, a) Transverse head

Q7, a) Ulnar n.

Q8, c) Median n.

DISSECTION EVALUATION

To be completed by anatomy lecturer

1 = Not at all

2 = Somewhat

3 = Moderately

4 = Very

5 = Extremely

	Not at all	Somewhat	Moderately	Very	Extremely
1, How well has the palmar aspect of the wrist been dissected?	1	2	3	4	5
2, How well has the palmar aspect of the hand been dissected?	1	2	3	4	5
3, How well has the palmar aspect of the fingers been dissected?	1	2	3	4	5
4, How well has the dorsal aspect of the wrist been dissected?	1	2	3	4	5

5, How well has the dorsal aspect of the

hand been dissected?   1   2   3   4   5

6, How well has the dorsal aspect of the

fingers been dissected?   1   2   3   4   5

7, How well have the structures been separated?   1   2   3   4   5

8, How much damage to the structures is there?   1   2   3   4   5

9, How well are the lumbrical muscles exposed?   1   2   3   4   5

10, How well is the deep palmar arch exposed?   1   2   3   4   5

11, How well is the superficial palmar arche

exposed?   1   2   3   4   5

12, How well are the fibrous flexor sheaths exposed?   1   2   3   4   5

13, How clearly can the flexor digitorum tendons

be seen entering the tendon sheaths?   1   2   3   4   5

QUESTIONNAIRE

College of Life Sciences – Centre for Anatomy and Human Identification (CAHID)

Virtual Reality Haptic Dissection

Upon completion, please return to: Caroline Erolin
c.d.erolin@dundee.ac.uk
CAHID
College of Life Sciences
University of Dundee
Dundee, DD1 5EH

Please answer the following questions by selecting the answer that best describes your experience. If you cannot or would rather not answer any of the questions, please leave them blank.

1 = Not at all

2 = Somewhat

3 = Moderately

4 = Very

5 = Extremely

	Not at all	Somewhat	Moderately	Very	Extremely
1, How easy and intuitive was the software to use?	1	2	3	4	5
2, How helpful was the training session?	1	2	3	4	5
3, How helpful was the dissection manual?	1	2	3	4	5
4, Is the model anatomically accurate?	1	2	3	4	5
5, How appropriate is the level of detail in the model?	1	2	3	4	5
6, Did you enjoy using the software?	1	2	3	4	5
7, Did the software improve your dissection (i.e. practical) skills?	1	2	3	4	5
8, Did use of the software improve your anatomical knowledge?	1	2	3	4	5
9, Did you felt more confident doing the cadaveric dissection after practicing on the software?	1	2	3	4	5

10, Please indicate roughly how much time you spent using the software.

0 hours

0 – 1 hour

1 – 5 hours

5 – 10 hours

10 hours +

11. How many training sessions did you attend?

0

1

2

3

4

5 +

12, If you used the keyboard and mouse interface (year two) how do you feel this affected the experience?
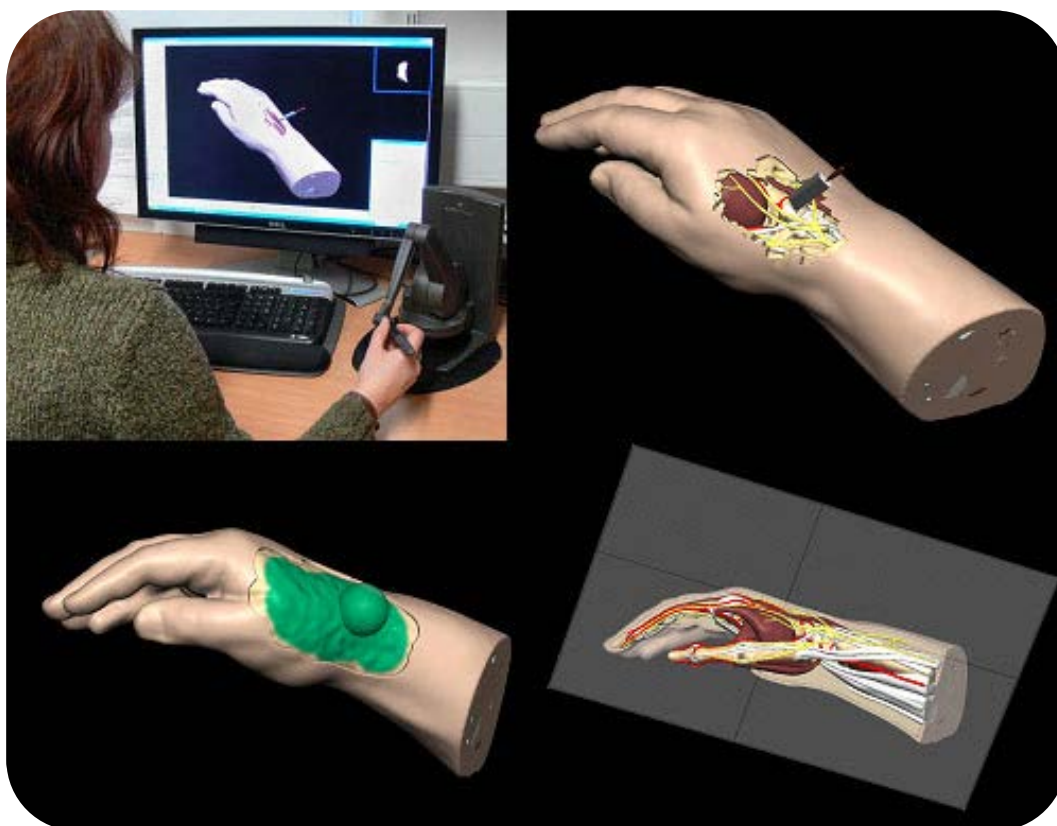
13, If you used the haptic interface (year three) how much do you feel this affected the experience?

14, What improvements would you like to see made to the software?

15, Any other comments?

Virtual Reality Hand & Wrist Dissector and User Guide

(Non-Haptic Edition)

For further information or training please contact:

Caroline Erolin

c.d.erolin@dundee.ac.uk

Centre for Anatomy and Human Identification

College of Life Sciences

University of Dundee

Dow Street

Dundee DD1 5EH

Tel: +44 (0)1382 38 8627/8352

Software User Guide

Getting Started

To open the model, go to 'File', 'Open' and navigate to 'VR Dissector' on the D drive.

If you wish to save your progress go to 'File', 'Save As' and save to your own folder.
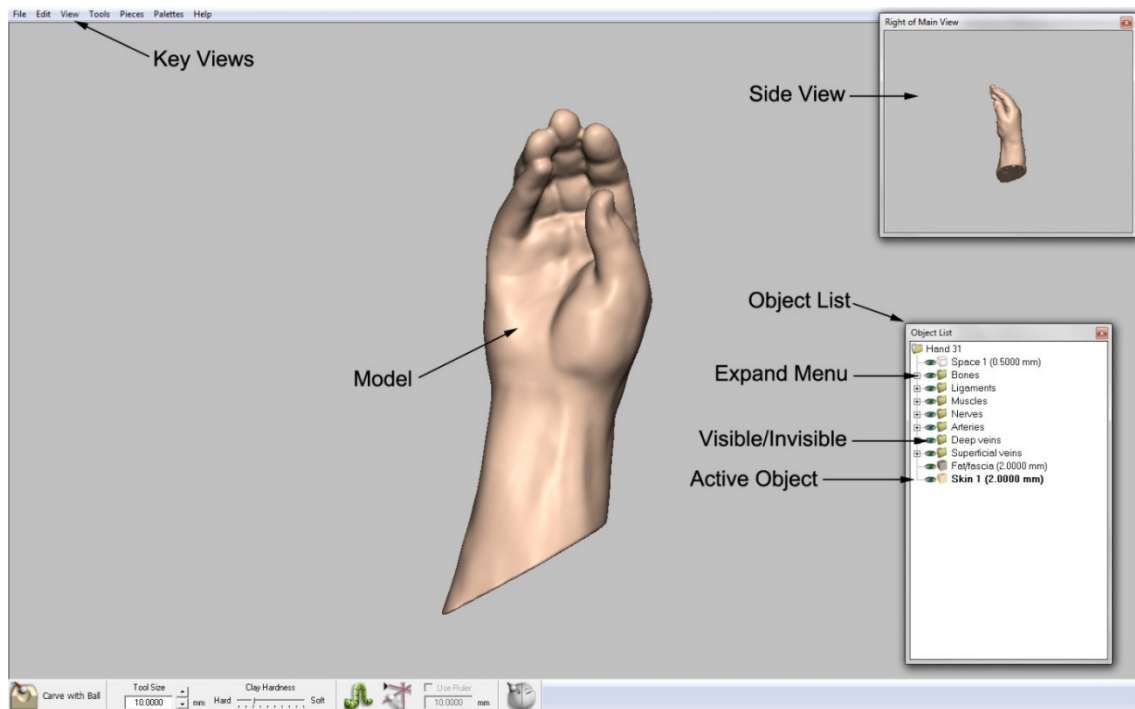
Navigation

Figure 1, Navigation list

Key Views allow you to view the model from the front, back, sides top and bottom. Go to 'View' and 'Standard Views' to access this feature.

Side Views can be activated by going to 'View' and 'Side Views'.

The **Object List** is activated by pressing 'O' on the keyboard. Structures can be activated from this list by right clicking on their name and selecting 'Activate'.

The **Expand Menu** button (+) will reveal the anatomical structures within each folder.

The **Visible/Invisible** (eye) button toggles each folder or object between visible and invisible.

Only the **Active Object** can be dissected at any time. To activate an object right click on its name and select 'Activate'. The active object is highlighted in the object list.

It is possible to make an object **transparent** by right clicking on the object name and selecting 'See Through' and 'See Through On'.

