Comparative Analysis of Neuroanatomy Teaching Techniques

Dr Hamish Newman AMusA BSc MD
21482057

School of Allied Health
Health Professions Education

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30th September, 2021

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The research involving human data reported in this thesis was assessed and approved by The University of Western Australia Human Research Ethics Committee. Approval # RA/4/20/5250. Written patient consent has been received and archived for the research involving patient data reported in this thesis.

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Hamish James Newman

21482057

Scholarly Output

Published Articles

Newman HJ, Meyer AJ, Wilkinson TJ, Pather N, Carr SE. Protocol for BEME Topic Review Group: Technology Enhanced Neuroanatomy Teaching Techniques: a BEME Systematic Review of Current Evidence. Reg Number 0129. BEME Collaboration. 2020. Available online at: https://bemecollaboration.org/Reviews+In+Progress/Modern+Neuroanatomy+Teaching+Techniques/

Newman HJ, Meyer AJ, Carr SE. Neuroanatomy Teaching in Australian and New Zealand Medical Schools. World Neurosurgery. 2021 May 1;149:e217-24.

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Articles Accepted for Publication

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Conference Presentations

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Abstract

Background Neuroanatomy is a challenging subject for health professionals due to the complexity and interconnectedness of anatomical structures. In the context of reduced teaching hours dedicated to anatomy in problem-based, integrated curricula, academics have increasingly sought modern alternatives to complement traditional approaches. However, there has been heterogeneous translation of these modern techniques into practice.

Aim The objectives of this thesis are fourfold: 1. To summarise available technology enhanced learning methods for neuroanatomy teaching according to the review standards set by the BEME Collaboration; 2. To review the neuroanatomy education of medical students in Australia and New Zealand; 3. To assess factors relevant to learning neuroanatomy including anxiety, motivation and spatial ability, and its respective influence on knowledge acquisition.; and 4. To compare the most effective methods of teaching for a range of neuroanatomical concepts through an intervention study.

Results A systematic review of modern techniques demonstrated the growing area of research, particularly for technologies such as augmented and virtual reality. There are promising results for these methods in teaching complex spatial anatomy and reducing cognitive load. In Australia and New Zealand, neuroanatomy content and instructional methodology were highly variable between institutions. The average time dedicated to teaching neuroanatomy was 46.0 hours, ranging from 12h to 160h. In a cohort study, the final unit score was positively correlated with perceived task value, and negatively correlated with anxiety. There was a positive correlation between spatial ability and spatial MCQ results. Finally, three out of seven laboratories were completed of the intervention-based study before in-class participation was suspended due to risk mitigation during the COVID-19 pandemic. In response to the pandemic, students tended to prefer traditional methods of teaching in favour of digital methods.

Conclusion Neuroanatomy teaching methods have been the focus of considerable research in the past decade. There are encouraging signs that modern learning methods may complement traditional methods of learning to enhance the education of this valuable subject.

Abbreviations

AMC	Australian Medical Council
AI	Artificial Intelligence
AR	Augmented Reality
BEME	Best Evidence Medical Education
DASS-21	Depression, Anxiety and Stress Subscale
EGO	Extrinsic Goal Orientation (Motivation)
GP	General Practitioner
GPA	Grade Point Average
IGO	Intrinsic Goal Orientation (Motivation)
mAR	Mobile Augmented Reality
MRT	Mental Rotations Test
MSLQ	Motivated Strategies for Learning Questionnaire
PG	Post-graduate
RACS	Royal Australasian College of Surgeons
SRL	Self-Regulated Learning
TA	Test Anxiety
TV	Task Value
UG	Under-graduate
VR	Virtual Reality

Glossary of Terms

Artificial intelligence: “the theory and development of computer systems able to perform tasks normally requiring human cognition. In education, this relates to technologies that personalize learning experiences and reduce workloads”

Augmented reality: “adding digital elements to a live view”

Curriculum: “a prescriptive term that defines subjects comprising a course of study”

Effectiveness: “the ability of an educational tool to enhance student’s neuroanatomy knowledge in an appropriate, cost-effective, timely manner. Often used relative to other education tools.”

Engagement: “Zimmerman’s definition (1989) of self-regulated learning is used for this paper; that is, the extent to which students are ‘metacognitively, motivationally and behaviourally active participants in their own learning process’”

Mixed reality: “intersection between digital technology and the real world. Current available technologies are augmented reality or virtual reality. Holographic devices are emerging in this space.”

Mobile learning: “education or training conducted by means of portable computing devices such as smartphones or tablet computers.”

Modern teaching techniques: “novel teaching techniques researched with regards to their application to neuroanatomy, particularly in the last 10 years. Examples include those mentioned in the HORIZON report such as AR, VR, mobile technology, artificial intelligence and virtual assistants.

Neurophobia: “a fear of the neural sciences and clinical neurology that is due to the students' inability to apply their knowledge of basic sciences to clinical situations.” [1]

Performance: “in the context of neuroanatomy education, this will refer to students’ knowledge acquisition, ability to understanding the content and the long-term retention of information.”

Spatial ability: “capacity to understand, reason, and remember the spatial relations between objects or space”

Stereopsis: “the ability of both eyes to create the perception of depth by seeing an object as one image. Stereoscopy is a technique for creating or enhancing the illusion of depth in an image”

Virtual assistant: “the use of spoken commands, voice recognition and a natural user interface to connect students to the virtual environment”

Virtual reality: “implies a complete immersion experience and shuts out the physical world”

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CHAPTER 1:
Introduction

1.1 Overview

Neuroanatomy teaching plays a vital role in the education of health science students. A key to understanding neuroscience, it is imperative for learning the form and function of the nervous system, lays the foundations for treating neurological disorders, and is the basis of neuroscientific discoveries. I was fortunate to have several great teachers and mentors while in medical school, who taught what was known in neuroanatomy, and also devoted time to developing our interest in the unknown. With great interest, I pursued a Masters of Health Professions Education to learn more about, and hopefully discover, ways to optimise neuroanatomy education.

This chapter serves as an orientation to this thesis. To clarify the overall objectives of the work, the rationale for this thesis is explained, the broad research methods are covered, and justification for the presentation by publication is provided. Following this, various chapters are presented, building the overall narrative, and finally arriving at a summary of the work conducted during my candidature.

1.2 Background

Anatomy is one of the fundamental basic sciences covered in medical courses, integral for any clinician to understand for safe clinical practice [2, 3]. During the twentieth century, significant changes have occurred in the teaching of medical students. These changes have accommodated the growth in medical knowledge and cohort sizes and facilitated the increasing skills-based teaching approaches relevant to clinical practice [3]. As such, there has been a shift from the traditional discipline-based curricular approaches to integrated, systems-based, clinically-oriented modules [4].

As Turney (2007) suggested, '*anatomy has suffered as a subject because it is regarded as banausic, archaic, didactic, traditional, overly factual and unable to adapt to modern educational methods – an obvious target for those looking to reduce curriculum content and modernise the learning experience*.' This is reflected in historical data, which indicates a significant decline in anatomy teaching hours within medical courses in Australia, New Zealand, The United Kingdom and The United States of America [2, 5, 6]. A decrease in anatomy teaching has been associated with poorer knowledge of anatomy of medical students [7-9]; particularly in central and peripheral nervous system anatomy [7]. Long-term retention of central and peripheral neuroanatomy by medical science students is also a problem identified in the literature [10, 11]. This research suggests students' recollection of neuroanatomy drops by 46.5% over a 10-11 month period [10], and up to 60% by 33 months [11]. The decline in neuroanatomy knowledge of medical students may partially be explained by a reduced number of teaching hours dedicated to neuroanatomy [7].

Recent studies show the trend of decreasing anatomy teaching hours may be reversing, with a recent paper indicating a 24% increase in mean neuroanatomy teaching hours from 64h in 2014 to 80h in 2018 within United States' medical schools [12]. However, it is uncertain whether this increase in neuroanatomy teaching time is reflected in increased performance of medical graduates [12]. It is also unknown whether neuroanatomy teaching time has increased in other countries.

Learning central and peripheral neuroanatomy is particularly challenging for medical students, junior doctors, and General Practitioners due to the heavy reliance on spatial relationships often required to be learned from cross-sections [13]. Students must know salient anatomical features and their topography, spatial relationships and clinical significance, particularly when creating a spatially relevant 3D mental representation of sequential 2D digital formats such as CTs and MRIs [2, 13]. As one of the most challenging parts of the anatomy curriculum, neuroanatomy is often described as one of the leading causes of ‘neurophobia’, a fear of the neural sciences, that was a term introduced by Jozefowicz in 1994 [1].

The main effect of neurophobia may be the negative influence on the choice of neurology or neurosurgery as a career choice [14, 15]. A prospective survey instrument was applied to 243 medical students in Mumbai, India, which revealed that 43% of students identified neurophobia as a factor preventing them from pursuing neurology as a career [15]. A microsimulation supply model of the neurology workforce in the United States suggested the shortfall in neurologists will increase from 11% to 19% between 2012 and 2025 [14]. This simulation incorporated factors such as wait times, difficulty hiring new neurologists and numbers of physicians who do not accept particular patients [14]. With an ageing population and the global burden of neurological disease increasing, this represents a critical public health issue [16].

In terms of instructional methods, cadaver-based instruction has been the primary pedagogical tool for hundreds of years. However, limitations on curricular time, training of staff and faculty resources have led some medical schools to abandon costly and time-consuming dissection based learning [17]. Traditional laboratory teaching now mainly involves prosected human material, plastinated specimens, models and clinical imaging [6]. In the context of reduced teaching hours and combined curricula, innovative (primarily digital) teaching strategies and techniques have been adopted to improve long-term knowledge retention, spatial understanding and reduce neurophobia [2, 18].

Becoming more commonplace are multimedia resources and 3D digital representations of neuroanatomy [18]. Virtual (VR) and augmented (AR) reality are amongst newer technologies now available for teaching. Where virtual reality is a representation of a real environment, in AR the real environment is used as a background and elements are superimposed to add further information (e.g. sounds, animations, video, etc.) [19]. Other learning tools such as 3D printed models [20], and social media [21], also appear more frequently in the recent literature. No curriculum for using these tools exists, and naturally, the instructional methodology is highly variable between institutions [6]. This raises important questions about which tools are most beneficial for student knowledge acquisition and long-term retention, and how they are best implemented in neuroanatomy curricula.

There have been two systematic reviews conducted in this area of research in recent years. Arantes et al. (2018) reviewed 29 papers that assess the impact of using a specific teaching method on a student's learning of neuroanatomy as a guide for curricular improvements [18]. The second by Sotgiu et al. (2020) reviewed 16 studies to identify the most effective method to teach neuroanatomy [16]. Broadly these papers categorised resources into digital and non-digital. Generally, both studies demonstrated this is a growing area of research, with over 80% of studies published in the last eight years. Studies that focussed on digital, computer-based models for teaching found they were well-designed for students and faculty, and students had positive attitudes towards them. However, there were mixed findings of the effectiveness of the instruments, suggesting that the tools may be helpful in certain circumstances. However, this assumption cannot be generalised without further research. Both reviews recommended that a combination of learning approaches be used.

There are several limitations of the literature summarised by these reviews. First, implementation and measurement of the effect of educational interventions are complex. Various reviews and summaries of available evidence rely on a system that is too rigid for educators to interpret meaningful conclusions that are applicable to their teaching. A summary of modern techniques like AR and VR that identifies underlying causal mechanisms and explores how they work under what conditions may be helpful. Secondly, few studies have explored the relationship between factors relevant to learning and performance in neuroanatomy, such as the relative effect of spatial ability, intrinsic motivation or anxiety on student performance. These factors may allow researchers to draw on a broader array of research to help refine where improvements in pedagogy will be beneficial. Finally, many studies are limited by sample size, or the methods they use to assess knowledge retention.

As the breadth of our scientific knowledge expands, neuroanatomy forms a smaller part of medical curricula; but retains its importance for the education of future medical professionals. Educators face the challenge of overcoming reduced teaching hours in the context of integrated, problem-based curricular changes with an ever-expanding miscellany of subject matter. The challenge also applies to students, with pressures on the depth and breadth of student knowledge growing rapidly. Advancements in neuroanatomy education are required to maintain a high standard, while making this a feasible for the student to accomplish.

An overarching aim of this thesis was to compare available neuroanatomy teaching techniques to optimise their application in education. Objectives were therefore fourfold. First, to summarise and critically analyse the literature of the status of modern techniques such as AR and VR. Second, to review the neuroanatomy education of medical students in Australia and New Zealand to assess the progress of translating current research into practice. Third, to assess factors relevant to learning neuroanatomy including spatial ability, motivation and anxiety and their respective influence on knowledge retention. Finally, to compare the most effective methods of teaching a range of neuroanatomical concepts through an intervention study.

In this thesis, a series of peer-reviewed and published papers identify the gaps between research and practical classroom teaching. This focussed collection of work explains why these gaps exist, offers practical takeaways for educators applying technology-enhanced learning methods and offers perspectives on where future research may be directed to enhance education of this vital basic science.

1.3 Research Methods and Study Design

The research proposal for the Masters was approved after an internal review on the 26th February, 2019. As research progressed and my knowledge of the topic grew, minor alterations to the original proposal were made and are discussed in the respective prefaces for chapters. Of note, a major change was to add Chapter 2: Comparative analysis of modern neuroanatomy teaching techniques: a BEME systematic review. This was in response to an observed deficit in the reviews of modern technologies such as AR and VR. These technologies appeared frequently throughout this research, and a systematic, realist synthesis review of available literature on modern pedagogies was felt to be of benefit to the intended audience.

Ethics was approved by the Human Research Ethics Committee of The University of Western Australia on 29th March, 2019 (RA/4/20/5250). Ethics approval for the project was granted for a total of five years in accordance with the requirements of the *National Statement on Ethical Conduct in Human Research* (National Statement) and the policies and procedures of The University of Western Australia. As per conditional requirements, yearly renewal applications were submitted and approved throughout my candidature.