Identifying Structures

The object list can be searched using the find tool at the bottom of the window. Structures can be identified by left clicking on their name in the object list. The selected structure will be highlighted in green (Fig 2). Note – the active object cannot be highlighted. It is possible to select multiple structures by holding the Ctrl key.
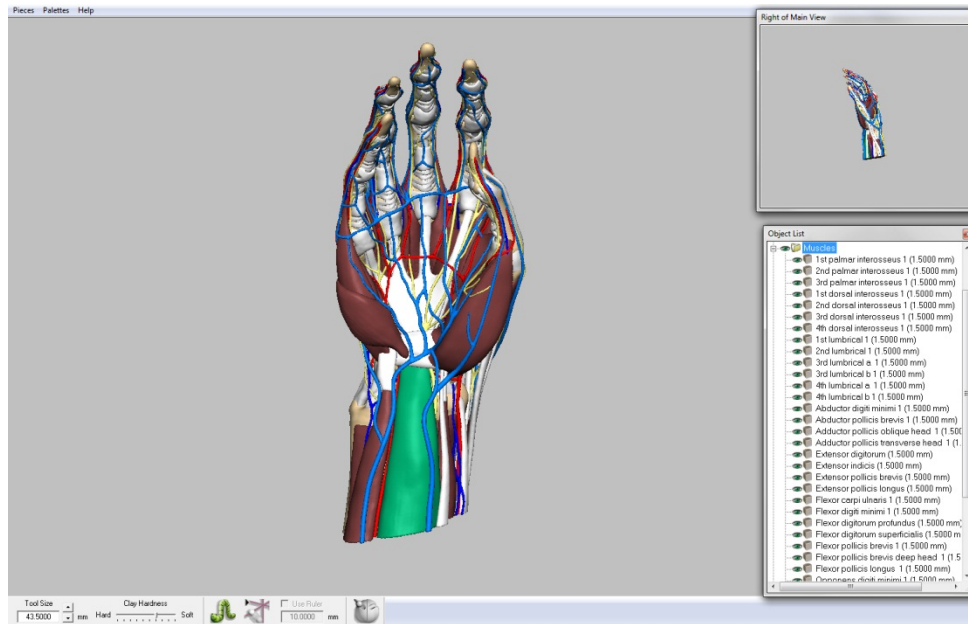
Figure 2, Identified structure highlighted in green

Moving the Model

- The left mouse button rotates the model
- The middle mouse button moves the model
- The right mouse button zooms in and out
- The arrow keys can also be used for fine movements

Dissecting the Model

The model can be 'dissected' by removing either individual objects or entire folders from view by clicking the Visible/Invisible (eye) symbol. Objects can also be made transparent by clicking on the object name and selecting 'See Through' and 'See Through On'.

Virtual Reality Hand & Wrist Dissector

(Adapted from Grant's Dissector)

Dissection Sequence

It is advantageous to dissect the upper limb in the following sequence: First the superficial veins and nerves and the deep fascia of the entire region will be explored. Secondly the muscles forming the flexor (anterior) compartment of the forearm will then be dissected. Third, the extensor (posterior) region of the forearm will be studied together with the dorsum of the hand and finally the contents of the palm will be explored.

1 Superficial Structures

The **superficial veins** and **cutaneous nerves** are contained within the superficial fascia. The first objective is to study these structures. To accomplish this, the wrist and hand should be skinned completely. The superficial fascia will first be made transparent and then removed, leaving the superficial veins and nerves intact.

NB: Both the superficial and deep fascia are represented in this model by one layer titled 'fat/fascia'.

Removal of Skin

- Remove the entire skin layer by making it invisible by clicking on the Visible/Invisible button.

Superficial Fascia, Veins and Nerves

- Active the fat/fascia layer and make it transparent by clicking on the object name and selecting 'See Through' and 'See Through On' to reveal the **superficial veins** and **cutaneous nerves** (Fig 3).
- On the dorsum of the hand, identify the superficial **dorsal venous network.**
- The superficial veins of the hand drain into the **basilic vein** and **cephalic vein,** identify these on the dorsum of the wrist.
- Continue to investigate the dorsum of the hand and wrist. Identify and trace some of the branches of the **superficial branch of the radial nerve**, the **dorsal branch of the ulnar nerve** and the **posterior antebrachial cutaneous nerve.**
- Rotating the model to the anterior aspect of the wrist, identify the **cephalic vein** on the radial side of the forearm and the **basilic vein** on the ulnar side of the forearm.
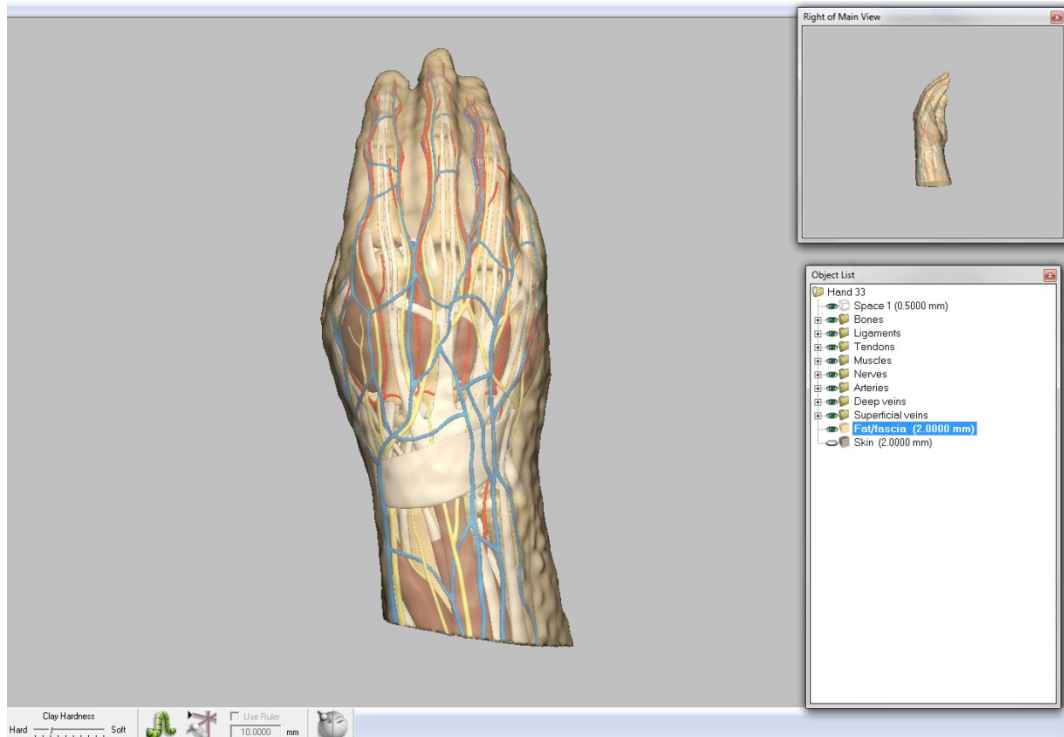
Figure 3, Transparency of the superficial fascia on the dorsum of the hand revealing the superficial veins and cutaneous nerves.

- Tracing the **cephalic** and **basilic veins** distally to the palm of the hand, identify a few branches of the **superficial palmar venous network.**
- The **fat/fascia** layer and **superficial veins** may now be made invisible by clicking on the Visible/Invisible button, as they will not be referred to again.

2 Flexor Region of Forearm

At the level of the wrist, the relative positions of muscles, tendons, vessels, and nerves will be identified. After removing the superficial flexor group the deep flexor group will be studied.

- From the lateral to medial side of the anterior wrist identify and examine the following (Fig 4):
    - Tendons of **abductor pollicis longus** and **brachioradialis;**
    - **Radial artery and vein;**
    - Tendon of **Flexor carpi radialis;**
    - **Median nerve;**
    - Tendon of **palmaris longus**
    - **Flexor digitorum superficialis;**
    - **Ulnar artery** and **ulnar nerve;**
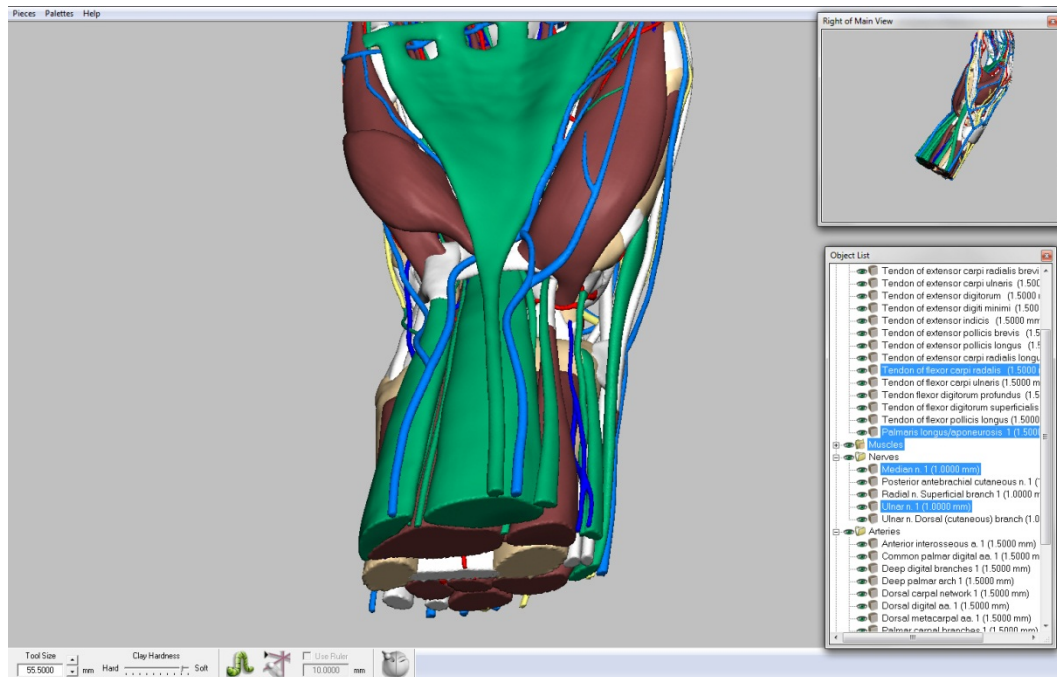   - **Flexor carpi ulnaris.**

Figure 4, From the lateral to medial side: abductor pollicis longus (tendon), brachioradialis (tendon), radial artery, flexor carpi radialis (tendon), median nerve, palmaris longus (tendon), flexor digitorum superficialis, ulna artery, ulna nerve and flexor carpi ulnaris.