Four studies were conducted, and a summary of the methods employed in each is below:

1. Technology Enhanced Neuroanatomy Teaching Techniques: a BEME Systematic Review of Current Evidence

An international research was formed, proposing to the BEME Collaboration to conduct a systematic review of available evidence of modern neuroanatomy teaching techniques. Electronic databases were systematically searched from January 2015 to June 2020 with keywords that included combinations of “neuroanatomy”, “technology”, “teaching” and “effectiveness”. Data was coded according to PRISMA guidelines and theorised mechanisms were discussed according to the principles of a systematic review [22]. The manuscript for this study was accepted for publication in Medical Teacher.

2. Neuroanatomy teaching in Australian and New Zealand Medical Schools

An electronically mailed survey containing 22 questions about course structure, neuroanatomy teaching, assessment and course development was sent to key academics from the 22 Australian and two New Zealand medical schools. Respondents were asked to provide information regarding the 2019 academic year. Frequency statistical analysis was required for binary, single- and multiple-selection and short-text responses. An inductive approach to thematic analysis was undertaken in this study to explore the themes identified in open-ended survey responses.

The following data was illustrated: medical schools participating in the study; average number of hours of gross neuroanatomy teaching by course length; types of resources available in neuroanatomy laboratories from most used to least used; and types of technologies utilised by neuroanatomy teachers from most used to least used.

This study was published in World Neurosurgery.

3. Role of Spatial Ability, Motivation and Anxiety in Learning Neuroanatomy

Measures of spatial ability, motivation and anxiety were compared to a student’s grade point average (GPA), weighted average mean (WAM), performance in written and practical examinations and final unit score to characterise the relationship between student factors and neuroanatomy retention.

Students’ spatial ability was assessed using the redrawn, validated Vandenberg and Kuse’s Mental Rotation Test [23]. A condensed 19-question version of the validated Motivated Strategies for Learning Questionnaire (MSLQ) [24], and 21 item Depression, Anxiety and Stress Subscale (DASS-21) [25], were used to gather data about motivation and anxiety.

The following data was illustrated: respondent demographic data; descriptive statistics and Pearson correlations of Mental Rotations Test and examination results in a neuroanatomy course; descriptive statistics, reliabilities and Pearson correlations of motivated strategies for learning questionnaire and final unit score in neuroanatomy course.

This manuscript has been accepted for publication in the Focus on Health Professional Education. This journal is published by the Australian and New Zealand Association for Health Professional Educators (ANZAHPE).

4. Comparative Analysis of Neuroanatomy Teaching Techniques: A Randomized Control Trial Affected by COVID-19

Students were randomly allocated to participate in a digital (2D and 3D digital computer-aided learning) or traditional laboratory (cadaveric and plastinated specimens). To compare knowledge acquisition and retention, participants were to complete a baseline pre-laboratory, and a four-week post-laboratory knowledge test. Originally, the trial was to be conducted over five selected laboratories. Only laboratories one, two and three were completed before in-class participation was suspended due to risk mitigation during the COVID-19 pandemic. Post-laboratory tests from laboratories one and two were conducted one-week later and analysed. Observations of student responses to the COVID-19 pandemic were collected and analysed thematically.

A table was presented for full data sets of the primary outcome, comparing pre-lab and 1-week post-lab test marks between conditions.

Data collection for the thesis occurred between March, 2019 and concluded in April, 2020. The specific research methods and study designs are described in detail in respective chapters. Data collection for our review of neuroanatomy teaching in Australia and New Zealand, and our analysis of factors relevant to learning neuroanatomy including motivation, spatial ability and anxiety was conducted in parallel. However, our intervention comparing teaching methods was conducted in series, relying on data obtained from these previous studies. Between March 2019 and September 2021, manuscripts were prepared, reviewed internally and edited before submitted for publication at relevant journals for peer review.

1.4 Thesis Structure

This thesis is presented as a series of papers, each an independent chapter, building towards an improved understanding of neuroanatomy teaching techniques and optimising their application in neuroanatomy education. The first paper is a realist synthesis and systematic review of modern methods of neuroanatomy teaching according to the review standards set by the BEME Collaboration. The second paper is a retrospective cohort study comparing the neuroanatomy education in Australian and New Zealand Medical Schools. The third paper is a prospective cohort study, analysing factors relevant to learning neuroanatomy by comparing results obtained in validated tools of anxiety, motivation and spatial ability, with respective students' examination scores. The fourth paper is a randomised-control study, a comparison of web-based versus traditional learning across a range of neuroanatomical concepts.

The four elements of this research, while complementary, were distinct in their objectives and in their research methodologies. It was felt it was most appropriate to present each as a distinct entity, and through the introduction, various prefaces, and conclusion, draw the narrative of the story together for the purposes of the thesis.

CHAPTER 2:
Technology Enhanced Neuroanatomy Teaching Techniques: a BEME Systematic Review of Current Evidence

Hamish J. Newman*[1,2], Amanda J. Meyer[1], Tim J. Wilkinson[3], Nalini Pather[4], Sandra. E. Carr[2]

[1] *Department of Anatomy, Physiology and Human Biology, School of Human Sciences, The University of Western Australia, Perth, Australia*
[2] *School of Allied Health, Health Professions Education, The University of Western Australia, Perth, Australia*
[3] *Education Unit, University of Otago, Christchurch, New Zealand*
[4] *Department of Anatomy, Faculty of Medicine and Health, University of New South Wales, Sydney, Australia*

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2.1 Preface

An addition to the original research protocol was to publish a realist, and systematic review, of the literature on modern techniques available for neuroanatomy educators. Realist syntheses analyse and interpret papers' contexts, mechanisms and outcome configurations to collectively form a programme theory. By taking context into consideration as integral for understanding the successes or failures of a method, a realist synthesis differs from systematic reviews, which considers context as a constant between papers. In the most recent reviews of teaching technologies, little was discussed about the most recent types of technology-enhanced teaching methods, including augmented or virtual reality. These technologies frequently appeared throughout the literature and offered highly realistic learning experiences supportive of complex learning and transfer. Their application in neuroanatomy teaching is of much interest to educators. A review that updates educators on the value of these recent technologies and how they have been applied to neuroanatomy teaching was required and thought to be of benefit to the intended audience.

For the purposes of this thesis, the BEME review offers a theoretical overview of modern technologies and the contexts in which they may work. The review provides possible explanations for why pedagogies work, to direct future research towards optimising their use. However, by offering ideas, they also allow the reader to challenge these and consider new theories.

BEME reviews are peer-reviewed reports of evidence related to medical and health professions education. As per guidelines, it was necessary to form a review team with specific knowledge of the area and be of an international composition of at least five members. As such, Professor Wilkinson and Professor Pather were approached, and kindly agreed to participate. A review protocol was drafted, and then peer-reviewed by an assigned BEME International Collaborating Centres (BICC) team. This protocol was accepted on 31st March, 2020 and published online: https://bemecollaboration.org/Reviews+In+Progress/Modern+Neuroanatomy+Teaching+Techniques/

The search was conducted of articles in various electronic databases between January 2015 to June 2020. A written report was produced following screening, data collection and group analysis. Following discussions between the review team and BEME Collaborative review panel, a decision was made to revise the manuscript from an attempted hybrid systematic review/realist synthesis to a more conventional systematic review. While no collective programme theory was presented, this allowed for clearer presentation of the results and explanations for why investigated techniques worked in certain circumstances could be elaborated upon for the reader’s interest. This report was submitted to BEME in May 2021, and accepted for publication in Medical Teacher in October, 2021.

2.2 Abstract

Background In response to growing curriculum pressures and reduced time dedicated to teaching anatomy, research has been conducted into developing innovative teaching techniques. This raises important questions for neuroanatomy education regarding which teaching techniques are most beneficial for knowledge acquisition and long-term retention, and how they are best implemented. This systematic review aims to provide a review of technology enhanced teaching methods available to neuroanatomy educators, particularly in knowledge acquisition and long-term retention, compared to traditional didactic techniques, and proposes reasons for why they work in some contexts. **Methods** Electronic databases were searched from January 2015 to June 2020 with keywords that included combinations of "neuroanatomy", "technology", "teaching" and "effectiveness" combined with Boolean phrases 'AND' and 'OR'. The contexts and outcomes for all studies were summarised while coding, and theories for why particular interventions worked were discussed. **Results** There were 4,287 articles identified for screening, with 13 studies included for final analysis. There were four technologies of interest: stereoscopic views of videos, stereoscopic views of images, augmented reality and virtual reality. No recommendation for a particular teaching method was made in six studies (46%) while recommendations (from weak to moderate) were made in seven studies (54%). There was weak to moderate evidence for the efficacy of stereoscopic images and augmented reality, and no difference in the use of stereoscopic videos or virtual reality compared to controls. **Conclusion** To date, technology-enhanced teaching is not inferior to teaching by conventional didactic methods. There are promising results for these methods in complex spatial anatomy and reducing cognitive load. Possible reasons for why interventions worked were described including students' engagement with the object, cognitive load theory, complex spatial relationships and the technology learning curve. Future research may build on the theorised explanations proposed here and develop and test innovative technologies that build on prior research.

PRACTICE POINTS

- Augmented reality and virtual reality and can be used in place of, or complementary to, traditional learning methods.
- Technology could be utilised where complex spatial relationships must be understood, and in advanced presentations where cognitive load must be reduced.
- To optimise teaching and learning, reduce extraneous cognitive load and learning curves required for the use of technologies.

KEY WORDS

Neuroanatomy, cranial anatomy, pedagogy, student, teaching, mixed reality, stereopsis, augmented reality, virtual reality, mobile technology, virtual assistants, learning, technology-enhanced learning

2.3 Background

Learning neuroanatomy is known to be challenging for medical students, junior doctors and many specialist doctors due to the complexity and interconnectedness of anatomical structures [13]. The difficulty in learning neuroanatomy was summarised by Jozefowicz who introduced the term 'neurophobia' in 1994 [1]. More recently, there has been a decrease in anatomy teaching hours within medical courses with associated claims of poorer knowledge of anatomy of medical students [7-9]; particularly with respect to nervous system anatomy [7]. Practically, lower levels of neuroanatomy knowledge are associated with reduced confidence of junior doctors in managing neurological conditions [26, 27], or with unsafe medical practice [7].

Traditional teaching in anatomy laboratories involves human prosected materials and plastinated specimens, models and medical imaging [6]. In efforts to improve long-term knowledge acquisition, spatial understanding and reduce neurophobia, in the context of reduced teaching hours and evolving curricula, research has also been conducted into developing innovative (largely digital) teaching strategies and techniques [2, 18]. No consensus for use of these methods exists, despite there being a core neuroanatomy curriculum, described by Moxham *et al.* (2015) [2, 6]. Without clear evidence to guide academics, the curriculum content, instruction methodology and assessment are at the discretion of individual institutions. It is therefore perhaps unsurprising that educational practice is highly variable among universities around the world [16]. This raises globally important questions in neuroanatomy education regarding which practices are most beneficial for knowledge acquisition and long-term retention, and how they are best implemented.

Two systematic reviews have been conducted into this area of research. Arantes *et al.* (2018) reviewed 29 papers that assessed the impact of using 15 methods of teaching on students' learning of neuroanatomy as a guide for curricular improvements [18]. The second, by Sotgiu *et al.* (2020), reviewed 16 papers covering eight teaching techniques in an attempt to identify the most effective method/s to teach neuroanatomy [16]. These techniques included 3D- and 2D- based computer tools, 3D physical models, tablet applications, near-peer teaching, equivalence-based instruction, face-to-face teaching, flipped classroom, inquiry-based learning and intensive modes of delivery among others. Sotgiu *et al.* recommended a combination of pedagogical resources when teaching neuroanatomy [16]. A limitation of both reviews is that the most recent types of technology-enhanced teaching methods, including augmented or virtual reality, were not included. Arantes *et al.* noted 83% of studies included were published between 2010 and 2018 and both papers illustrated this is a fast-moving area of research. The annual HORIZON Report describes emerging technologies in higher education that are likely to have an impact on teaching and learning. The 2019 report suggested four relevant technologies will have a major impact in the next five years: mobile learning, mixed reality, artificial intelligence and virtual assistants [28]. These educational tools are increasingly used in neuroanatomy education and have appeared more frequently in the literature, even since publication of these recent reviews [29-37].

The implementation and measurement of effect of educational interventions is complex. A systematic review that not only identifies and compares available teaching techniques, but through evidence synthesis raises possibilities for why they work in some contexts and not others, would form a useful guide for educators and researchers into modern practices and their application. Neither systematic review (Arantes et al., 2018; Sotgiu et al., 2020) commented on context and/or description of educational tools in sufficient detail. If neuroanatomy educators understood the context in which an educational tool was investigated (in terms of curricula alignment and learning outcomes being assessed) and/or understood the circumstances in which tools are the most effective, they are better placed to apply the research into practice.

New educational technologies offer highly realistic learning experiences supportive of complex learning and transfer, and their application in neuroanatomy teaching is interesting to educators [38]. A review that updates educators on the application of the most recent technology-enhanced teaching methods in neuroanatomy education, and offers clarification as to why they may work in some contexts over others, is required. This review may form a useful update for educators regarding these technologies and their evidence for use.

REVIEW QUESTIONS

Regarding neuroanatomy teaching methods:

- Which technology-enhanced teaching methods are available? How can they be applied?
- How do technology-enhanced teaching methods compare with traditional learning techniques? Which are associated with improved knowledge acquisition and long-term retention?
- How/why do some methods work in some contexts and not others?

2.4 Materials and Methods

The study presents a systematic review of quantitative research, undertaken according to the PRISMA checklist of systematic review sections [22]. It applied Cook's Framework for the descriptive outcomes (what was done), justification outcomes (did it work) and clarification outcomes (why or how did it work) for each study [39]. This allowed for a discussion of the context of selected papers, and a synthesis of the proposed reasons for the relationship observed between outcomes and the contexts in which technologies were investigated.

A full protocol was published by Best Evidence Medical Education (BEME) Collaboration [40].

Search strategy

Electronic databases were searched from January 2015 to June 2020 including PubMed, Medline (EBSCO), Cinahl Plus (EBSCO), Academic Search Premier (EBSCO), ProQuest Central (ERIC), EBook Central (ERIC), ERIC, Scopus, Web of Science, and SAGE. Keywords included combinations of "neuroanatomy", "technology", "teaching" and "effectiveness" combined with Boolean phrases 'AND' and 'OR' (Table 1).

In addition, authors hand searched the references of all included studies and any relevant reviews. A hand search of key journals in medical education was conducted using combinations of key search terms including: *Medical Teacher, Medical Education, Academic Medicine, Anatomical Sciences Education*. Grey literature was excluded.

A population, intervention, comparison and outcome-based strategy informed our inclusion and exclusion criteria.

Table 1. Search terms used in PubMed, Cinahl Plus, EBSCO, Scopus, Web of Science and Sage Databases.

Neuroanatomy	**AND Technology**	**AND Teaching**	**AND Effectiveness**
OR cranial anatomy OR skull base anatomy OR brain anatomy OR head anatomy OR central nervous system anatomy OR peripheral nervous system anatomy OR cranial nerves OR peripheral nerves OR spinal cord OR deep brain structures	OR technology OR mixed reality OR virtual reality OR augmented reality OR mobile technology OR virtual assistants OR artificial intelligence OR 3D OR computer-assisted instruction/methods OR computer simulation	OR learning OR education	OR instructional effectiveness OR knowledge OR retention OR memory OR understanding OR application OR enhance

Inclusion and Exclusion Criteria

Population: preference was given to those learning in health sciences contexts (e.g., medical and allied health) but studies were not excluded on this basis (e.g., veterinary sciences were included).

Intervention: advanced learning methods identified in the HORIZON report including augmented reality (AR), virtual reality (VR), mobile learning, mixed reality, artificial intelligence and virtual assistants.[41] Three-dimensional computer-based technology was excluded unless augmented by modern devices (e.g. stereoscopic 3D learning technologies).

Comparison: Any comparison of two different teaching methods. An ideal control cohort was those learning under traditional circumstances, comparisons of two technology-enhanced learning methods (e.g. stereotactic learning compared to 3D computer-based learning) were not excluded. Traditional learning was defined as didactic lectures supplemented by cadaveric- or model-based laboratories.

Outcome: Any quantitative assessment of knowledge acquisition and retention in neuroanatomy. Secondary outcomes included a description of teaching methods or analysis of other learning factors such as spatial ability.

Screening, Data collection, analysis and synthesis

A standard proforma for screening and data collection was followed. HN and AM screened all references and abstracts using Covidence software (Veritas Health Innovation, Melbourne, Australia). Disagreements were resolved by discussion (SC). A coding sheet was designed and discussed as a group, with all reviewers coding the same paper independently to ensure consistency. Each author was allocated three included papers for coding, with HN coding all papers. All conflicts were able to be resolved by discussion. Where relevant, data is presented as mean test scores, with standard deviations provided where available. P-values are extracted from relevant papers and specific statistical tests used may be found in source articles.

Papers were graded for their quality of evidence, determined by incorporating risk of bias and then critiquing the reported study design and methodology. Papers were appraised according to PRISMA guidelines, with risk of bias assessed with the Cochrane Risk of Bias tool [42]. Methodological quality was reported according to the grades outlined in Colthart et al.’s (2008) method: Grade 1 (no clear conclusions can be drawn; not significant), Grade 2 (results ambiguous, but there appears to be a trend), Grade 3 (conclusions can probably be based on the results), Grade 4 (results are clear and very likely to be true) and Grade 5 (results are equivocal) [43]. Where a recommendation was made, the strength of recommendation was made by HN informed by the strength of the quantitative findings/result (e.g. weak $r=0.10-0.39$, moderate $r=0.4-0.69$, strong $r=0.70-0.89$) [44], quality of evidence and risk of bias.

The context and outcomes for all studies were summarised while coding. HN theorised proposed reasons for why interventions worked by tabulating key results of similar papers against their methodology, identifying recurrent patterns between similar studies, proposing various reasons and discussing this synthesis with the review team. Where the authors of individual papers suggest explanations/hypotheses, explicit mention is made to differentiate their input from ours. Key terms are defined in a glossary of terms.

2.5 Results

The screening process is summarised in Figure 1, with 4,287 articles identified for screening. HN and AM demonstrated ‘moderate’ inter-rater reliability, with a Cohen’s Kappa of 0.503 [45]. The main features of included articles are summarised in Table 2. The 13 included studies are summarised in Table 3.

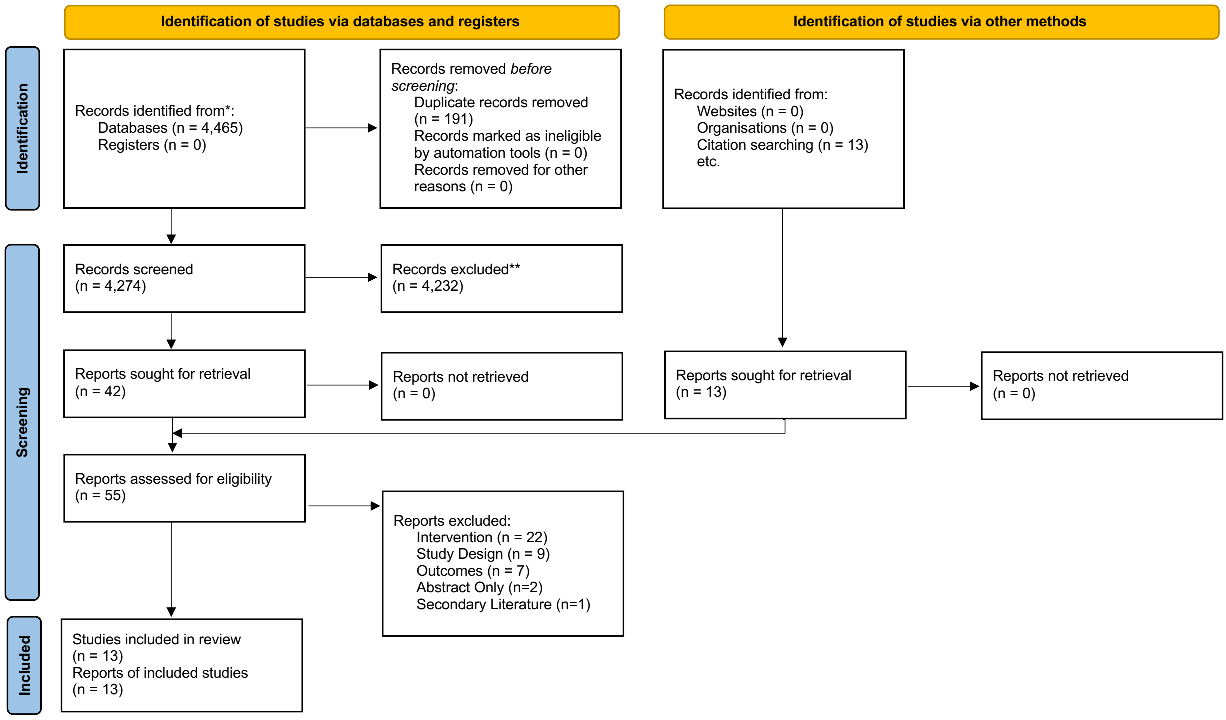
There were five papers published in the United States of America (USA), and one each in Australia, Canada, New Zealand, Brazil, the Netherlands, Turkey, Germany and France. There was a total of 1,208 students, with a mean of 93 students for each study. Medical students were the most common type of participant (n=8 articles), with biomedical students (n=1 article) and high school students (n=1 article) included. There were three studies that included students from non-specific university backgrounds. Pre-intervention knowledge tests were completed in nine studies (69%). Post-intervention knowledge tests were done immediately after the intervention in nine studies (69%), while four studies assessed retention by testing students between one- and eight-weeks after the intervention (31%). No recommendation for a particular teaching method was made in six studies (46%) while recommendations (from weak to moderate) were made in seven studies (54%). Strength of evidence and risk of bias according to Colthart et al. (2008) and the Cochrane Risk of Bias Assessment Tool are summarised in Table 3.

Table 2. Main features of manuscripts included for analysis (n=13)

Features	**Number (%)**	**Studies (#)**
Year		
2015	2 (15.38)	1, 4
2016	2 (15.38)	5, 7
2017	4 (30.77)	2, 6, 9-10
2018	2 (15.38)	11,12
2019	0 (0)	
2020	3 (23.08)	3, 8, 13
Country		
USA	5 (38.46)	2, 4, 6, 10, 12
France	1 (7.69)	3
Brazil	1 (7.69)	5
Netherlands	1 (7.69)	8
Canada	1 (7.69)	11
Germany	1 (7.69)	1
Turkey	1 (7.69)	7
Australia	1 (7.69)	9
New Zealand	1 (7.69)	13
Number of participants		
0-50	2 (15.38)	6, 8
51-100	8 (53.85)	4-5, 7, 9-13
101-150	0 (0)	
151-200	2 (15.38)	1, 3
200+	1 (7.69)	2
Type of participants		
Medical students	8 (61.54)	1, 3, 5-7, 10-11, 13
Biomedical students	1 (7.69)	8
High school students	1 (7.69)	4
Non-specified university-students	3 (23.08)	2, 9, 12
Type of teaching tool		
Stereoscopic 3D video	3 (23.08)	1-3
Stereoscopic 3D images	3 (23.08)	4-6
Augmented reality	2 (15.38)	7-8
Augmented and Virtual reality	1 (7.69)	9
Virtual reality	4 (30.77)	10-13

Figure 1. PRISMA Flow Chart of studies included for analysis

PRISMA 2020 flow diagram for new systematic reviews which included searches of databases, registers and other sources



From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71. For more information, visit: http://www.prisma-statement.org/

Stereoscopic 3D Video tools

Assessed in three studies [32, 46, 47], stereoscopic 3D video tools made no difference to overall knowledge acquisition compared to 2D videos of the same content. Stereoscopic resources were popularised for their use in neuroanatomy teaching in 2011 by Dr Albert Rhoton Jr, who designed an entire collection of images of the brain for use by neurosurgeons [48]. Stereoscopy is a technique used to give the illusion of depth, or 3-dimensions, by using stereopsis for binocular vision. Traditionally, this is done by presenting two offset images to the left and right eye independently (practically, students wear glasses that are often red- and blue-coloured, anaglyph glasses) which are then combined by our visual cortex to give the perception of 3D. In stereoscopic 3D video tools, students watch audiovisual material while wearing a stereoscopic device (glasses or otherwise) allowing them to appreciate the video in 3D.

Kockro et al. (2015) randomly allocated 169 medical students to receive a pre-recorded audio lecture accompanied by either a 2D Microsoft PowerPoint presentation or a 3D animated tour of the third ventricle with DextroBeam (Bracco Advanced Medical Technologies, Princeton, USA), a stereoscopic viewing device. On a 10-question test administered immediately after the lecture, there was no significant difference between the 2D and 3D group (5.19 vs 5.45, $p>0.05$).

Similarly, Goodarzi et al. (2017) sought to investigate the difference that visualising a video with stereopsis had on the short-term acquisition of skull-base anatomy knowledge compared to 2D. The authors compared the performance of School of Education students ($n=249$) in tests conducted immediately before and after watching a video of the anatomy of the skull base from the Rhoton Collection of the American Association of Neurologic Surgeons. Students were assigned to watch the video in 2D or 3D (stereoscopic). The 3D group performed better in both pre- and post-intervention tests. However, the magnitude of improvement between 2D and 3D groups was no different (48.7% vs 53.5%, p=0.855).

Bernard et al. (2020) also conducted a similar experiment, comparing 175 students' results on a 30-item test done immediately before, and one-month after watching a five-minute instructional video on the cerebrovascular system of the brain. Students were randomised into two groups, a 3D group (stereoscopic) and a 2D group (non-stereoscopic). Scores were similar in the fundamental knowledge test one-month after the intervention (mean 73.2% and 74.4%, p=0.37).

Participants in all studies were observers, with limited interaction with the content. This was likely done to isolate stereopsis as the variable of interest. While a legitimate teaching tool, the ability to learn from watching audio-visual material is limited by the extent to which a learner can engage with the video [49]. A problem with any video animation is the difficulty people have with the real-time perception of animated visuals and 'extraction' of the message [50]. Authors of this review hypothesised this to be due to a so called 'temporal split-attention effect' [51]. One element of this is where multiple elements of interest are displayed simultaneously, requiring the learner to distribute their attention across multiple areas. The extraneous cognitive load negatively influences learning [51]. This effect would be independent of what modality the video is viewed through and may be an explanation for why Kockro et al. (2015), Goodarzi et al. (2017) and Bernard et al. (2020) found no difference in knowledge acquisition between stereoscopic views of videos and normal 2D.

There may be other factors for why no significant differences were observed in these studies. For example, post-intervention tests may not have had the number or type of questions suitable to find a difference, increasing the risk of type II error. Power analysis of question type prior to test administration would be an important addition for future studies. Further, by selecting students with minimal or no prior neuroanatomy knowledge, the findings from both papers may not be generalised to all fields of education. Further evidence may be gathered in different populations (for example, neurosurgical residents) to validate the study findings.

One finding of interest was in Bernard et al. (2020)'s paper, the 3D group performed better in questions requiring an understanding of anatomical relationships (86.4% vs. 63.5%, $p=0.004$). It is possible that where students were able to perceive and extract the content of the videos, the stereoscopic views displayed anatomical relationships in a way that was easier to understand and facilitated students' learning. This is discussed further in reference to other technologies.

Stereoscopic 3D Image tools

Three papers assessed the value of learning 2D images with stereoscopic 3D image visualisation [33, 52, 53]. As opposed to the previous section on stereoscopic videos, students would view sequences of still images while wearing a stereoscopic viewing device, creating the illusion of 3D.

Ferdig et al. (2015) compared the results of 89 high-school students on an eight-item test immediately after a laboratory from which they were allocated to learn brain structure and function from either 2D or 3D stereoscopic images. The students in the 3D stereoscopic group scored significantly better than the control group (80% vs 73.6%, p value unknown).

De Faria et al. (2016) described the development of a library of stereoscopic images, evaluating the pedagogy by randomly allocating 84 medical students into a 2D images, 2D interactive and non-stereoscopic, and 3D interactive and stereoscopic groups. Students studied the components of the limbic system for 50-60 minutes, and then were asked to recall how many they could remember immediately after the laboratory. The interactive groups scored significantly higher than the 2D image group (6.03 ± 1.20 and 5.97 ± 1.28 vs. 4.72 ± 1.20, $p<0.05$), and the addition of a stereoscopic view of the images did not result in a significant difference in knowledge acquisition compared to 2D viewing (6.03±1.20 and 5.97±1.28, $p>0.05$).