- The **median nerve** supplies most of the muscles of the flexor region of the forearm. To expose the median nerve, the most superficial layer of anterior forearm muscles must be first removed. Proceed as follows:

  o Using the Visible/Invisible button make the tendon of **flexor carpi radialis, flexor carpi ulnaris** and the tendon of **palmaris longus** invisible.

- **Flexor digitorum superficialis** should now be fully exposed. This muscle constitutes the second layer of the superficial muscles of the anterior forearm.
  o Using the Visible/Invisible button make **Flexor digitorum superficialis** invisible.
  o Observe the path of the **median nerve** within the forearm.
  o Observe the paths of the **ulna nerve** and **ulna artery.**

- Study the three deep flexor muscles of the forearm: **flexor digitorum profundus, flexor pollicis longus,** and **pronator quadratus.**
  o **Flexor digitorum profundus** is innervated by both the **median** and **ulnar nerves**. Observe these nerves running either side of the muscle.
  o Observe **flexor pollicis longus** entering beneath the **flexor retinaculum.**
  o Observe how **pronator quadratus** runs transversely from the **ulna** to **radius**

(you may need to remove flexor digitorum profundus in order to see clearly).

3 Extensor Region of Forearm and Dorsum of Hand

First the **anatomical snuff box** will be defined and studied. Next, the superficial posterior forearm muscles will be identified and their tendons will be followed distally. Subsequently, the deep extensor muscles will be studied.

The anatomical snuff box is a triangular depression on the radial, dorsal aspect of the hand. The name originates from the use of this area for placing and then sniffing powdered tobacco, or "snuff." Observe the boundaries of the anatomical snuff box:

- The tendons of **abductor pollicis longus** and **extensor pollicis brevis** bound the snuff box anteriorly.
- The tendon of **extensor pollicis longus** bounds it posteriorly. These three tendons belong to muscles of the deep extensor group.
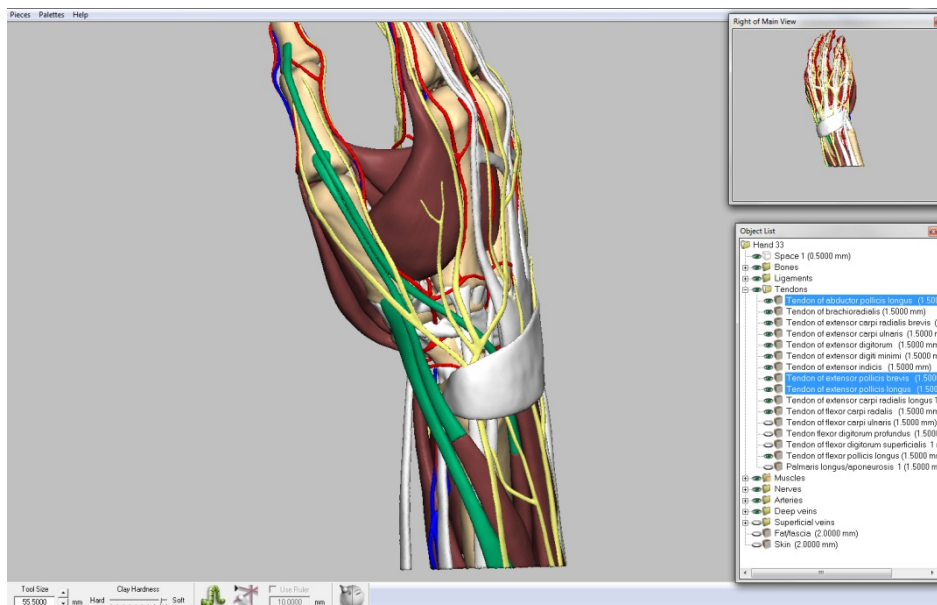

Figure 5, Abductor pollicis longus, extensor pollicis brevis and extensor pollicis longus are highlighted to demonstrate the 'anatomical snuff box'.

- Deep within the snuff box find the **radial artery**. Trace it distally (as it forms the **dorsal carpal network** and the **deep palmar arch**) to where it disappears between the two heads of the **1st dorsal interosseous** muscle.
- Identify the four **dorsal interossei muscles.** Note that these occupy the intervals between metacarpal bones. These are abductors; they pull the fingers from an imaginary line through axis of the middle finger.
- Trace the three tendons bounding the anatomical snuff box proximally into the forearm.

- Identify and study the following muscles and tendons of the **superficial extensor group**:
    - Lateral to the outcropping of muscles of the anatomical snuff box find the tendons of **brachioradialis**, **extensor carpi radialis longus**, and **extensor carpi radialis brevis**.
    - Medial to the outcropping of muscles of the anatomical snuff box find the tendons of **extensor digitorum**, **extensor digiti minimi**, and **extensor carpi ulnaris**.
    - Follow the flattened tendons of the **extensor digitorum** to their insertions. Note their cross connections on the back of the hand.
    - Identify and then remove the **extensor retinaculum** (by clicking on the 'Visible/Invisible button') to reveal the tendons of **extensor digitorum** within.
    - Remove the tendons of **extensor digitorum** (by clicking on the Visible/Invisible button) to expose **extensor indicis** beneath.
    - Observe how the **superficial branch** of the **radial nerve** and the **dorsal (cutaneous) branch** of the **ulna nerve** each innervate half of the dorsum of the hand.
- **Muscles of the Deep Extensor Group.** Now the muscles of the deep extensor group can be studied in their entirety.   Identify and study the following muscles:
    - The three muscles bounding the snuff box **(abductor pollicis longus; extensor pollicis brevis; extensor pollicis longus**) and **extensor indicis.** (Note that proximally, towards the elbow, is the **supinator,** the fifth deep extensor muscle that is not included on this model)

4 Palm of the Hand

There are two superficial muscle masses in the hand: the **thenar group** forming the ball of the thumb, and the **hypothenar group** forming the ball of the little (5th) finger. In the middle of the palm is a thick fibrous sheet, the **palmar aponeurosis**. Deep to the palmar aponeurosis are the tendons of the deep and superficial digital flexors. These tendons reach the palm through the carpel tunnel. Deep in the palm is a series of small muscles.

The palm is supplied with blood by two arterial arches: the **superficial arch** is mainly derived from the **ulnar artery** and the **deep arch** from the **radial artery**. The nerve supply of the palmar (or volar) aspect of the hand is derived from the **median** and **ulnar nerves**.

Superficial Structures of the Palm

- Identify the **flexor retinaculum** and the **palmar aponeurosis.** Note the four longitudinal bands of aponeurosis, one to each finger.
- Remove the **palmar aponeurosis** by clicking on the Visible/Invisible button.

- Observe **Palmaris brevis**, the most superficial muscle of the hypothenar group.
- Remove **palmaris brevis** (by clicking on the Visible/Invisible button) so that the **ulnar artery** and **nerve** can be more easily followed into the palm.
- Observe the **superficial palmar arch** arising from the **ulnar artery.** Identify the **pisiform bone** and verify that the **ulnar artery** and **nerve** lie lateral to it (anatomical position) (Fig 6).
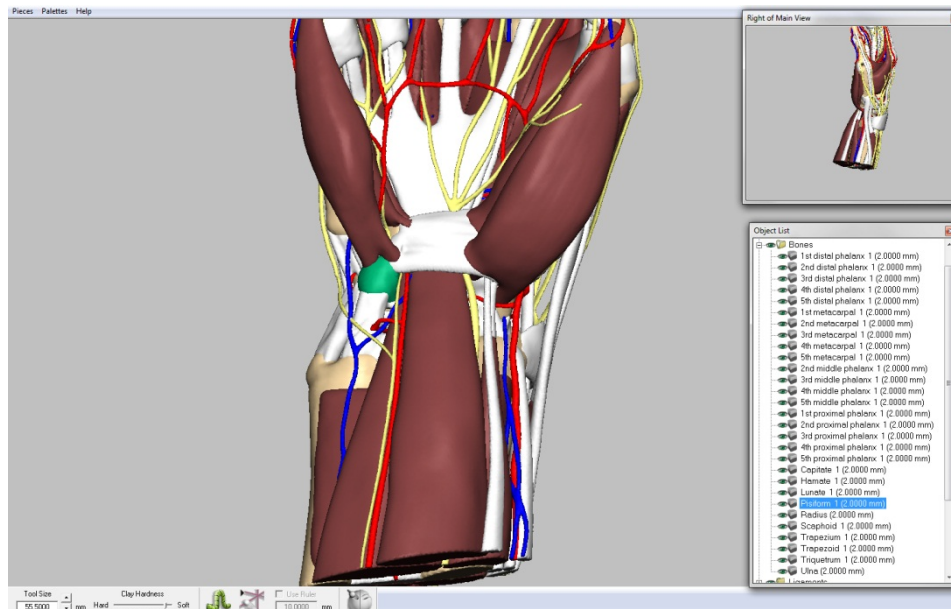

Figure 6, The pisiform bone is highlighted in green. Note the ulnar artery and nerve laterally.

- Observe the (superficial branch of) **ulnar nerve** and trace its path along the 5th and medial side of the 4th fingers.
- Identify and then remove the **flexor retinaculum** (by clicking on the Visible/Invisible button) to reveal the contents of the carpal tunnel, including the **median nerve** and several **digital flexor tendons**.
- Identify and trace the **median nerve** and its branches. Observe the branches to the thenar muscles and to the first 3½ digits.
- Examine the three **thenar muscles**:
    - **Abductor pollicis brevis;** remove by clicking on the Visible/Invisible button;
    - **Opponens pollicis;** deep to the removed abductor;
    - **Flexor pollicis brevis;** note the (recurrent) branch of the median nerve crossing over it.
- **Hypothenar muscles.** Identify:
    - **Abductor digiti minimi,** arising from the pisiform bone;
    - **Flexor digiti minimi;**
    - **Opponens digiti minimi.**
- Identify the **fibrous digital sheaths** housing the long flexor tendons.

- Identify the four small **lumbrical muscles** originating from the profundus tendons (Fig 7).
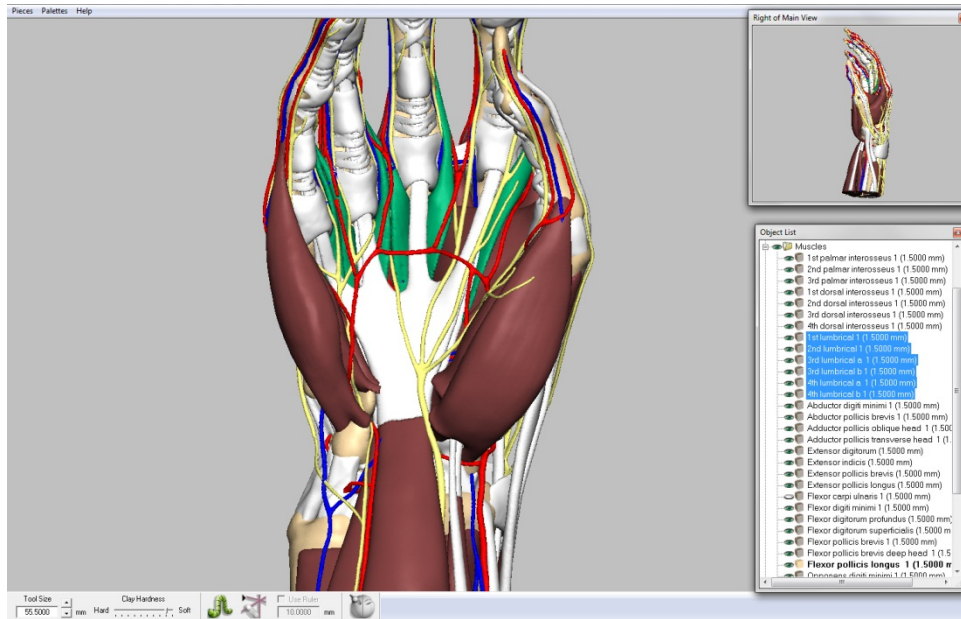

Figure 7, The four lumbrical muscles highlighted in green.

- Remove the **fibrous digital** sheath from the fingers (by clicking on the Visible/Invisible button) to study the interactions of the tendons of **flexor digitorum superficialis** and **profundus** (you will need to make superficialis visible again). Note that the profundus tendon pierces the superficialis tendon. Verify that the superficialis tendon acts on the middle phalanx, whereas the profundus tendon acts on the distal phalanx of fingers 2 through 5.

Deep Structures of the Palm

- Identify and remove **flexor digitorum profundus** and **superficialis** and their tendons (by clicking on the Visible/Invisible button) to reveal **pronator quadratus.**
- Identify the **deep palmar arch** (artery)**.**
- Remove the four **lumbrical** muscles (by clicking on the Visible/Invisible button) to reveal the three **palmar interossei muscles** and the deep palmar space**.**
- Follow the (deep branch of) **ulnar nerve** across the deep structures of the palm (Fig 8).
- Identify the two heads (transverse and oblique) of **adductor pollicis.** This muscle draws the thumb toward the palm, a movement of considerable importance.
- Identify the three **palmar interossei muscles** originating from the metacarpal bones of digits 2, 4, and 5. Note that they insert into the bases of the proximal phalanges. These are adductors; they pull the fingers toward an imaginary line through the axis of the middle finger.

Upon completion of your dissection you can either save your progress (by going to 'File', 'Save As' and saving to your own folder), begin again or quit.
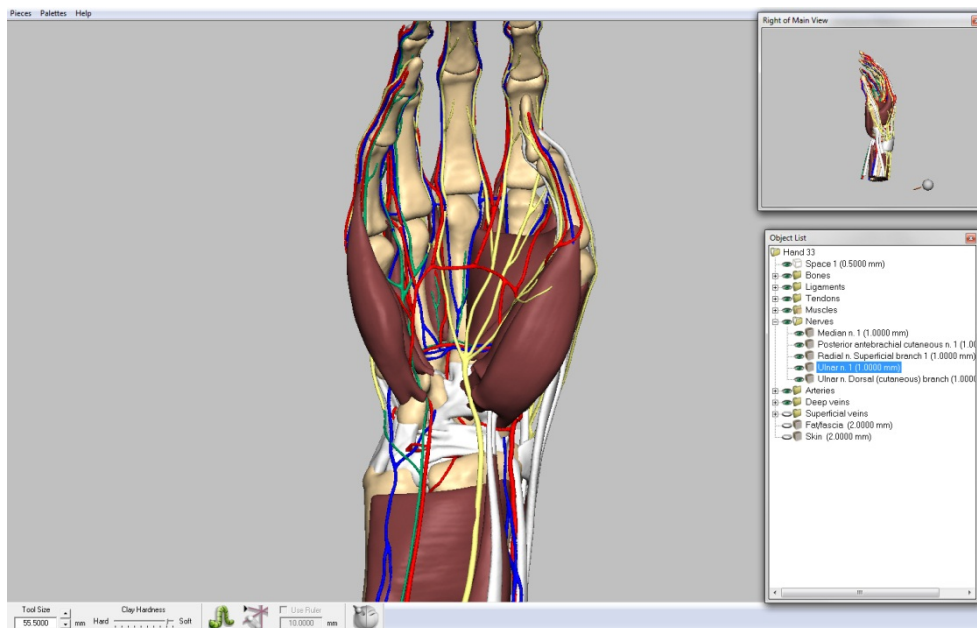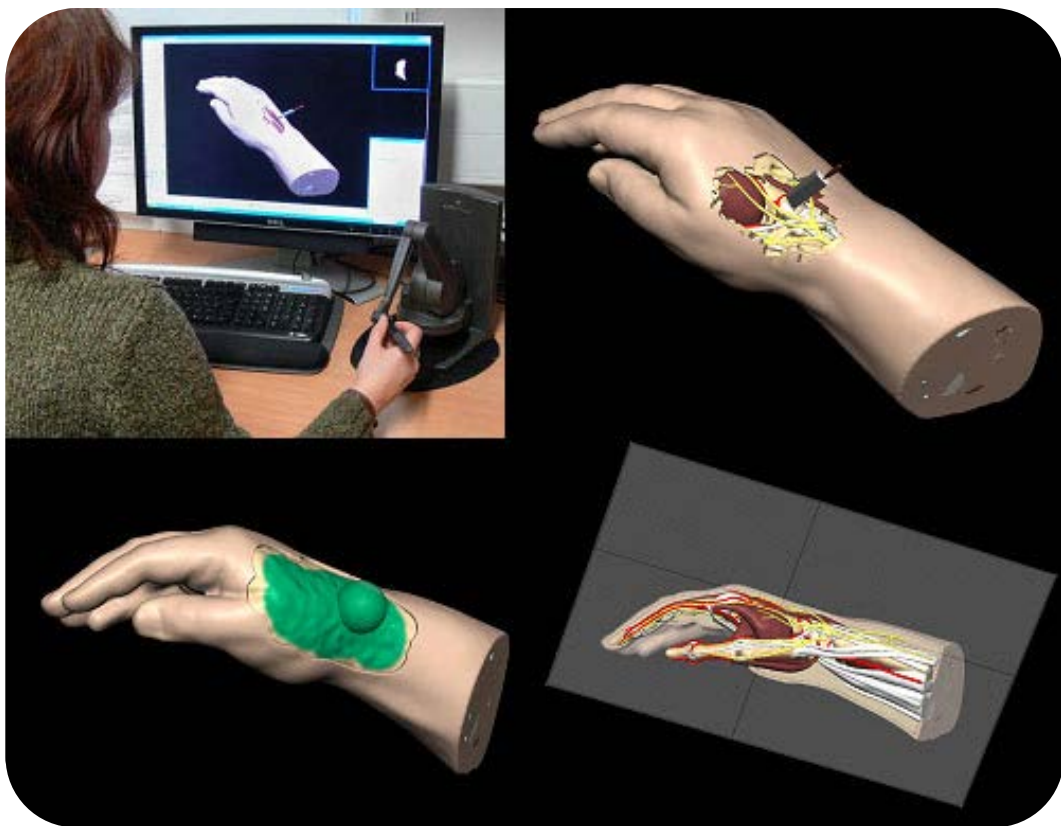

Figure 8, The deep branch of the ulnar nerve highlighted in green.