Cui et al. (2017) randomly allocated 39 first-year medical students to learn the cerebral vasculature for 20-minutes by either 3D stereoscopic models or 2D images captured as snapshots of these models and the radiographic images from which they were built. There was a significant difference in the post-intervention test results between the 2D and 3D groups (mean= 58.3% vs. 76.19%, $p=0.003$). Further, students in the 3D learning session with a low-spatial ability measured using the Mental Rotations Test (MRT) [54], improved in their post-laboratory test to a level comparable to that demonstrated by students with high-spatial ability. This was not the same for the 2D learning group, where students with a higher spatial ability improved relatively more.

Ferdig et al. (2015) and de Faria et al. (2016) both incorporated elements of learner-content interaction in their studies to facilitate learning, while in Cui et al. (2017), participants were passive observers [55]. Specifically, Ferdig et al. (2015) allowed students to rotate through images at their own pace, while de Faria et al. (2016) had students choose the viewpoint from which they observed anatomical specimens, with or without stereopsis. Interaction is naturally a key element of learning, as without engaging with the content, learners cannot change their understanding, or perspective, or any other cognitive structure [55]. Holmberg described the 'internal didactic conversation' where learners 'talk to themselves' about the information they encounter [56]. By facilitating this internal dialogue with increased interaction, Ferdig et al. (2015) and de Faria et al. (2016) demonstrated improved learning.

There was conflicting data on how useful the addition of stereoscopy was in learning from 2D images. While Ferdig et al. (2015) and Cui et al. (2017) demonstrated improved performance in knowledge tests with stereopsis, it did not result in a significance difference in de Faria et al. (2016)'s study. It is difficult to say why this is the case. Theoretically, and as the authors of both studies propose, stereopsis would allow learners to appreciate anatomical relationships between structures better by displaying specimens in 3D [57, 58]. It is possible that virtual manipulation of the object, whether in 2D or 3D was enough for learners to appreciate these anatomical relationships sufficiently [33]. An interesting study to investigate this theory would be a comparison of an interactive 3D software that is displayed in 2D and a stereoscopic view of a 2D image. As discussed, there may be other reasons for why significant differences were not found, including the types of knowledge tests utilised by the authors and insufficient power of the studies.

Augmented Reality

Coming in many forms, augmented reality allows the user to 'augment' their view of reality with additional material, typically with projection onto a real-time visual display of the viewed subject matter. The technology requires a processor, display, sensors and input devices. Smart phones or tablets have these elements including a camera, and sensors such as accelerometer, solid state compass and global positioning systems that make them suitable AR platforms. Augmented reality was assessed specifically in two studies, with mixed results in terms of knowledge acquisition [29, 37]. A consistent finding was that AR reduced the cognitive load of students in learning neuroanatomy.

Henssen et al. (2020) investigated the performance of GreyMapp-AR (GreyMapp-AR, Radboud University, the Netherlands) compared to traditional, cross-sectional learning of general brain anatomy and subcortical structures. Medical and biomedical students (n=31) were randomly allocated into the two conditions and completed a two-hour laboratory followed by a test immediately after. Students learning by 2D images performed significantly better on test scores than students who worked with AR (21.1 vs. 23.9, $p<0.05$). However, the difference could be reversed by excluding cross-sectional anatomy questions. Further, the AR group experienced lower germane and extraneous cognitive load than the 2D group, although the sample size limited the reliability of these conclusions.

Küçük et al. (2016) investigated the use of mobile augmented reality (mAR) compared to traditional 2D presentation materials when studying the anatomy of the spinal cord tracts. Mobile AR is a sub-type of AR while the smart phone device is the platform of choice. Undergraduate medical students (n=70) had five hours of teaching on the subject. The authors randomly allocated students to study the material either with mAR, or with the 2D learning resources, before independently completing a 30-item knowledge test. There was a significant difference in test results of students who studied the anatomy with mAR compared to traditional learning resources (78.1% vs. 68.3%, $p<0.05$). Students studying with mAR reported significantly lower cognitive load than their counterparts in the control group.

The mixed results between these studies may have been due to study design and participant number. Küçük et al. (2016) showed improved performance when using mAR. In interpreting this study, and the broader literature, the authors of this paper suggest this may have been due to the application's ability to improve visualisation of abstract structures and clarify complex topics with overlayed information [59-61]. Henssen et al. (2020)'s experiment had less than half the number of participants; introduced to the GreyMapp software through a short introductory training session using a similar, but not the same, application. Compared to the relatively intuitive mAR utilised by Küçük et al. (2016), participants using GreyMapp-AR may have required a longer introduction to familiarise themselves with the technology. Across one laboratory, this may have been a significant enough hindrance in learning to affect the result.

Virtual Reality

Virtual reality was assessed in five studies [34-36, 62, 63]. Whereas augmented reality involves digital overlays onto perceptions of the real world, virtual reality replaces the real world with a simulated one. Various devices enable the user to immerse themselves in this environment, commonly with a head-mounted device and eye-tracking technology.

Moro et al. (2017) investigated the utility of both augmented and virtual reality compared to tablet-based learning. Investigators randomly allocated 59 medical, biomedical and health science students to one of the three learning modes before completing a ten-minute lesson in skull anatomy and sitting a 20-item anatomical knowledge test. There was no significant difference found in mean assessment scores between the groups. However, students in the virtual reality group experienced side effects such as headaches (25%), dizziness (40%) or blurred vision (35%).

Stepan et al. (2017) assessed the utility of a head-mounted display for learning the ventricular system and cerebral vasculature compared to online textbooks. There were 66 students randomly allocated to each learning mode, before completing a 30-minute laboratory. There was no significant difference in anatomy knowledge assessed in pre-intervention, post-intervention and 8-week retention quizzes between learning methods.

Ekstrand et al. (2018) conducted a randomized control study investigating the performance of 66 university students on a 22-item test sat before, immediately after, and one-week after studying the spatial relationships between nine neural structures for 12 minutes by either virtual reality or paper-based means. There was no significant difference between experimental and control groups for any of the testing intervals.

Wismer et al. (2018) conducted an experiment where university students studied gross brain anatomy for ten-minutes using either a plastic physical model (PM; n = 29) or models presented in virtual reality (VR; n = 32). There was no difference reported in knowledge gained between 2D and virtual reality groups in a post-laboratory knowledge test conducted immediately after the lesson. However, by using surveys of students, Wismer et al. (2020) describe learners with VR experienced less spatial workload, mental demand and frustration.

Wang et al. (2020) randomly assigned 52 medical students to three learning tools: text-only, three-dimension visualisation on a 2D screen or mixed reality. Students learned about the anatomy of the visual system for 20 minutes, and then completed a knowledge test one-month after. The mixed reality group performed worse in acquiring nominal based information, with no difference in mixed/spatial questions compared to 3D visualisation or text-only groups. However, the mixed-reality group retained information better in nominal and spatial type questions after a month.

Across the five studies investigating the utility of virtual reality, there was no advantage in using VR as an educational tool. The methodologies and results were similar enough between papers to be synthesised together. The “redundancy principle” of the cognitive theory of multimedia learning may apply to VR in this setting. The principle states that people learn better from graphics and narration than from graphics, narration and printed text (Mayer, 2009). Extraneous overload occurs when cognitive processing (the ability of a learner to understand the essential material) and extraneous cognitive processing (ability of a learner to interpret or overcome confusing layout of presented material) exceed the learner’s cognitive capacity [64]. This may be applicable to the results of studies investigating VR, where the extra information provided to the learner does not necessarily aid in understanding the content, or in its translation to memory [64].

Further explanation for lack of significant results were the required training of participants in learning to navigate a new technology, termed the ‘technology learning curve’ [65]. Familiarising themselves with VR may have taken critical time away from learning the proposed content. As VR becomes more accessible and commonplace, the extraneous cognitive processing and time required to learn how to use and understand VR may offer the learner a valuable perspective on neuroanatomical material. The adverse physical side-effects of using the VR devices such as dizziness must also be taken into consideration, especially amongst a VR-naïve group. Benefits of VR discussed by the authors were a reduction in workload, mental demand and frustration and authors found this technology more engaging, specifically due to greater immersion, clarity of the learning tool and novelty of the instrument.

2.6 Discussion

Based on the current evidence, technology-enhanced teaching is similar to learning by traditional techniques in terms of knowledge acquisition, with only weak-to-moderate evidence for the use of stereoscopic 3D images and augmented reality, and only in particular settings. Where there was a difference, technology aided most when students were required to learn anatomy with complex spatial arrangements or that were difficult to visualise in a laboratory setting.

The included studies demonstrated significant heterogeneity in terms of the teaching tool they were investigating and their methodology, with many being statistically underpowered. Studies often assessed immediate recall rather than long-term knowledge retention. Further, outcome measures of studies, being mostly knowledge tests, were also heterogeneous and difficult to evaluate for quality, with few details provided that would allow for re-producible trials.

Four explanations as to why some technology-enhanced methods were more effective than others in promoting neuroanatomy knowledge acquisition and long-term retention were synthesised. When assessing educational pedagogy, clarifying reasons why some interventions work in some contexts over others can be difficult However, by using existing theories of learning or inferring from data available to reviewers in the papers, one may be able to theorise potential explanations. The four areas are discussed in further detail below: engagement with the object; cognitive load theory; complex spatial relationships; and the technology learning curve.

Engagement with the object

A problem with any audio-visual material is the difficulty people have with the real-time perception of visuals and ‘extraction’ of the message [50]. A ‘temporal split-attention effect’ describes the phenomenon where users must split their attention between the materials, for example, an image and text, to understand the information being conveyed. This is more likely to occur where multiple elements of interest are displayed simultaneously, requiring the learner to distribute their attention. The “redundancy principle” of the cognitive theory of multimedia learning may apply here as well, where cognitive processing (the ability of a learner to understand the essential material) and extraneous cognitive processing (ability of a learner to interpret or overcome confusing layout of presented material) exceed the learner’s cognitive capacity [64]. This extraneous cognitive overload may limit learning and is discussed further below. Learning through stereoscopic views of videos and virtual reality are examples of where students may be limited by the extent to which they can cognitively comprehend and engage with material [49]. This may be an important consideration in the design of future technologies, where the intention should be to stagger the material exposure in a spatial and temporal manner.

Engagement may also be considered as the extent to which there is learner-content interaction. Between studies, this interaction varied from allowing users to select the viewpoint from which they viewed virtual anatomical specimens or choosing the order in which they viewed images of objects of interest. De Faria et al. (2016) demonstrated that learner-content interaction, independent of the learning modality (traditional vs. stereoscopic visualisation), was associated with increased neuroanatomy knowledge acquisition. A student's ability to interact with an object encourages Holmberg's 'internal didactic conversation', where learners 'talk to themselves' about the information they encounter [56]. This encourages a change from observation to understanding and perception of knowledge, thus enhances learning. The level of learner-content interaction, particularly how much a learner can choose their views of an object, is a therefore a key variable to be considered in future studies of technology-enhanced neuroanatomical resources.

Cognitive load theory

Cognitive load theory also explains why some modalities may work in some contexts over others; in particular extraneous overload, where a learner's cognitive capacity is exceeded in certain situations. The cognitive load theory states that to acquire biologically secondary knowledge, a learner must obtain novel information in small amounts compatible with the working memory's ability to process it [66]. Stereoscopic 3D video and virtual reality are good examples of where learners may experience the split-attention affect when presented with too much information simultaneously, and the extraneous cognitive load applied may have a negative influence on learning. These modalities may be better suited where less content is presented, and the novelty of the learning tools may be beneficial for engagement of the students.

Augmented reality and some select instances of virtual reality (where structure labelling was presented in a more user-friendly manner) decreased cognitive load and facilitated student learning. This difference may have been due to presentation formats. For example, in Wismer et al. (2018) the virtual reality model had labelled structures that could be toggled on and off, compared to the physical model that had numbered structures labelled on a piece of paper. The extra mental step in connecting numbered labels to structure identifiers may have explained the difference in spatial workload, mental demand and frustration experienced by students in the physical model group. Similarly, augmented reality allows information to be virtually overlayed onto the object, decreasing the time and mental workload involved in matching information presented in a laboratory textbook and the specimen. Augmented reality, in terms of ease of access to smart phone technology and ease of user interface, may serve as the ideal intermediate.

Complex spatial relationships

Three-dimensional stereoscopic videos were no more advantageous in neuroanatomy knowledge acquisition than viewing in 2D. However, there seemed to be marginally more evidence for the efficacy of learning by 3D stereoscopic images than 2D. A unifying theme is that stereoscopy is most effective compared to learning by 2D images when teaching students complex spatial anatomy. That is, a 3D representation of images is most useful when anatomical relationships are difficult to conceptualise, such as deep-brain structures or C-shaped features of the brain including the cingulum, corpus callosum, fornix, lateral ventricles and caudate nucleus. There may be additional benefit to those students with a low-spatial ability, and may also be used in identifying small structures, or those with complex relationships where the learner may have difficulty viewing during routine anatomy laboratories, such as the middle and inner ear anatomy of the temporal bone [53]. A possible explanation for the limited role of stereoscopic versus 2D views of videos is that in a video, students have a chance to appreciate complex anatomical relationships while the subject matter moves through various view-points. A stereoscopic view may not offer the student any additional information compared to 2D. A useful study may be the comparison of 2D video of a 3D anatomical feature, and a 3D stereoscopic image of that feature. Similarly, comparison of an interactive 3D software that is displayed in 2D compared to stereoscopic view of a 2D image would rely on similar theoretical principles, with the added variable of interaction. Equivocal results may be supportive of this hypothesis.

The benefit of technology-enhanced teaching in understanding complex spatial anatomy was also true in selective studies that investigated AR or VR, particularly where spatial question types were investigated separately. AR facilitated the learning of spinal cord pathways in one paper [29], but resulted in poorer knowledge acquisition, especially in cross-sectional anatomy, in the other [37]. The study methodology, in particular the training needed by participants in how to use the technology, may have resulted in differences in the findings as discussed. In one study, a group learning by mixed reality retained information better in nominal- and spatial-type questions after a month [63]. Similar to the findings of stereoscopic and augmented reality technologies, there may be an advantage in virtual reality allowing the user to understand complex spatial relationships more easily than 2D presentations. Other studies have investigated alternative pedagogies such as play-doh or printed models that improve understanding of spatial relationships effectively, and may be a cheaper alternative [20, 67].