Virtual Reality Hand & Wrist Dissector and User Guide

(Haptic Edition)

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Software User Guide

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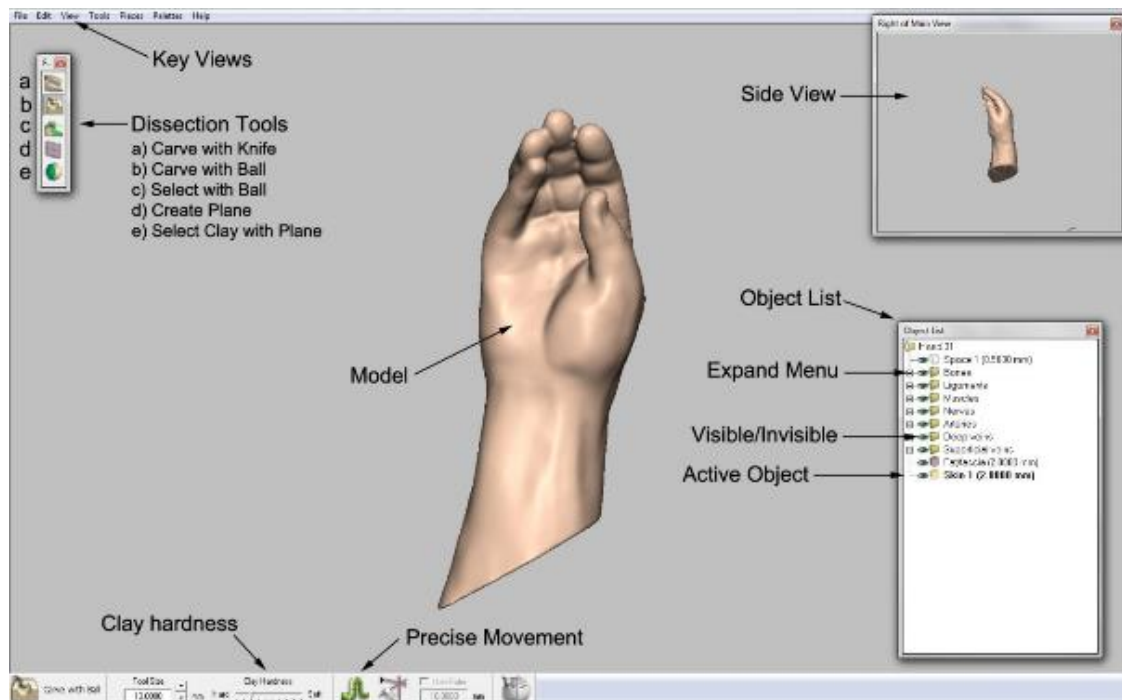
Navigation

Figure 1, Navigation list

Key Views allow you to view the model from the front, back, sides top and bottom. Go to 'View' and 'Standard Views' to access this feature.

Side Views can be activated by going to 'View' and 'Side Views'.

Dissection Tools – these are the only tools you will need to interact with the model:
a) Carve with a Knife
b) Carve with a Ball
c) Select with Ball
d) Create Plane
e) Select Clay with Plane

Clay Hardness can be altered by moving the cursor from hard to soft, located on the bottom toolbar.

The **Precise Movement** button allows for carving in slow motion, use for detailed dissection.

The **Object List** is activated by pressing 'O' on the keyboard. Structures can be activated from this list by right clicking on their name and selecting 'Activate'.

The **Expand Menu** button (+) will reveal the anatomical structures within each folder.

The **Visible/Invisible** (eye) button toggles each folder or object between visible and invisible.

Only the **Active Object** can be dissected at any time. To activate an object right click on its name and select 'Activate'. The active object is highlighted in the object list.

It is possible to make an object **transparent** by right clicking on the object name and selecting 'See Through' and 'See Through On'.

Identifying Structures

The object list can be searched using the find tool at the bottom of the window. Structures can be identified by left clicking on a structure name in the object list will cause it to become highlighted in green (Fig 2a & b). It is generally easier to identify structures when the entire surface is visible (Fig 2a). However, it is more realistic and useful to be able to identify structures through a more limited 'window of view' (Fig 2b) created through the dissection process. Note – the active object cannot be highlighted. It is possible to select multiple structures by holding the Ctrl key.
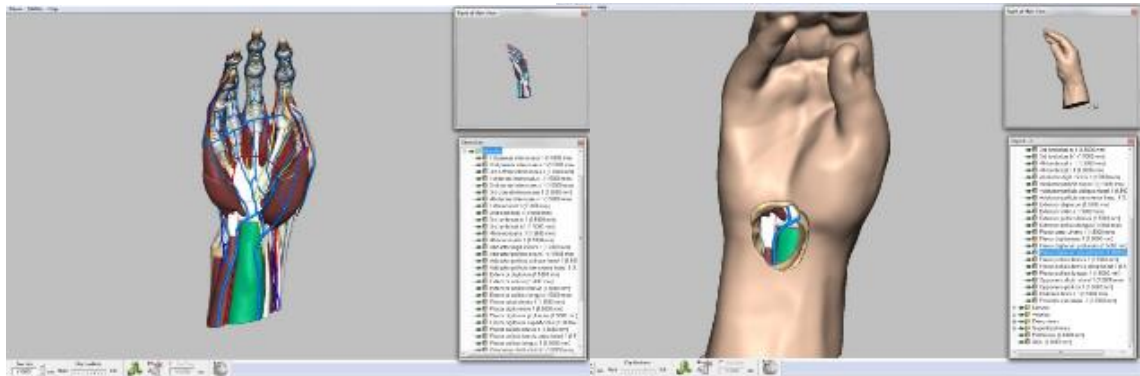
Figure 2, Identified structure highlighted in green, a) With entire surface visible and b) through a 'window of view'

Moving the Model

- To move, rotate and zoom the model, hold the 'G' key while moving the haptic device.
- To move and zoom the model without rotation hold the 'H' key while moving the haptic device.
- The left mouse button rotates the model
- The middle mouse button moves the model
- The right mouse button zooms in and out
- The arrow keys can also be used for fine movements

Dissecting the Model

Several methods to virtually dissect the model are introduced below. These can either be used in isolation or combined with one another.

NB: Pressing Ctrl & Z buttons will undo an action, you can undo 20+ actions.

Using the Carve Tool

The *Carve* tool offers the most realistic way of dissecting the model. This tool allows you to cut/scrape away tissue to reveal underlying structures (Fig 3).

- Select the *Carve* tool from the left hand menu. The tool size can be increased and decreased using the + and – buttons on the keyboard.
- Move the tool to where you wish to dissect and, while pressing the button on the haptic device, begin to scrape away tissue.
- Only the active object (see above) can be dissected at any time.
- The *Precise Movement* button can be used for more detailed dissection
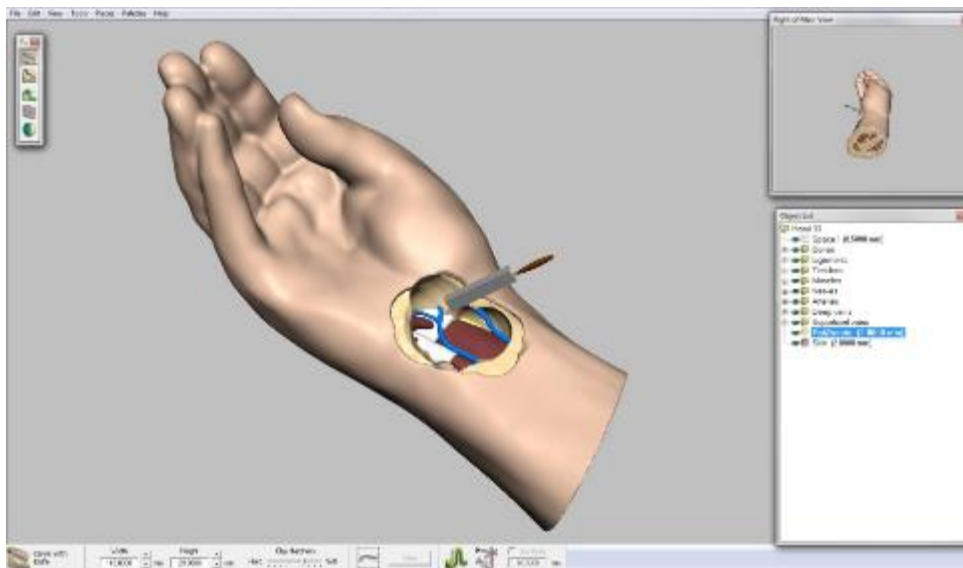
Figure 3, Dissecting with the *Carve* tool

Using the Select with Ball Tool

The *Select with Ball* tool allows for quicker selection and removal of tissue than the *Carve* tool. Although it feels less realistic to use, the resulting 'window of view' is similar to that created by the *Carve* tool (Fig 4).

- Select the *Select with Ball* tool from the left hand menu. The ball size can be increased and decreased using the + and – buttons on the keyboard.
- Move the tool to where you wish to dissect and, while pressing the button on the haptic device, 'paint' the area you would like remove with the Selection tool. (You can also erase selected areas with the Deselect tool)

- Once selected, click the 'Cut' button on the bottom (the sixth tool along the bottom toolbar) to remove.
- Remember, only the active object (see above) can be dissected at any time.
- The toolbar across the bottom of the screen also contains a number of additional tools which may be of use including: Select All, Clear and Invert Selection. Feel free to experiment with these.

Figure 4, Dissecting with the *Select with Ball* tool

Using Planes

Planes can be used to remove tissue quickly and in key views (Fig 5).

- Go to 'View', 'Standard Views' and select a key view in which to add a plane.
- Selecting *Create Plane* will cause a plane to be added in front of the model.
- Note that the size and location of the plane will depend on which structure is active.
- Using the haptic device, place the cursor in the centre of the plane to move it to the desired position within the model.
- Once in position, select *Select Clay with Plane.* Using the haptic device, move the cursor onto the plane and click on its surface to select it.
- Using the haptic device, touch and click the tissue you would like to remove. Selected tissue will be highlighted in green. (You can also erase selected areas with the Deselect tool.)
- If the correct area of tissue is highlighted, either press the 'Delete' key on the keyboard or click the 'Cut' button (the sixth tool along the bottom toolbar) to remove.
- To move a plane after it has been selected, right click on it in the object list and select 'Edit'.
- Planes can be made invisible by clicking on the visible/invisible button.
- The toolbar across the bottom of the screen also contains a number of additional tools which may be of use including: Select All, Clear and Invert Selection. Feel free to experiment with these.
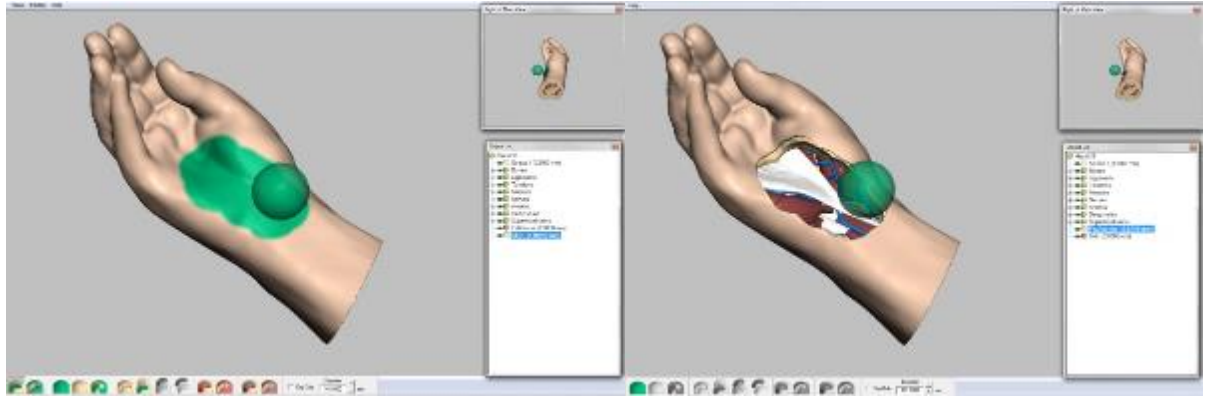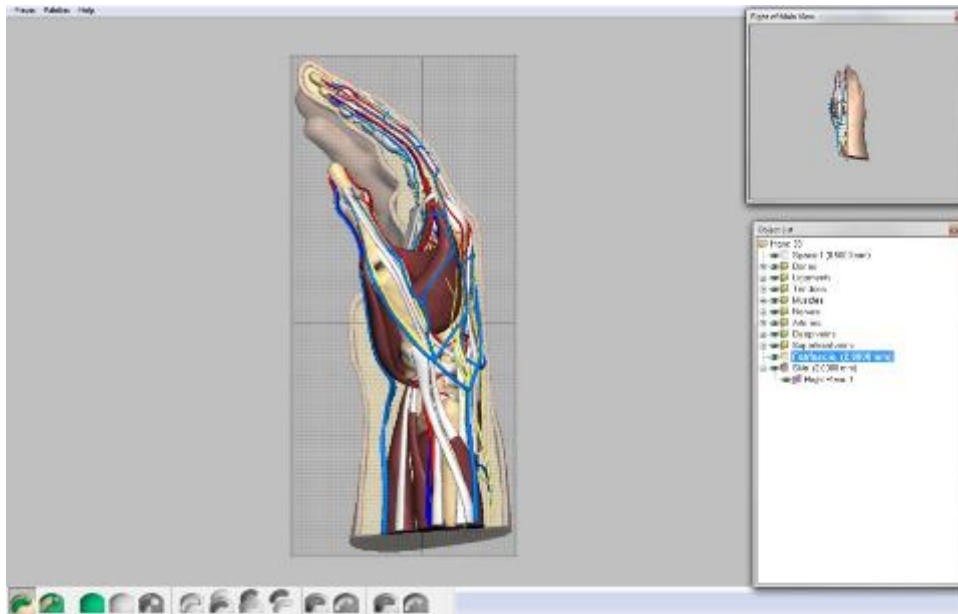
Figure 5, Dissecting using planes

Virtual Reality Hand & Wrist Dissector

(Adapted from Grant's Dissector)

Dissection Sequence

It is advantageous to dissect the upper limb in the following sequence: First the superficial veins and nerves and the deep fascia of the entire region will be explored. Secondly the muscles forming the flexor (anterior) compartment of the forearm will then be dissected. Third, the extensor (posterior) region of the forearm will be studied together with the dorsum of the hand and finally the contents of the palm will be explored.

The tools described below for dissecting at each stage are suggestions only, feel free to use whichever tool/s you are most comfortable with.

REMEMBER: Only the Active Object can be dissected at any time. To activate an object right click on its name and select 'Activate'. The active object is highlighted in the object list.

1 Superficial Structures

The **superficial veins** and **cutaneous nerves** are contained within the superficial fascia. The first objective is to study these structures. To accomplish this, the wrist and hand should be skinned completely and the superficial fascia removed, leaving the superficial veins and nerves intact.

NB: Both the superficial and deep fascia are represented in this model by one layer titled 'Fat/fascia'.

Removal of Skin

- The easiest way to remove the entire skin layer is to make it invisible by clicking on the Visible/Invisible button.
- Alternatively, the skin can be removed with either the *Carve* or *Select with Ball* tools.

Superficial Fascia, Veins and Nerves

- Remove the top layer of fascia using the *Carve* or *Select with Ball* tools.
- Enough fascia needs to be removed to reveal the **superficial veins** and **cutaneous nerves** (Fig 6).
- On the dorsum of the hand, identify the superficial **dorsal venous network.**
- The superficial veins of the hand drain into the **basilic vein** and **cephalic vein,** identify these on the dorsum of the wrist.

- Continue to investigate the dorsum of the hand and wrist. Identify and trace some of the branches of the **superficial branch of the radial nerve**, the **dorsal branch of the ulnar nerve**, and the **posterior antebrachial cutaneous nerve.**
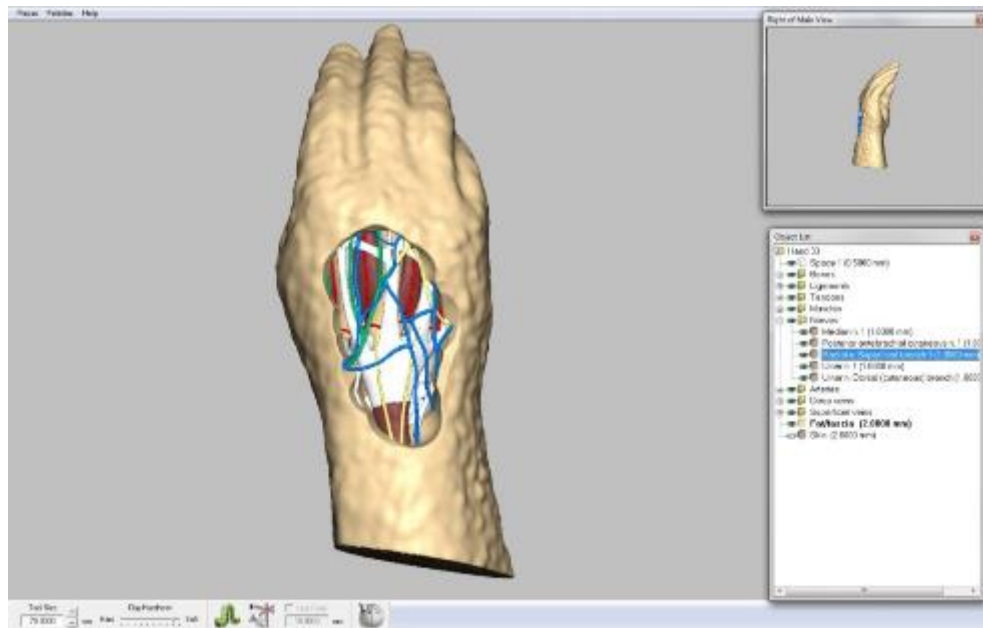

Figure 1, Dissection of the superficial fascia on the dorsum of the hand revealing the superficial veins and cutaneous nerves. The superficial branch of the radial nerve is highlighted in green.

- Rotating the model to the anterior aspect of the wrist, identify the **cephalic vein** on the radial side of the forearm and the **basilic vein** on the ulnar/medial side of the forearm (you may need to remove more fascia in order to see them).
- Tracing the **cephalic** and **basilic veins** distally to the palm of the hand, identify a few branches of the **superficial palmar venous network.**
- The **superficial veins** may now be made invisible by clicking on the Visible/Invisible button, as they will not be referred to again.

2 Flexor Region of Forearm

At the level of the wrist, the relative positions of muscles, tendons, vessels, and nerves will be identified. After removing the superficial flexor group, the deep flexor group will be studied.

- Begin to remove the remaining superficial and deep fascia from the anterior of the wrist (using the *Carve* or *Select with Ball* tools) to expose the superficial muscles. From the lateral to medial side identify and examine the following (Fig 7):
   - Tendons of **Abductor pollicis longus** and **brachioradialis;**
   - **Radial artery and vein;**
   - Tendon of **flexor carpi radialis;**
   - **Median nerve;**
   - Tendon of **palmaris longus;**

- o **Flexor digitorum superficialis;**
- o **Ulnar artery** and **ulnar nerve;**
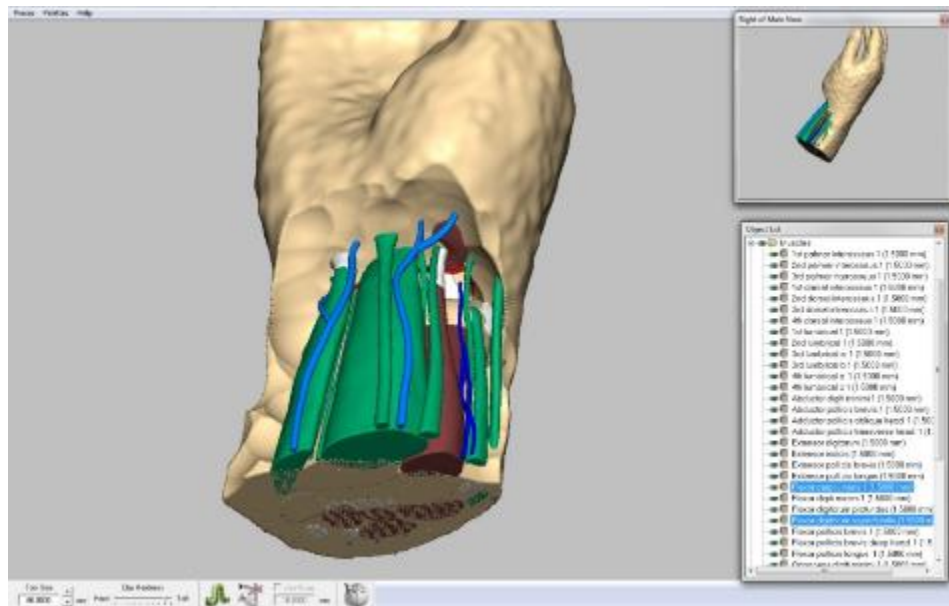- o **Flexor carpi ulnaris.**

Figure 2, From the lateral to medial side: abductor pollicis longus (tendon), brachioradialis (tendon), radial artery, flexor carpi radialis (tendon), median nerve, palmaris longus (tendon), flexor digitorum superficialis, ulna artery, ulna nerve and flexor carpi ulnaris.