It is possible that novelty of the technology encouraged students to study more, and the measurable differences in knowledge acquisition can be attributed to it requiring 'work' on the part of the student, rather than the technology itself. However, it is difficult to quantify this relative affect. While not inferior, the expense of virtual reality technologies may be prohibitive for many institutions to roll-out this teaching method broadly. Finally, an important consideration was that VR made some students physically ill, a side-effect that will have to be further investigated and minimised in future iterations for duty of care.

Technology learning curve

A limitation across many mixed reality studies was the time required to teach students how to use the teaching method. This may have resulted in student performance being spuriously low in experimental groups due to differences in familiarity with the learning tool. While a mixture of pedagogical techniques is theorised to be the best method of teaching neuroanatomy [16], incorporating too many novel techniques may overwhelm students, who spend as much time learning how to use the tools as they do learning content. This may change as novel techniques become more mainstream, and technology literacy grows.

Limitations

While some papers specify the number of assessment items and question-types, most studies did not provide the test itself making evaluation of outcomes difficult to evaluate for quality. Further, the methodology behind the test administration was often flawed, as the post-intervention tests were done immediately following the intervention. The results of these studies therefore give a measure of short-term memory, as opposed to knowledge acquisition and retention. Tests conducted one-week after the experiment or longer give a more robust assessment of learning. One feature that papers do not comment on is the social aspect of learning, and the relative collaborative/cooperative characteristics of novel technologies. Future studies may comment on these elements and their impact on learning.

This review included analysis of only 13 studies. As such, it presents a focused review of the most recent technology-enhanced learning methods. Two authors' screening search items demonstrated moderate inter-rater reliability, raising the possibility of missed papers, and may be due to a 10-year difference in experience levels. New studies into technology-enhanced teaching continue to be added so it may be relevant to establish a running commentary in a public forum. However, the intention is to update this review in three years for a systematic appraisal of new evidence, as per the original protocol.

In this study, technological interventions are considered equal, and the quality and learner experience of the individual interventions is not examined. As such, the degree to which learners a learner's experience is affected by using a difficult, not-fully developed technology as opposed to a well-established, traditional methodology Is not appreciated.

2.7 Conclusion

To date, technology-enhanced teaching methods are not inferior to conventional didactic methods, although their efficacy in learning neuroanatomy may not be as ground-breaking as one would originally have hoped. So far, there is only weak-to-moderate evidence for the use of stereoscopic 3D images and augmented reality, and only in particular settings. Limited engagement with content due to extraneous cognitive overload, and technology learning curves associated with new technologies are amongst the possible reasons for why these technologies are not performing as expected. However, there are promising results for technology-enhanced teaching in complex spatial anatomy and reducing cognitive load in some instances. Future research may validate the theorised reasons proposed in this review and develop and test innovative technologies that build on prior research.

Table 3. Summary of included studies.

#	Reference	Title	Country	Participants	Study design; Technology (control vs experimental)	Method	Outcome	Conclusion	Strength of evidence (Risk of bias)	Limitations
1	Kockro et al. 2015	Stereoscopic neuroanatomy lectures using a three-dimensional virtual reality environment	Germany	169 (second year medical students, University of Mainz)	RCT; 2D lecture vs Stereoscopic 3D video	10-multiple choice question anatomy test immediately after 20-minute laboratory	No difference was reported in knowledge between 2D and 3D stereoscopic groups	No recommendation for either	3 (medium)	Test of short-term memory Too few test items
2	Goodarzi et al. 2017	Effect of Stereoscopic Anaglyphic 3-Dimensional Video Didactics on Learning Neuroanatomy	USA	249 (school of education students, University of California)	Case control study; Online 2D video vs Stereoscopic 3D video	Anatomy tests (details unknown) immediately before and immediately after one-hour laboratory	No difference was reported in knowledge gained between 2D and 3D stereoscopic groups	No recommendation for either	2 (low)	Test of short-term memory
3	Bernard et al. 2020	Does 3D stereoscopy support anatomical education?	France	190 (second year medical students, University of Angers)	RCT; Online 2D video vs Stereoscopic 3D video	30-mixed question type anatomy tests immediately before and one-month after 5-minute laboratory	No difference was reported in knowledge gained between 2D and 3D stereoscopic groups. Stereoscopic group performed better in questions relating to anatomical relationship	Weak recommendation for stereoscopic 3D in anatomical relationship knowledge acquisition and retention	4 (medium)	
4	Ferdig et al. 2015	Using stereoscopy to teach complex biological concepts	USA	89 (high school students)	Mixed, randomised; 2D images vs Stereoscopic 3D	8-multiple choice question anatomy test immediately after laboratory	Stereoscopic 3D group scored significantly better than the classmates learning traditionally	Moderate recommendation for stereoscopic 3D in knowledge acquisition	2 (low)	Test of short-term memory Too few test items

5	de Faria et al. 2016	Virtual and stereoscopic anatomy: when virtual reality meets medical education	Brazil	84 (graduate medical students, University of São Paulo)	RCT; Lecture vs 3D Computer-Based vs Stereoscopic 3D	1- short answer (10-part) anatomy test immediately before and repeated immediately after one-hour laboratory	3D-Computer Based and Stereoscopic 3D groups both performed equally, and better than lecture only	Weak recommendation for stereoscopic 3D and 3D computer based in knowledge acquisition over lecture only	3 (medium)	Test of short-term memory Too few test items
6	Cui et al. 2017	Evaluation of the Effectiveness of 3D Vascular Stereoscopic Models in Anatomy Instruction for First Year Medical Students	USA	39 (first year medical students, University of Mississippi Medical Center)	RCT; 2D images vs Stereoscopic 3D	15-question anatomy tests immediately before and after 20-minute laboratory	Stereoscopic 3D group scored significantly better than the 2D learning group	Strong recommendation for stereoscopic 3D in knowledge acquisition, particularly for students with low spatial ability	4 (medium)	
7	Küçük et al. 2016	Learning anatomy via mobile augmented reality: Effects on achievement and cognitive load	Turkey	70 (second year medical students, Ataturk University)	Mixed, randomised; Textbook vs Augmented Reality	30-multiple choice question anatomy test immediately after a three-hour laboratory	Mixed augmented reality group had higher anatomy test scores and lower cogntiive scores compared to the control	Moderate recommendation for AR in knowledge acquisition and cognitive load	4 (medium)	Test of short-term memory
8	Dylan et al. 2020	Neuroanatomy Learning: Augmented Reality vs. Cross-Sections	Netherlands	31 (first year biomedicine students, Radboud University)	RCT; 2D images vs Augmented Reality	25-mixed question type anatomy tests immediately before and after two-hour laboratory	Students in the control group (2D learning only) performed significantly better in the post-laboratory test than the AR group	Moderate recommendation for traditional learning in knowledge acquisition	3 (medium)	Test of short-term memory
9	Moro et al. 2017	The Effectiveness of Virtual and Augmented Reality in Health Sciences and Medical Anatomy	Australia	59 (medical, biomedical and health sciences students, Bond University)	RCT; Tablet vs Augmented Reality vs Virtual Reality	20-, multiple choice question anatomy test immediately after 10-minute laboratory	No difference was reported between tablet-based, augmented reality or virtual reality groups	No recommendation for any particular method	3 (medium)	Test of short-term memory Too few test items Limited laboratory time

10	Stepan et al. 2017	Immersive virtual reality as a teaching tool for neuroanatomy	USA	66 (first and second year medical students, Icahn School of Medicine)	RCT; Online textbook vs Virtual Reality	10-, 25-, 15-mixed question type anatomy tests immediately before, immediately after and 8-weeks after a 30-minute laboratory	No difference was reported between traditional learning or virtual reality groups (0.75±0.16 vs 0.76±0.14, p=0.95)	No recommendation for either	3 (medium)	
11	Ekstrand et al. 2018	Immersive and interactive virtual reality to improve learning and retention of neuroanatomy in medical students: a randomized controlled study	Canada	64 (first and second year medical students, University of Saskatchewan)	RCT; 2D images vs Virtual Reality	22-multiple choice question anatomy tests immediately before, after and seven days after a 12-minute laboratory	No difference was reported in knowledge gained between 2D and virtual reality groups	No recommendation for either	4 (medium)	Limited laboratory time
12	Wismer et al. 2018	A Workload Comparison During Anatomical Training with a Physical or Virtual Model	USA	61 (university students, University of Central Florida)	Case control study; Physical models vs Virtual Reality	25-mixed question type anatomy tests immediately before and after 10-minute laboratory	No difference was reported in knowledge gained between 2D and virtual reality groups	No recommendation for either	4 (medium)	Test of short-term memory
13	Wang et al. 2020	A Randomised Control Trial and Comparative Analysis of Multi-Dimensional Learning Tools in Anatomy	New Zealand	52 (second year medical students, University of Otago)	RCT; Textbook vs 3D Computer-Based vs Virtual Reality	18-short answer question anatomy tests before and one-month after laboratory	Mixed reality performs worse in acquiring nominal based information, with no difference in mixed/spatial questions compared to 3DM or text-only. However, MR group retained information better in nominal and spatial type questions after a month	Weak recommendation for MR in long-term retention of neuroanatomy	4 (medium)	

CHAPTER 3:
Neuroanatomy teaching in Australian and New Zealand Medical Schools

Hamish J. Newman* [1,2], Amanda J. Meyer[1], Sandra E. Carr[2]

[1] School of Human Sciences, The University of Western Australia, Perth, Western Australia; and
[2] School of Allied Health, Health Professions Education, The University of Western Australia, Perth, Western Australia

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3.1 Preface

In 2010, Craig et al. performed a study on anatomy teaching in Australia and New Zealand, demonstrating considerable heterogeneity in the content, delivery and assessment of anatomy in medical schools. To understand how research being conducted into neuroanatomy teaching techniques was being translated into practise, a review of teaching in universities was required. While heterogeneity was expected, the degree to which was unknown, and the perspective it may offer researchers looking to improve neuroanatomy education and how it could direct future research were tangible justifications to run a dedicated study.

The BEME review offered readers a perspective on why teaching technologies worked, thereby directing research into developing ways to optimise their development and application. By contrast, the review of neuroanatomy teaching in Australian and New Zealand medical schools offers the perspective of what teaching strategies are employed currently, and how this differs to the results of available literature. The results allow one to consider the logistical issues in adopting new techniques into neuroanatomy education.

The review of Neuroanatomy teaching in Australian and New Zealand Medical Schools was conducted between March 2020, and accepted for publication in World Neurosurgery in February, 2021. The study was endorsed by the Royal Australasian College of Surgeons prior to data collection and included 22 out of 24 Australian and New Zealand medical schools. Results have been presented in poster format at the Australia and New Zealand Association of Clinical Anatomists Annual Meeting in December 2019, and at the Neurosurgical Society of Australia Annual Scientific Meeting in September 2021 (Appendix D).

3.2 Abstract

Background. Graduate doctors' knowledge of central and peripheral nervous system anatomy is below an acceptable level. New technologies have been introduced to enhance education in the context of integrated curricula and reduced anatomy teaching hours in medical schools. However, it is unknown how varied this instruction has become between universities. This mixed methods study aimed to describe neuroanatomy teaching in medicine across Australian and New Zealand. **Methods.** An electronic survey was sent to Australian (n=22) and New Zealand (n=2) medical schools, endorsed by the Royal Australasian College of Surgeons. Academics were asked to comment on the course, content, instruction and assessment of neuroanatomy for the 2019 academic year. **Results.** Ninety-two percent (22/24) of medical schools responded. Neuroanatomy content and instructional methodology was highly variable between institutions. The average time dedicated to teaching neuroanatomy was 46.0 hours (±38.1) with a range of 12 hours to 160 hours. Prosections (77%) and models (77%) were used at most universities. Dissection was utilised at 13/22 (59%) universities. Incorporation of new technologies was highly variable, the most common being 3D software (59%) and eBook (55%). Adoption of any virtual reality technologies was low (36%). Seven universities used an established curriculum (29%), while most did not (61%). Academics indicated anxiety and student motivation were key elements of student engagement. **Conclusion.** Results demonstrate widespread heterogeneity in the way neuroanatomy is taught to medical students. A standardized curriculum may improve collaboration between universities and facilitate translation of future research in the area into practise.

3.3 Background

Studies conducted in the early-to-mid 2000s brought attention to reduced anatomy knowledge of medical graduates in the context of integrated, problem-based curricular changes; particularly in central and peripheral nervous system anatomy [7-9]. Practically, lower levels of neuroanatomy knowledge are associated with poor confidence of junior doctors in managing neurological conditions [26, 27] and unsafe medical practice [7].

In efforts to improve knowledge acquisition and long-term knowledge retention, research has been conducted into developing innovative (largely digital) teaching strategies and techniques [2, 18]. Multimedia resources and 3-Dimensional (3D) digital representations of neuroanatomy are becoming commonplace [18]. Virtual (VR) and augmented (AR) reality are amongst newer technologies now available for teaching [19, 68]. Anatomage Tables® (Anatomage, San Francisco) are virtual dissection, 3D anatomy visualization systems that have been introduced into medical schools [17]. Sectra Tables® (Mentone Educational Center, Australia) are based on a similar design, with ergonomic touch screen displays allowing access to a specialist educational portal. No national curriculum for use of these tools exists, despite there being a core neuroanatomy curriculum published by Moxham et al. (2015).

Neuroanatomy teaching of medical students must be optimised in the context of integrated curricular changes and reduced time dedicated to teaching anatomy. The challenge in learning neuroanatomy goes beyond neuroanatomical knowledge acquisition; a major effect being the negative influence on the choice of neurosurgery or neurology as a career path in medicine [14, 69]. Because instruction of this important basic science is left up to the discretion of individual institutions, it is currently unknown how this is being done. The rationale for this study is to characterize neuroanatomy instruction to provide the basis for more informed discussion and future research into improving educational systems surrounding neuroanatomy. If researchers are aware of the constraints within which neuroanatomy educators are working, developing technologies can be tailored to the needs of the end-user. Further, other educational institutions may be able to learn from the experiences of Australian and New Zealand medical schools. Internationalization of medical education through collaboration has been identified as an important part of medical education [70]. To do so, this study aimed to describe the content, instruction and assessment of neuroanatomy in Australia and New Zealand medical schools.