- The **median nerve** supplies most of the muscles of the flexor region of the forearm. To expose the median nerve, the most superficial layer of anterior forearm muscles must be first removed. Proceed as follows:
    - o Using either the *Carve* or *Select with Ball* tools, remove the following; tendon of **flexor carpi radialis, flexor carpi ulnaris,** and the tendon of **palmaris longus** (up to the flexor retinaculum).
    - o NB: The median nerve can be highlighted at any time (by left clicking on it in the object list) as a target while the other structures are dissected around it.

- **Flexor digitorum superficialis** should now be fully exposed. This muscle constitutes the second layer of the superficial muscles of the anterior forearm.
    - o Using either the *Carve* or *Select with Ball* tools, remove **flexor digitorum superficialis.**
    - o Observe the path of the **median nerve** within the forearm.
    - o Observe the paths of the **ulna nerve** and **ulna artery.**

- Study the three deep flexor muscles of the forearm: **flexor digitorum profundus, flexor pollicis longus,** and **pronator quadratus.**
    - o **Flexor digitorum profundus** is innervated by both the **median** and **ulnar nerves**. Observe these nerves running either side of the muscle.

o Observe the tendon of **flexor pollicis longus** entering beneath the **flexor retinaculum.**

o Observe how **pronator quadratus** runs transversely from the **ulna** to **radius** (you may need to remove flexor digitorum profundus in order to see clearly).

3 Extensor Region of Forearm and Dorsum of Hand

First the **anatomical snuff box** will be defined and studied. Next, the superficial posterior forearm muscles will be identified and their tendons will be followed distally. Subsequently, the deep extensor muscles will be studied.

The anatomical snuff box is a triangular depression on the radial, dorsal aspect of the hand. The name originates from the use of this area for placing and then sniffing powdered tobacco, or "snuff." Remove enough fascia so that you can define the tendons that constitute the boundaries of the anatomical snuff box (Fig 8):

- The tendons of **abductor pollicis longus** and **extensor pollicis brevis** bound the snuff box anteriorly.
- The tendon of **extensor pollicis longus** bounds it posteriorly. These three tendons belong to muscles of the deep extensor group.

Figure 3, Abductor pollicis longus, extensor pollicis brevis and extensor pollicis longus are highlighted to demonstrate the 'anatomical snuff box'.

- Deep within the snuff box find the **radial artery**. Trace it distally (as it forms the **dorsal carpal network** and the **deep palmar arch**) to where it disappears between the two heads of the **1ˢᵗ dorsal interosseous** muscle.

- Identify the four **dorsal interossei muscles.** Note that these occupy the intervals between metacarpal bones. These are abductors; they pull the fingers from an imaginary line through axis of the middle finger.
- Trace the three tendons bounding the anatomical snuff box proximally into the forearm.
- Identify and study the following tendons and muscles of the **superficial extensor group**:
  - Lateral to the outcropping of muscles of the anatomical snuff box find the tendons of **brachioradialis**, **extensor carpi radialis longus**, and **extensor carpi radialis brevis**.
  - Medial to the outcropping of muscles of the anatomical snuff box find the tendons of **extensor digitorum**, **extensor digiti minimi**, and **extensor carpi ulnaris**.
  - Follow the flattened tendons of the **extensor digitorum** to their insertions. Note their cross connections on the back of the hand.
  - Identify and then remove the **extensor retinaculum** (either by clicking on the visible/invisible button or using the *Carve* or *Select with Ball* tools) to reveal the tendons of **extensor digitorum** within.
  - Remove the tendons of **extensor digitorum** (using the *Carve* or *Select with Ball* tools) to expose **extensor indicis** beneath.
  - Observe how the **superficial branch** of the **radial nerve** and the **dorsal (cutaneous) branch** of the **ulna nerve** each innervate half of the dorsum of the hand.
- **Muscles of the Deep Extensor Group.** Now the muscles of the deep extensor group can be studied in their entirety. Identify and study the following muscles:
  - The three muscles bounding the snuff box (**abductor pollicis longus**; **extensor pollicis brevis; extensor pollicis longus**) and **extensor indicis.** (Note that proximally, towards the elbow, is the **supinator,** the fifth deep extensor muscle that is not included on this model)

4 Palm of the Hand

There are two superficial muscle masses in the hand: the **thenar group** forming the ball of the thumb, and the **hypothenar group** forming the ball of the little (5th) finger. In the middle of the palm is a thick fibrous sheet, the **palmar aponeurosis**. Deep to the palmar aponeurosis are the tendons of the deep and superficial digital flexors. These tendons reach the palm through the carpel tunnel. Deep in the palm is a series of small muscles.

The palm is supplied with blood by two arterial arches: the **superficial arch** is mainly derived from the **ulnar artery** and the **deep arch** from the **radial artery**. The nerve supply of the palmar (or volar) aspect of the hand is derived from the **median** and **ulnar nerves**.

Superficial Structures of the Palm

- Begin by removing the superficial and deep fascia from the palm of the hand using the *Carve* or *Select with Ball* tools. Identify the **palmar aponeurosis** and the **flexor retinaculum.** Note the four longitudinal bands of aponeurosis, one to each finger.

- Remove the **palmar aponeurosis** entirely. The easiest way is to make it invisible by clicking on the Visible/Invisible button. Alternatively, it can be removed with either the *Carve* or *Select with Ball* tools.

- Observe **palmaris brevis**, the most superficial muscle of the hypothenar group.

- Using either the *Carve* or *Select with Ball* tools, remove **palmaris brevis** so that the **ulnar artery** and **nerve** can be more easily followed into the palm.

- Observe the **superficial palmar arch** arising from the **ulnar artery.** Identify the **pisiform bone** and verify that the **ulnar artery** and **nerve** lie lateral to it (in the anatomical position) (Fig 9).
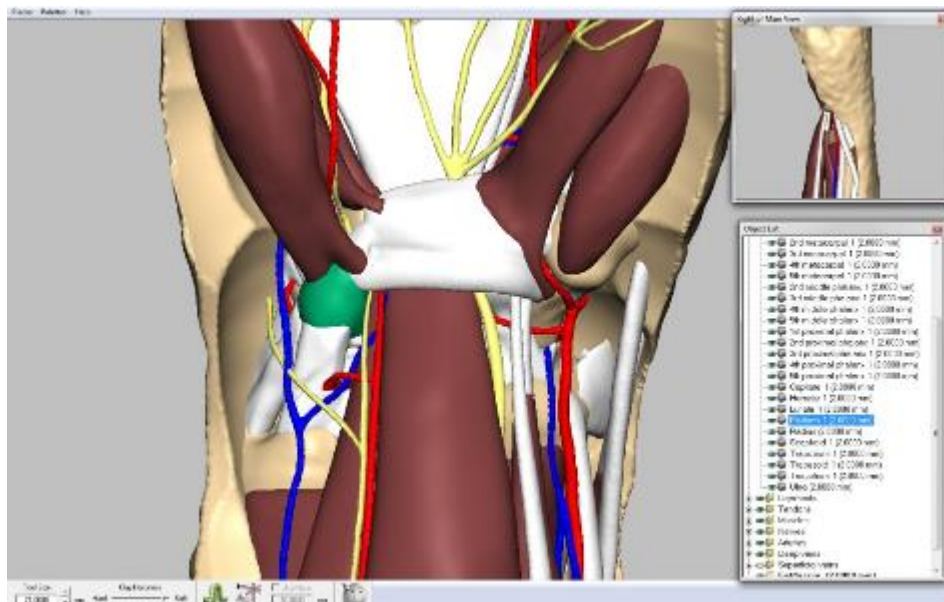

Figure 4, The pisiform bone is highlighted in green. Note the ulnar artery and nerve laterally.

- Observe the (superficial branch of) **ulnar nerve** and trace its path along the 5th and medial side of the 4th fingers (you will need to remove the skin and fascia if you haven't already done so).

- Identify and then remove the **flexor retinaculum** (either by clicking on the Visible/Invisible button or using the *Carve* or *Select with Ball* tools) to reveal the contents of the carpal tunnel, including the **median nerve** and several **digital flexor tendons**.

- Identify and trace the **median nerve** and its branches. Observe the branches to the thenar muscles and to the first 3½ digits (you will need to remove the skin and fascia if you haven't already done so).

- Examine the three **thenar muscles**:

- o **Abductor pollicis brevis;** remove using either the *Carve* or *Select with Ball* tools;
  - o **Opponens pollicis;** deep to the removed abductor;
  - o **Flexor pollicis brevis;** note the (recurrent) branch of the median nerve crossing over it.
- **Hypothenar muscles.** Identify:
  - o **Abductor digiti minimi,** arising from the pisiform bone;
  - o **Flexor digiti minimi;**
  - o **Opponens digiti minimi.**
- Identify the **fibrous digital sheaths** housing the long flexor tendons.
- Identify and remove the tendon of **flexor digitorum superficialis** proximal to the **fibrous digital sheath** (using the *Carve* or *Select with Ball* tools) to expose the tendons of **flexor digitorum profundus.**
- Identify the four small **lumbrical muscles** originating from the profundus tendons (Fig 10).
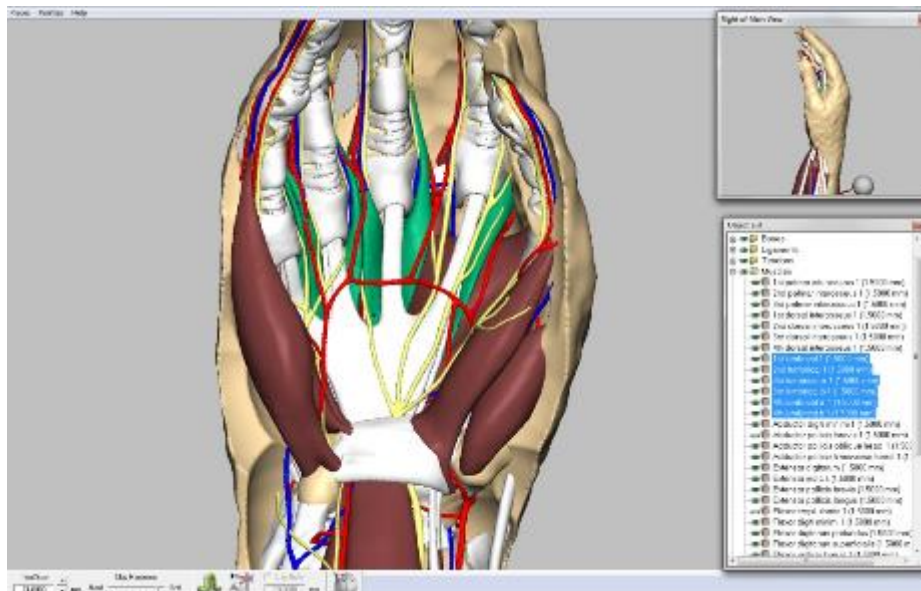

Figure 5, The four lumbrical muscles highlighted in green.