3.4 Methods

This descriptive, mixed methods study was approved by the Human Research Ethics Committee of The University of Western Australia (RA/4/20/5250) and endorsed by the Royal Australasian College of Surgeons. An electronically mailed survey containing 22 questions about course structure, neuroanatomy teaching, assessment and course development was sent to a key academic from the 22 Australian and two New Zealand medical schools (Supplementary Material Appendix A). The survey consisted of a combination of questions requiring binary (yes/no) responses (n=7), single-selection multiple choice (n=3), multiple-selection multiple choice (n=6), short-text responses (n=3), open-ended responses (n=2) and a response on a ten-point Likert scale (n=1). Respondents were asked to provide information regarding the 2019 academic year.

The SPICES model summarizes the six educational strategies relevant to the curriculum in a medical school. Each issue can be represented as a spectrum or continuum: student-centred/teacher-centred, problem-based/information-gathering, integrated/discipline-based, community-based/hospital-based, elective/uniform and systematic/apprenticeship-based [71]. To better characterise whether neuroanatomy teaching in medical schools is related to the educational strategy employed by the institution, participants were asked to characterize where their university sits for each issue by using a sliding 1-10 scale.

Analysis

Survey data was collected using Qualtrics (Provo, Utah, USA). Frequency statistical analysis was required for binary, single- and multiple-selection and short-text responses and was conducted in Microsoft Excel (Version 16.39, 2020). No means testing between universities was necessary. An inductive approach to thematic analysis based on the phases described by Braun and Clarke (2013) was undertaken in this study to explore the open-ended survey responses' emerging themes [72]. Quantitative data was reviewed by all authors. Patterns of responses were observed and recurring comments became ‘codes’. Themes were produced after codes were diagrammed to visualise various relationships. These themes were then triangulated between authors and finalised by consensus.

3.5 Results

QUANTITATIVE FINDINGS

There was a total of 22/24 (91.7%) responses from medical schools across Australia (n=20) and New Zealand (n=2) shown in Table 4. There were 21 medical schools that submitted a single response, while one medical school, requiring information from two colleagues, submitted two surveys with responses compiled by the first author.

Table 4. Respondent Universities

Country	University	
Australia	Australia National University Deakin University Flinders University Griffith University James Cook University Macquarie University Melbourne University Monash University The University of Newcastle Undisclosed	University of Adelaide University of New England University of New South Wales University of Notre Dame Sydney University of Queensland University of Sydney University of Tasmania University of Western Australia University of Wollongong
New Zealand	University of Otago Auckland University	

Course Structure

Ten universities (45.4%) had post-graduate (PG) medical schools. Six universities (27.3%) had undergraduate courses (UG) and six universities (27.3%) had combined UG and PG courses. Eleven universities (50%) had four-year courses, five universities had five-year courses (22.7%), and five universities had six-year courses (22.7%), shown in Table 5. One university with combined PG and UG entry had both a four- and five-year course respectively. This university was classified as a four-year course in this study based on the greater proportion of students enrolled. Eleven universities had problem-based courses (54.5%), seven courses had integrated curricula (31.8%), three universities had systems-based courses (13.6%). Mean values ± SD for the SPICES model continuums are illustrated in Figure 2, which provide a cross-sectional snapshot of educational strategies employed by Australian and New Zealand medical schools. Analysis using the SPICES model reflects that half of the Australian medical schools are using student-centred learning, integrated and core or standard approaches to including neuroanatomy in the curriculum. Less than half are applying problem-based approaches, and most are teaching neuroanatomy in a hospital-based environment.

Table 5. Average number of neuroanatomy specific teaching hours by course length (±SD) (*min-max)*

Course Length	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
4-Year Course (n=12)	11.3±10.1 *(1-40)*	24.9±17.5 *(2-50)*	12.5±13.4 *(3-120)*	1.5±0 *(1.5-1.5)*	NA	NA
5-year Course (n=5)	3.8±2.2 *(1-6)*	22.0±2.7 *(20-25)*	17±17 *(5-29)*	0	5±10 *(5-5)*	NA
6-year Course (n=5)	19.8±9.2 *(12-30)*	33.8±25.8 *(10-70)*	43.3±51.9 *(10-120)*	20±14.1 *(10-30)*	10±0 *(10-10)*	0
All Courses (n=22)	11.5±10.0 (1-40)	26.44±17.77 (2-70)	29.0±38.2 (3-120)	13.8±14.6 (1.5-30)	8.3±2.9 (5-10)	0

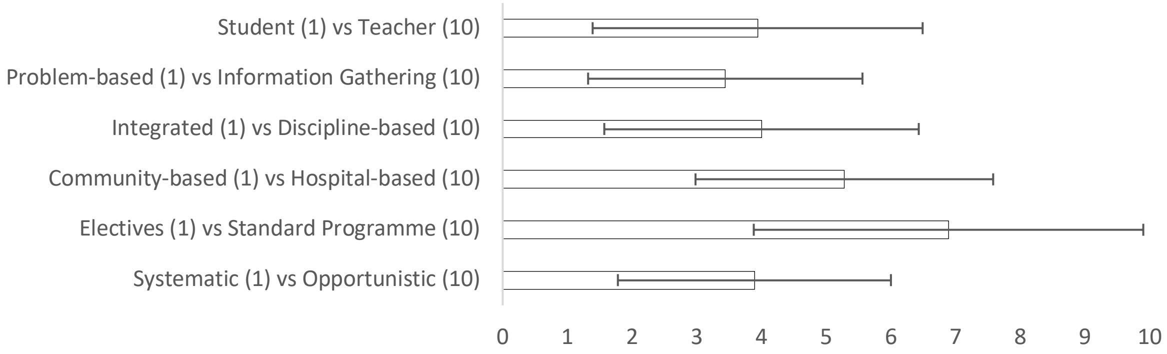

Figure 2. Diagrammatic representation of SPICES Model Continuum scores illustrated as mean ± SD. Participants were asked to characterize their university according to the SPICES model on a ten-point Likert scale item.

Teaching Methods

Cadaveric anatomy laboratories and lectures were utilised by 100% of respondent universities. Neuroanatomy-specific cadaveric labs were offered to first- and/or second-year medical students in 86% of universities, and in third-year or later in 32%. Plastic anatomical model or plastinate laboratories ('dry labs') were offered to first- and/or second-years in 55% of universities, and third-year or more in 27%. Lectures were offered to first- and/or second-years in 82% of universities, and third-year or later in 45%. The types of resources used in these labs and how frequently are indicated in Table 6. Sixteen universities (73%) responded saying they used technology to enhance laboratories including use of virtual and augmented reality (25%), Sectra Table® (13%), Anatomage Table® (8%), 3D prints and tablet software applications such as Visible Body® (4%). Specific applications were not specified by other respondents. Frequency of use of particular tools is summarized in Table 7.

Table 6. Types of resources available in neuroanatomy laboratories from most used to least used.

Resource type	Every	Most	Some	Rarely	Never
Prosections	45% (10)	32% (7)	23% (5)	0% (0)	0% (0)
Radiologic images	23% (5)	36% (8)	36% (8)	5% (1)	0% (0)
Models	59% (13)	18% (4)	18% (4)	0% (0)	5% (1)
Computer models	23% (5)	27% (6)	32% (7)	9% (2)	9% (2)
Plastinated specimens	23% (5)	14% (3)	18% (4)	5% (1)	41% (9)
Dissection	0% (0)	14% (3)	18% (4)	27% (7)	41% (8)

Table 7. Types of technologies utilised by neuroanatomy teachers from most used to least used.

Resource type	Every	Most	Some	Rarely	Never
3D Software	14% (3)	14% (3)	18% (4)	14% (3)	41% (9)
eBook	9% (2)	18% (4)	27% (6)	0% (0)	45% (10)
Tablets	9% (2)	23% (5)	5% (1)	14% (3)	50% (11)

Virtual Reality	0% (0)	0% (0)	23% (5)	14% (3)	64% (14)
Virtual Dissection	9% (2)	9% (2)	5% (1)	5% (1)	73% (16)
HoloLens	0% (0)	0% (0)	9% (2)	5% (1)	86% (19)
Haptic	0% (0)	0% (0)	5% (1)	9% (2)	86% (19)

Dissection was offered in 14 respondent universities (64%); as an elective course (n=6), prescribed course (n=6) or not specified (n=2). Courses varied in how this was delivered as either teacher-directed dissection (n=4), text-directed (n=5) or not specified (n=5). Specific dissection topics of four courses were peripheral nervous system dissection (n=1), animal dissection in comparative neuroanatomy (n=1), lateral to medial dissections of brainstem (n=1) and cranial nerves dissection (n=1).

Twelve universities (55%) indicated that they adapted the teaching methodology to suit neuroanatomical content. Incorporating clinical images (n=4), emphasising 3D relationships (n=3), drawing (n=2), adapting combinations of wet and dry labs (n=1), emphasising theoretical models (n=1), interactive displays (n=1) and e-cases (n=1) were methods of adaption specified by respondent academics.

Neuroanatomy teaching time

The mean time dedicated to teaching neuroanatomy was 46.0 hours (±38.1). Most (n=19) medical schools scaffold the teaching of their neuroanatomy over the duration of the course by teaching neuroanatomy in more than one year. Nineteen universities taught neuroanatomy in first year, seventeen in second year, eight in third year, three in fourth year and three in fifth year. The time (±SD) dedicated to neuroanatomy teaching by course length is illustrated in Table 5. Six-year courses had the highest number of teaching hours dedicated to neuroanatomy (89.4) followed by four-year courses (33.3) and five-year courses (30). Twenty medical schools taught less than 65 hours of neuroanatomy, and two universities taught 145 hours or more. Universities utilising a systems-based approach had the greatest time dedicated to teaching neuroanatomy at 63 hours on average (±71), followed by problems-based courses (36 hours ±13) and integrated curricular (29 hours ±7).

In terms of the time of different teaching methods, cadaveric labs were on average 117 minutes, dry labs 107 minutes and lectures 72 minutes. The number of hours involved in cadaveric dissection was not specified.

Curriculum

Seven universities indicated they were using a set curriculum to guide neuroanatomical content delivered to their medical students, three of which were university-specific and four did not specify which curriculum had been set. Twenty universities (91%) indicated neuroanatomy teaching had changed significantly in the last five years, with content refined/condensed (n=6), greater use of imaging (n=5), more practical assessment (n=2), online content (n=2) and reduced time available (n=2) examples identified by academics. Seventeen universities (77%) indicated they evaluated their teaching, mostly through student evaluation surveys and evaluation of assessment results.

Seventeen universities (77%) integrated neuroanatomy teaching with other subjects, predominantly within clinical skills teaching sessions (n=9) and case-based learning curriculums (n=5). Others (n=2) indicated they transition from foundations of embryology, gross anatomy and histology for junior years to application in clinical scenarios, testing and imaging for more senior medical students.

Assessment

Twenty-one universities (95%) used some form of summative assessment to assess levels of neuroanatomy knowledge. Formative assessment of neuroanatomy was utilised by 19 universities (86%). Types of assessment include multiple choice questions (91%), short answer questions (64%), practical SAQ (55%), extended-matching questions (41%), practical MCQ (41%) and practical oral (18%).

QUALITATIVE FINDINGS

A thematic analysis of the open-ended responses from the respondents concerning overall students' engagement revealed three central themes: motivation for learning, anxiety about neuroanatomy and applied techniques for improved engagement. These themes and relevant codes are illustrated in Figure 3 and summarised with textual citations from survey responses in Table 8.

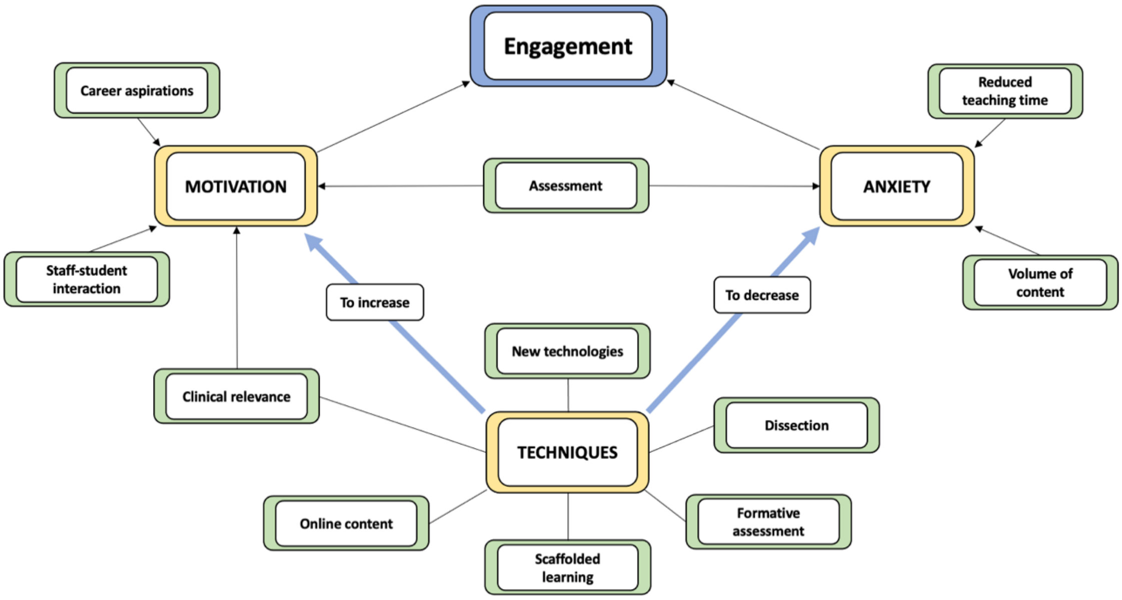

Figure 3. Thematic map of qualitative themes extracted from open-ended responses. Academics were asked to comment on facilitators, challenges and opportunities in student engagement (in blue, large font) in neuroanatomy education. The diagram should be read from the bottom to the top. Yellow boxes (medium font) were the key themes relating to how educators sought increased engagement of their students. 'Techniques' used by educators are able to do so by increasing or decreasing motivation/anxiety of students respectively (blue lines). Green boxes (small font) are 'codes', recurring comments made by the respondents that relate to each of the three themes. Each have a connection to a relevant theme denoted by the black lines.

Table 8. Thematic analysis of qualitative survey responses.

Theme	Code	Citations
Motivation for learning	Assessment	*"Main motivation as always is passing the exam..."* University 4
		"Their motivation varies but assessment is a (too) larger driver." University 7
	Staff-student interactions	*"Student engagement and student motivation is high overall. Highly skilled and enthusiastic staff, high levels of staff-student interactions, pre-lab preparation materials make labs high value and high yield." University 5*
	Clinical relevance	*"… students are very well engaged and extremely interested about the neuroanatomy program. The strong clinical focus of the program is the main driving force." University 13*
		"Student's strategies, their learning and their engagement is dependent on the assumed clinical relevance of the material. Delivering the material with an emphasis on the clinical links is a good motivator." University 16
Anxiety	Difficulty	*"Students find neuroanatomy extremely overwhelming… The way we have attempted to reduce student anxiety is to teach neuroanatomy for 4 weeks…" University 6*
	Motivator for improving teaching	*"Most students are intimidated by neuroanatomy. We worked hard to make it easier to comprehend and digest, then provide clear pathways to applying it in a context suitable for a junior, general clinician, not a specialist." University 17*
Driving for improved engagement	Scaffolding learning	*"… we are building content in a spiral, with basic concepts presented in first year being expanded upon and enriched in future years of the program." University 15*
	Clinical relevance	*"Delivering the material with an emphasis on the clinical links is a good motivator." University 16*
		"We have tried to make our teaching more clinically relevant, provide hands-on dissection experience, use e-cases to assist their learning…." University 2
	Technology	*The use of technology has not necessarily increased engagement, some students are still more comfortable with 'traditional' teaching approaches"* University 1
		"I'd say two of the major challenges are the consistency of teaching delivery and resource access when students reach clinical years (and so this content is delivered by different facilitators and in different locations across the cohort). Not sure what we can do to improve this - although an incorporation of teaching technologies has helped to minimise some of this." University 12
	Demonstrator experience	*"…high-quality demonstrators with clinical experience adding to subjectively interesting and relevant material, challenging but not overwhelming amount of content each week (hopefully)…" University 18*

Motivation for Learning

There was a range of responses identifying the perceived level of motivation for learning neuroanatomy and the relative impact on engagement, as well as specific internal or external factors motivating learning. Assessment was a key motivating factor identified by respondents, others identified that student motivation was influenced by the student-teacher interactions and clinical focus of the course. Career aspirations of students in areas such as neurology or neurosurgery were also seen as motivating factors.

Anxiety about neuroanatomy

Anxiety about neuroanatomy was a key factor related to engagement of students identified by academics, citing subject difficulty as a major precipitating factor. Other factors that have contributed according to academics has been reduced teaching time, and increased volume of content required to teach. These experiences amongst educators have been a motivating factor to try alternative strategies to reduce anxiety and increase engagement.

Driving for improved engagement

Academics discussed techniques used to increase engagement either directly, or by increasing motivation or reducing anxiety. Scaffolding learning by introducing the content in the first year; then revisiting material and expecting students to apply knowledge into clinical examples in subsequent years was identified as a method to reduce anxiety. Respondents wrote about enhancing the clinical relevance to improve engagement. Using interactive teaching techniques such as online quizzes/continuous assessment so that students could monitor their own progress was identified as a strategy to improve engagement with the content. However, not all respondent academics agreed that technology definitively increased engagement. The quality of the demonstrators' or teachers' teaching was also identified as a key area for improving engagement and reducing anxiety.

3.6 Discussion

This is the first review of neuroanatomy education in Australian and New Zealand Medical Schools. An overall impression of these results is the demonstration of heterogeneity between medical schools in the content, delivery, assessment and development of neuroanatomy teaching, with variable uptake of evidence-based methods. It is reflective of the current climate in which teaching of basic sciences, without an established curriculum guiding content or delivery, is left to the discretion of the academic. Since the 1990s, the curricular paradigm in the basic sciences teaching for medical students has undergone significant change. The shift towards integrated, inter-disciplinary curricula is evident in the results of this study and is reflected in the variable methodology employed by academics to teach neuroanatomy.

Neuroanatomy teaching hours for medical students are highly variable between institutions, ranging from 12 to 160 hours. The mean time dedicated to neuroanatomy teaching in Australia and New Zealand is 42.5% less than that of US institutions' mean time of 80 hours [5, 73]. A high degree of variability was reported by McBride and Drake in this population also, as institutions reported a range of 4 to 200 hours. Based on the significant variability in these hours, there may be insufficient quantity of neuroanatomy education in some institutions. However, the authors recognize the difficulty in quantifying an ideal amount of neuroanatomy teaching for a medical degree. The analysis of hours by SPICES model responses also confirms the historical trend of decreasing hours in the context of integrated, problem-based curricular changes. That is, universities that utilise a predominantly problem-based model had the least neuroanatomy-specific teaching compared to systems-based approaches.

Learning strategies based on superficial learning are likely to increase neurophobia and reduce student performance in neuroanatomy [16]. There are educational and assessment methods that promote superficial learning and rote learning such as use of MCQs and didactic lectures present in every respondent university medical school, sometimes exclusively. This is an understandable finding, as universities must balance cost, time limitations, curriculum pressures, staffing and other factors while also trying to optimize teaching strategies [17]. However, it is also sub-optimal; as universities should be encouraging deep learning approaches that enhance interest in the subject area [13].

This is not to say didactic methodologies cannot be used at all. Generations of successful health care professionals learned their anatomy by these techniques. However, as techniques in health care have advanced, so too must educational methodologies. The difficulty with a didactic model is as follows. First, the reduced number of lecture slots in medical schools dedicated to anatomy is insufficient to transfer important anatomical principles and concepts necessary for students to gain a full appreciation of form and function. As a result, students may “learn” anatomy by rote-learning rather than with a sound under-pinning of principles to understand anatomy [8]. Second, there is minimal time for students to handle anatomical specimens. In student-led environments, the experience they do get is often on the content they know best and are happiest with, encouraged to migrate there by the didactic, tutorial-based practicums [74]. Finally, there is a low degree of flexibility in these approaches to tailor the learning experience towards students’ individual needs.

There is a growing number of randomized trials comparing pedagogical tools used in neuroanatomy teaching, although most papers on the topic lack sufficient sample size and quality of design to make concrete recommendations [16]. Further, research is often scaled to a single-institution with an independent-curriculum. It often lacks the applicability necessary for educators to have complete faith that results would be reproducible in their cohorts [16].

This is reflected in the heterogenous uptake of these new technologies amongst medical schools. Even for those papers that show a significant difference between teaching methods, the link to current practise has not been made. For example, Allen et al. (2016) demonstrated students who accessed 3D online resources based on data from the Visible Human Project scored significantly higher than students using 2D resources [75, 76]. However, only 28% of universities had incorporated 3D software in most or every session while 2D images were used in over 59%. There are methods such as mobile augmented reality [29] and use of clay-modelling [67] known to reduce cognitive load and increase performance that are only used rarely (14%) or not at all (50%). This paper does not aim to provide an exhaustive list of differences between evidence-based methods and current practise, or act as a guideline for use of certain methodologies. However, it does illustrate that either there is a paucity of quality research into neuroanatomy pedagogy, and/or that there is a problem in its translation into practise.

In terms of curriculum, most medical schools scaffolded the teaching of neuroanatomy over the duration of the course by teaching neuroanatomy in more than one year, termed ‘vertical integration’. This is a valuable methodology, as it allows students to not only demonstrate they can recall information, but also apply it in a clinical setting. By reaching higher levels of Bloom’s Taxonomy - a theoretical model frequently used to structure curriculum learning objectives – greater learning may be effected [77]. However, few universities employed an established curriculum to their neuroanatomy teaching, and of these, most utilised university-specific guides. The lack of a standardized, evidence-based curriculum increases the workload for teaching academics in deciding what content to cover and inhibits strategy- and resource-sharing between institutions.

A Delphi study of neurologists, neurosurgeons and academics would be useful to standardize neuroanatomy learning objectives medical students and junior doctors should know. This would be beneficial in two areas: First, while it may not guarantee learning outcomes are met, the pressure may be taken off academics to decide what to teach, and rather on to how to teach it. Second, further research will be conducted on similar populations. This standardization of learning objectives and teaching methods must be put in the context of academic freedom and individual faculty members and programs. A strict standard may in fact stifle future innovations and consideration should be given to protecting this important academic freedom. Research based on populations of students learning from national curriculum, endorsed by governing bodies such as RACS or the AMC, may facilitate the translation of research into practise and allow for standardized assessment of graduate levels of knowledge of neuroanatomy.

The qualitative themes emerging from the surveyed academics text responses are useful in framing the current focus of neuroanatomy educators. First, the motivation of students learning neuroanatomy are important considerations for teachers. Conscious efforts have been made to link clinical relevance to the content and adapt teaching methodologies to suit intrinsic and extrinsic motivators. Educators are also cognisant of the anxiety of their students, reducing the taught curriculum to the essential knowledge, scaffolding learning and introducing new technologies to mitigate neurophobia. Further research may attempt to elucidate the link between motivation and anxiety on learning neuroanatomy.

The findings of this study support those reported elsewhere, agreeing that despite the flaws of traditional approaches, limitations on curricular time, trained anatomy faculty, resources for gross anatomy courses in integrated curricular as well as historical trends of teaching mean academics still predominantly rely on didactic methodologies. At this time, there is not enough quality evidence to support the use of modern, self-directed alternatives such as mobile technology, mixed reality, artificial intelligence or virtual assistants for academics to take the brave leap away from traditional teaching approaches. This move may be favoured if research illustrates the deficit in neuroanatomy knowledge continues and pressures of integrated curriculum and limited time endure.

Limitations of the study

This study did not explore the relative effectiveness of teaching methodologies employed by universities' medical schools. Further, whether this heterogeneity produces tangible differences in the level of graduate knowledge remains unknown. Future studies may compare graduates' neuroanatomical knowledge between institutions to determine whether any difference exists.

Self-reported data from individual institutions is inherently subject to bias. This was minimised by anonymising the academics, and there are no links to reported data and individual institutions that may be inferred from the results in this paper. An independent body that examines each institutions neuroanatomy teaching may offer a solution.

3.7 Conclusion

Content, delivery, assessment, and development of neuroanatomical knowledge between medical schools in Australia and New Zealand is highly variable, particularly with regards to uptake of newer technologies. A problem remains in the transfer of evidence-based strategies from research to educational practice. As medical schools continue to adjust to problem-based, integrated curriculums with fewer hours dedicated to neuroanatomy teaching – this research translation will become increasingly important. A national curriculum for content and delivery would encourage strategy- and resource-sharing between universities, enabling research to be based on similar populations and facilitating uptake of significant advancements. The authors of this paper recommend a Delphi study of neurologists, neurosurgeons and academics be conducted to establish a national curriculum for this important basic science.

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CHAPTER 4:
Role of Spatial Ability, Motivation and Anxiety in Learning Neuroanatomy

Hamish J. Newman* [1,2], Sandra E. Carr[1], Amanda J. Meyer[2]

[1] School of Allied Health, Health Professions Education, The University of Western Australia, Perth, Western Australia; and
[2] School of Human Sciences, The University of Western Australia, Perth, Western Australia

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4.1 Preface

Improving a student's approach to learning is a critical part of the solution to optimising neuroanatomy education. It has been demonstrated that in engineering courses that students participating in a dedicated course designed to enhance spatial ability had improved knowledge retention in their studies over the course of a year [78]. Identifying factors relevant to learning neuroanatomy such as spatial ability, motivation or anxiety, and improving these intrinsic factors, or modifying teaching methodologies may improve education.

Identifying factors that are related to improved knowledge acquisition and retention may be the start of developing individualised education for post-graduate students. Currently, there is heterogeneous, and inconsistent uptake of new technologies in neuroanatomy education in Australian and New Zealand medical schools. Different pedagogies may be better suited to some students than others, for different neuroanatomical content. To better delineate this line of enquiry, this study was conducted to characterise the relationship between spatial ability, motivation and anxiety on learning neuroanatomy.

Results were gathered for this study between April 2019 and June 2019. After data analysis, it was realised our initial measure of anxiety was test-induced anxiety, rather than a more general measure of neurophobia. On the same cohort of students, a former Masters student, Jessica Ogilvie, gathered DASS-21 data, providing a quantitative measure of distress along three axes: depression, anxiety and stress. This data was necessary for a more accurate correlation to be drawn between students' academic results and anxiety of the subject matter, and permission was granted to use these results. Following this, the manuscript was submitted for publication in March, 2021 and accepted for publication in Focus on Health Professional Education: A Multi-Professional Journal in September, 2021.

4.2 Abstract

Introduction In the last decade, medical student neuroanatomy knowledge has been below an acceptable level. Teaching interventions targeted towards factors relevant to learning neuroanatomy such as spatial ability or motivation may be developed to improve knowledge acquisition and long-term retention. This paper seeks to characterize the relationship between spatial ability, motivation and anxiety on learning neuroanatomy. **Materials and methods** Students (n=131) were enrolled in an undergraduate neuroanatomy course (males n=53, females n=78, age=22±6 (mean±stdev) years). After volunteering to participate, students completed a Mental Rotations Test (MRT), condensed Motivated Strategies for Learning Questionnaire (MSLQ) and Depression, Anxiety and Stress subscale survey (DASS-21) to assess spatial ability, motivation and anxiety, respectively. Spearman correlations were calculated between students' scores on these tools and examination/unit results. Ethics approval was obtained from The Human Ethics Committee from The University of Western Australia RA/4/20/5250. **Results** Final unit score and perceived task value were weakly positively correlated (r_s=0.22, p=0.016, n=112), whereas final unit score and anxiety were weakly negatively correlated (r_s= -0.22, p=0.04, n=82). There was a weak positive correlation between spatial ability and spatial MCQ results (r_s=0.232, p=0.016, n=108), but no other assessment modality. **Conclusions** Targeting interventions to increase students' perceptions of the value of learning neuroanatomy and reduce anxiety will further improve student performance in this subject. Data from this report may guide the development of personalised educational techniques with the aim of improving knowledge acquisition. Future research into devising these interventions and characterizing their effect on neuroanatomy learning would be beneficial.