- On the middle digit, remove the **fibrous digital sheath** (using the *Carve* or *Select with Ball* tools) to study the interactions of the tendons of **flexor digitorum superficialis** and **profundus**. Note that the profundus tendon pierces the superficialis tendon. Verify that the superficialis tendon acts on the middle phalanx, whereas the profundus tendon acts on the distal phalanx of fingers 2 through 5.

Deep Structures of the Palm

- Remove the tendons and muscle belly of **flexor digitorum profundus** entirely (either by clicking on the visible/invisible button or using the *Carve* or *Select with Ball* tools) to reveal **pronator quadratus.**
- Identify the **deep palmar arch** (artery)**.**

- Remove the four **lumbrical** muscles (either by clicking on the Visible/Invisible button or using the *Carve* or *Select with Ball* tools) to reveal the three **palmar interossei muscles** and the deep palmar space**.**
- Follow the (deep branch of) **ulnar nerve** across the deep structures of the palm (Fig 11).
- Identify the two heads (transverse and oblique) of **adductor pollicis.** This muscle draws the thumb toward the palm, a movement of considerable importance.
- Identify the three **palmar interossei muscles** originating from the metacarpal bones of digits 2, 4, and 5. Note that they insert into the bases of the proximal phalanges. These are adductors; they pull the fingers toward an imaginary line through the axis of the middle finger.

Upon completion of your dissection you can either save your progress (by going to 'File', 'Save As' and saving to your own folder), begin again or quit.
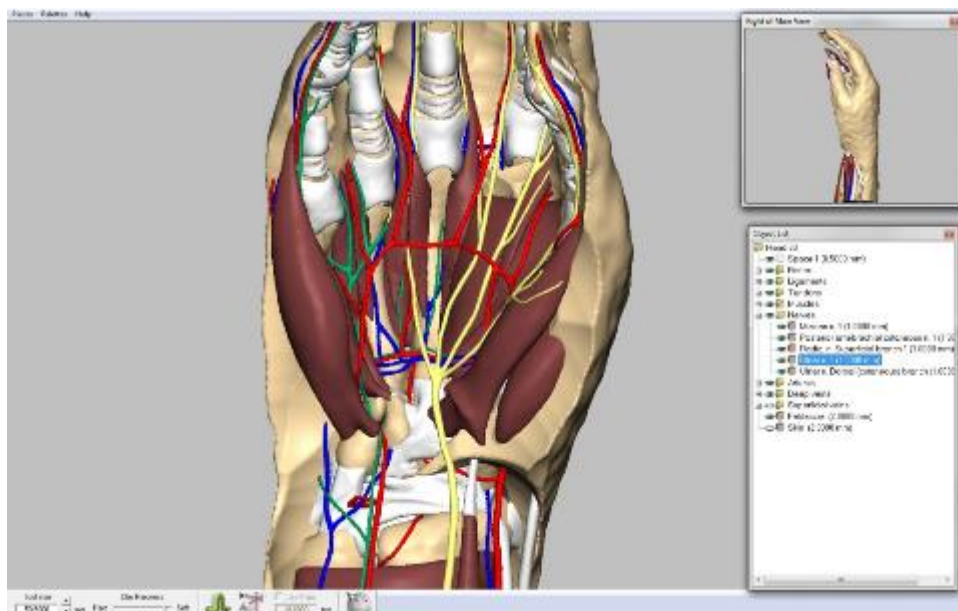

Figure 6, The deep branch of the ulnar nerve highlighted in green.

PARTICIPANT CONSENT FORM

College of Life Sciences – Centre for Anatomy and Human Identification (CAHID)

Virtual Reality Haptic Dissection

Researcher:　　　　　　　Caroline Erolin
　　　　　　　　　　　　　　c.d.erolin@dundee.ac.uk
　　　　　　　　　　　　　　CAHID
　　　　　　　　　　　　　　College of Life Sciences
　　　　　　　　　　　　　　University of Dundee
　　　　　　　　　　　　　　Dundee, DD1 5EH

Supervisors:　　　　　　　Prof Caroline Wilkinson
　　　　　　　　　　　　　　c.m.wilkinson@dundee.ac.uk
　　　　　　　　　　　　　　Dr Clare Lamb
　　　　　　　　　　　　　　c.z.lamb@dundee.ac.uk

I have read and understand the research project information: I GIVE CONSENT for my participation in this project.

_____

Participants name (printed)

_____

Signature of participant

_____

Date

_____

Course and year of Study

_____

Email

Details of person obtaining consent

_____

Name of person obtaining consent (printed)

_____

Signature of person obtaining consent

_____

Date

FOR THE PARTICIPANT

Research Project Information

College of Life Sciences – Centre for Anatomy and Human Identification (CAHID)

Virtual Reality Haptic Dissection

Researcher:
Caroline Erolin
c.d.erolin@dundee.ac.uk
CAHID
College of Life Sciences
University of Dundee
Dundee, DD1 5EH

Supervisors:
Prof Caroline Wilkinson
c.m.wilkinson@dundee.ac.uk

Dr Clare Lamb
c.z.lamb@dundee.ac.uk

You are **invited to participate** in research proposed by Caroline Erolin, a graduate student in the *Centre for Anatomy and Human Identification* at the University of Dundee, toward a degree in Doctor of Philosophy in Medical Visualisation.

This document summarises the project – it's purpose, method, data management, and ethical considerations. It defines the role of the participant, and identifies potential research outcomes.

Project description
Three dimensional digital models of human anatomy are increasingly being used in medical and anatomical education. In some instances they are used in place of cadaveric dissection and in others in addition to it. More recently, the development of Haptic feedback (the sense of touch) has been integrated into surgical simulators, allowing for a much greater sense of realism. This research aims to combine developments in both fields by creating a virtual reality haptic dissector. This software will allow the student to virtually dissect the hand and wrist through a haptic interface.

Testing will take place over three successive years. In year one, students will have *no access* to the software but will be asked to complete an optional knowledge test (on the anatomy of the hand and wrist) and the condition of each cadaver will be qualitatively evaluated after dissection by an anatomy lecturer. During years two and three the software will be made available to students in addition to their normal tuition for a number of weeks before, during and after cadaveric dissection of the hand and wrist takes place. In year two the software will use a *non-haptic* interface (a mouse & keyboard) and in year three a *haptic* interface. Use of the software will be optional and tuition will be provided. Students will again be asked to complete an optional knowledge test as well as feedback questionnaire. The condition of each cadaver will be qualitatively evaluated after dissection by an anatomy lecturer.

The researcher will compare the (optional) test results and quality of cadaveric dissection to assess if there is an improvement to dissection and in understanding throughout the three years.

What you will be asked to do:
(You will take part in one group only. You will be informed which group you are in)

Group One

- You will be asked to use the *(non-haptic)* Dissection Software prior to dissecting the hand and wrist.

- Training sessions for the software will be available at regular intervals throughout the study. These will take place within the Centre for Anatomy and Human Identification and will be advertised to all participants via email.

- At the end of the module you will be asked to complete (non-assessed) optional tests on the anatomy of the hand and wrist.

- At the end of the module you will be asked to complete an optional and anonymous questionnaire on how useful or otherwise you felt the software to be.

Group Two

- You will be asked to use the *(Haptic)* Dissection Software prior to dissecting the hand and wrist.

- Training sessions for the software will be available at regular intervals throughout the study. These will take place within the Centre for Anatomy and Human Identification and will be advertised to all participants via email.

- At the end of the module you will be asked to complete (non-assessed) optional tests on the anatomy of the hand and wrist.

- At the end of the module you will be asked to complete an optional and anonymous questionnaire on how useful or otherwise you felt the software to be.

- You will be asked to do an online spatial ability test consisting of ten questions. The results will be anonymised and compared with your test results and feedback responses.

Time commitment
The duration of time spent using the software will be up to the individual student. It is advised that you spend at least 30 minutes using the software; however there is no upper limit.

The anatomy test should take no longer than 30 minutes to complete.

The questionnaire should take no longer than 15 minutes to complete.

Cost, reimbursement and compensation
Participation is voluntary with no financial payment.

Termination of participation
You may withdraw from the study at any stage without explanation or penalty.

Risks

There are no known risks associated with this study.

Data collection and storage

No personal information will be collected during this study. Any analysis and/or comparison of test results and dissection quality will not be linked to individual students.

Questionnaires will be distributed after completion of the study. These will be anonymous and completion will be optional.

Contact / further information

For further information about this research study you may contact:

Researcher:	**Supervisors:**
Caroline Erolin	Prof Caroline Wilkinson
c.d.erolin@dundee.ac.uk	c.m.wilkinson@dundee.ac.uk
CAHID	
College of Life Sciences	Dr Clare Lamb
University of Dundee	c.z.lamb@dundee.ac.uk
Dundee, DD1 5EH	

The University Non-Clinical Research Ethics Committee of the University of Dundee has reviewed and approved this research study.