Key words: neuroanatomy, learning, motivation, spatial ability, anxiety, education

4.3 Introduction

Learning neuroanatomy is challenging for students and junior doctors due to the complexity of the topic, difficult clinical aspects relating to the anatomy and interconnectedness of anatomical structures [1, 13, 79]. In practise, lower levels of neuroanatomy knowledge are associated with poorer confidence of junior doctors and general practitioners in managing neurological conditions [26, 27, 80, 81], Evidence has implicated lack of understanding of neuroanatomical variations to unsafe medical practise and major complications in clinical work [7, 82, 83]. As medical education has changed, with integrated curricula and fewer hours dedicated to teaching neuroanatomy, students' performance in neuroanatomy may be below an acceptable level [7-9, 12, 84, 85]. Three factors have been identified in the literature as being relevant to a student's learning of anatomy: spatial ability, motivation and anxiety [86-88].

Spatial ability

Spatial ability can be measured in many ways, with one of the simplest and most validated being the Mental Rotations Test (MRT). Developed originally by Shepard and Metzler [54], the MRT has been adapted [23], and redrawn [89] to stay relevant to educational research. In Roach et al. (2020)'s paper, across 15 studies and 1,245 participants, spatial ability was weakly associated with anatomy performance ($r_{pooled} = 0.240$; CI at 95% = 0.09, 0.38; $P = 0.002$). Performance on spatial and relationship-based assessments (i.e., practical assessments and drawing tasks) was correlated with spatial ability, while performance on assessments utilizing non-spatial multiple-choice items was not correlated with spatial ability [90]. A study of 13 undergraduate health science students showed a significant correlation between spatial ability and neuroanatomy test scores [91]. However, authors of this paper suggested larger studies be conducted to verify this finding [91]. Another study showed that spatial ability had a weak, positive correlation to performance on neuroanatomy tests when assessing the effectiveness of a 3D online learning module [75]. A study is yet to fully characterize the relationship between spatial ability and neuroanatomy across a range of assessment modalities as well as content.

Targeting spatial ability to improve knowledge acquisition is not a new concept. It was shown in a group of engineering students with poor spatial ability that participating in a three-credit, dedicated course designed to enhance spatial ability through lectures and computer laboratories had a significant, positive effect on knowledge acquisition in their studies over the course of a year [78]. Research has already been conducted into developing teaching techniques that specifically aid student conceptualisation of complex neuroanatomy, including development of interactive 3D learning tools [92]. If spatial ability is well correlated to learning neuroanatomy, early identification of weak spatial ability and targeted academic interventions may increase performance of these students [93, 94].

Motivation

The theory of self-regulated learning (SRL) is a framework used by educators to measure engagement at the classroom level [95]. Zimmerman defines learners as 'self-regulating' based on the extent to which they are 'metacognitively, motivationally and behaviourally active participants in their own learning process' [95]. There are well-designed instruments such as the Motivated Strategies for Learning Questionnaire (MSLQ) for measuring SRL empirically [24, 96]. This tool assesses multiple factors of motivation including intrinsic and extrinsic goal orientation, task value, control of learning belief, self-efficacy for learning and performance, and test anxiety [24, 96]. The early psychometric research conducted on this instrument is described in the MSLQ manual [24]. Over the past decade, the MSLQ has been validated by many Australian health and science students, such as nursing (Salamonson et al., 2009), midwifery (Carter et al., 2017), medical (Soemantri et al., 2018) and chiropractic science students (Meguid et al., 2019).

Motivation has been linked with anatomy examination performance in two recent studies. Intrinsic goal orientation, task value, control of learning beliefs and self-efficacy for learning were significantly positively correlated with American medical students' final score in their gross anatomy course [88]. The subscale "Self-Efficacy for Learning and Performance" was significantly positively associated with Australian chiropractic science students' final score in their gross anatomy course (Meguid et al., 2019). The relationship between motivation subscales and neuroanatomy performance is unknown.

Anxiety

The concept that test anxiety is negatively correlated with student performance has been established [97], and it is hypothesized it contributes to poor performance in neuroanatomy education [1]. Methods for reducing test anxiety can be divided into two categories: behavioural modifications and environmental adjustments. Behavioural modifications include social-psychological interventions that target students' beliefs, thoughts and feelings about learning, and when applied in the correct context have been shown to improve students' performance [98]. Journaling, for example, has been shown to reduce test anxiety and increase elementary students' examination scores in mathematics [99]. Self-administered interventions such as progressive muscle relaxation increase the pass-rate of medical students re-sitting licensure examinations [100]. Behavioural adjustments rely on students implementing the modifications to reduce their anxiety.

A review of nine methods for reducing neuroanatomy anxiety was published in 2016 and included implementing team-based learning, use of digital teaching tools, and integration of basic and clinical sciences [69, 101]. A survey of medical students found more bedside tutorials and patient exposure would be helpful in reducing neurophobia [27]. Many other studies have investigated ways of mitigating neurophobia [102-109]. Targeted teaching strategies such as interactive virtual reality tools are amongst those that may reduce anxiety and improve knowledge acquisition for students [36].

However, there is little data in the available literature for which specific interactive tools are empirically proven to do so and would be a useful area for future research to explore [16].

The Depression Anxiety Stress Scales (DASS-21) is a quantitative measure of distress along three axes: depression, anxiety and stress [25]. It is a psychometrically validated, short form of Lovibond and Lovibond's (1995) 42-item self-reporting questionnaire [25]. Clark and Watson (1991) made the comment that while anxiety and depression are phenomenologically distinct, it is difficult to distinguish between these constructs by empirical means [110]. It is expected this is due to the common factor of negative affectivity, predisposing an individual to perceived susceptibility for any one construct [111]. The psychometric analysis demonstrated DASS-21 scales are a blend of variance common to stress, anxiety and depression. However, it is acceptable to use these scales with acknowledgement of this caveat in the design of its use [25]. A previous study demonstrated high internal consistency (Cronbach's α 0.79) of the DASS-21 survey in an Australian general population of 18-24 year olds [112].

There is a lack of quantitative supporting data that spatial ability, motivation or anxiety are correlated to performance in learning neuroanatomy. This may be useful information for evidence-based educators and allow informed discussion for how to apply them to optimize student support. Trying to quantify the role of these factors in learning neuroanatomy is a difficult task. Differences in the role of spatial ability, motivation and anxiety in learning neuroanatomy may be present according to different teaching modalities applied. For example, it has been observed that in anatomy laboratories, cadaveric material is a well-known source of stress and anxiety; not present in a lecture, virtual learning environments or problem-based learning classes [113]. Conversely, motivation has been enhanced in dissection environments compared to traditional lectures [114]. Similarly, perceived roles of anxiety, motivation or spatial ability may change depending on the assessment modality used [115], or other factors including cultural differences or language barriers. Therefore, any factor that is being addressed as relevant to a students' learning of neuroanatomy must be studied within the constraints of the teaching, and assessment, modalities applied.

To better inform further investigation into devising targeted teaching strategies, this cohort study aimed to assess relationships between these factors and students' final unit scores in an undergraduate neuroanatomy course. Based on studies of learning anatomy more broadly, it is hypothesized that all motivation subscales (except for test anxiety) will be positively correlated with final scores in a neuroanatomy unit.

4.4 Methods

The Human Research Ethics Committee of The University of Western Australia gave approval for this study to be conducted RA/4/20/5250.

Subject groups

Participants (n=138) were science, biomedical science and neuroscience enrolled in the neuroanatomy unit ANHB2217 in 2019. The unit consisted of 24 one-hour lectures and 12 two-hour laboratories over a 12-week semester taught by an experienced, clinical anatomist. The mixed-method lectures are didactic with elements of active learning strategies such as spot-tests included. The lectures cover content outlined in Moxham's neuroanatomy curriculum [2]. Laboratories are traditional in nature, consisting of prosections, plastinated specimens, models and clinical images arranged in five stations, with 20 minutes dedicated to each station. Laboratories cover content from the previous weeks' lectures. There is no dissection. Students repeating the unit, not providing consent or sitting the deferred examination were excluded from the study. Final unit score was derived from a practical manual completion mark (10%), mid-semester theoretical exam (20%), end-of-semester theoretical exam (40%) and end-of-semester practical exam (30%). No assessments were 'must-pass' assessments; that is, none were required to be passed in order to pass the unit.

MRT

During an allocated 20-minute station of a compulsory laboratory mid-way through semester, information and consent forms were explained and signed. A student's spatial ability was assessed using the 24-item, redrawn, validated Mental Rotation Test version A (MRT-A) [23, 89], using the same procedure outlined by Peters et al.[89] Each question shows one illustrated 3D shape composed of 10 cubes on the left, and four possible rotations of the target figure on the right. Two of the four stimulus figures are rotated versions of the target figure. Both correct choices had to be identified in order to score one point. Students had six minutes to complete the test, with a two minute break at three minutes [89]. The six-minute timeframe was chosen over eight-minutes as it has previously been shown to heighten perceived differences in spatial ability within the study population [89].

A meta-analysis of MRT results and procedures showed that effect size varies according to how the test is administered or scored [116]. For face validity, results obtained in this study were compared to Guimarães et al. (2019). This was of a similar test design as outlined by Voyer et al. (1995) in scoring procedure, individual vs group testing and age/sex of the experimenter [116].

MSLQ and DASS-21

In three separate laboratories, a condensed 19-question version of the Motivated Strategies Learning Questionnaire (MSLQ) and the DASS-21 was administered [24, 96]. The MSLQ subscale items assessing intrinsic motivation (IGO, n=4), extrinsic motivation (EGO, n=4), task value (TV, n=6) and test anxiety (TA, n=5) were included. These questions were completed on a Qualtrics electronic survey where demographic data was also collected.

Examination

The end-of-semester examination consisted of practical (one-hour) and theoretical (two-hours) components during the University examination period, approximately five- and eight-weeks after gathering MSLQ and MRT data, respectively. The practical examination consisted of 22 stations with a stimulus (prosection, model, plastinated specimen, image) and question list, with two minutes per station. The question list were drawn from a range of Bloom’s Taxonomy levels [77, 117]. Level one to three questions, including identification, featured at every station, with the occasional use of higher-order analysis level questions. The theory examination consisted of six short-answer (one-to-five word answers) and 39 multiple-choice questions. Two authors (HN and AM) independently reviewed the multiple-choice questions and extracted spatial (n=5) and non-spatial (n=34) questions.

Spatial questions were those requiring students to form mental images built from visual perceptions of objects. For example: ‘what is the orientation of the medial lemniscus tract in a mid-level axial section of the pons’ with options such as: coronal plane, anterior; coronal plane, posterior; sagittal plane, anterior; sagittal plane, posterior. To increase the number of spatial questions, spatial MCQ data were extracted from two other intra-semester examinations from the same cohort using the same extraction process. First, from a pre-laboratory knowledge test (n=9) ten-weeks prior to the final examination; second, from a mid-semester examination six-weeks prior to the final examination (n=4). Full data sets of spatial MCQ questions were available for 108 students.

Students’ demographic data, MRT, MSLQ, grade point average (GPA), final unit result, final spatial MCQ score, final non-spatial MCQ score, final SAQ score and final practical score were linked to a unique de-identified student code and analysed. GPA, as a marker of previous performance, was included to assess whether motivation, spatial ability and anxiety were correlated. Previous academic performance is a good predictor of future performance in medical education [118].

Statistical analysis

Where relevant, data is presented as mean ± standard deviation (SD). A p-value of <0.05 was considered significant. Statistical analyses were performed using R software, Version 3.2, Austria [119]. Spearman’s correlation co-efficient between MRT results (ordinal values) and age, GPA, spatial MCQ, non-spatial MCQ, SAQ, practical examination result and total score were calculated. Independent t-tests were used to detect for relevant differences between males and females. A one-way ANOVA was used to detect interactions between the type of course studied by the student and results obtained in the unit.

Internal reliability of measurement scale responses (Cronbach alpha) for the MSLQ, DASS-21 and examination scores were assessed. Means for Intrinsic Motivation (IGO), Extrinsic Motivation (EGO), Task Value (TV) and Test Anxiety (TA) were calculated. Spearman correlations with final unit score and GPA and their significance were reported.

4.5 Results

Demographic data is illustrated in Table 9. There were 131 (out of 185 enrolled, participation rate 70.8%) participants included in the study. There were seven students that did not consent to have their GPA accessed specifically and 19 students did not complete the MSLQ. These students were not included in relevant calculations and are indicated where appropriate. Three questions were excluded from the practical exam due to specimen orientation changing between students, and the final practical exam question number was reduced to 19. There were 108 complete data sets for spatial MCQ questions.

Table 9. Respondent demographic data

Measure	Response
Age	Mean 22.0 (±5.6), range 18-57 years
Gender	Male: 53 (41%) Female: 78 (59%)
Course	BBioMedSci: 56 (42%) BSc: 63 (48%) DipSci: 1 (<1%) MBioMedSci: 3 (2%) MBioMedSci: 6 (4%) PhD: 6 (4%) BPhil (Hons): 1 (<1%) Other: 1 (<1%)

The mean final unit result was 69.7±15.3%. There was no significant difference between males and females (males=71.1±13.8%, females=68.8±16.2%, p=0.41). There was no significant difference in students' results based on their enrolled course (1-way ANOVA, F=0.67, p=0.65).

MRT

The mean MRT result was 10.6±4.7. Male students achieved mean MRT scores 37% higher compared to female students (males=12.6±4.8; females=9.2±4.1; Cohen's d=0.77; p<0.001). MRT score was not correlated with age (p=0.06).

A student's spatial ability was not correlated to final unit result (r_s=0.122, p=0.16). However, there was a significant, weak positive correlation between MRT and spatial MCQ score (r_s=0.232, p=0.016, n=108). Correlation co-efficient between MRT and final unit result, spatial MCQ, non-spatial MCQ, SAQ and practical examination are shown in Table 10. MRT scores were not correlated to a student's GPA (p=0.59, n=124).

Table 10. Descriptive statistics, including standard deviation (SD), and Spearman correlations (r_s) of Mental Rotations Test and examination results in a neuroanatomy course (n=131).

QUESTION TYPE	MEAN %	±SD %	CRONBACH ALPHA	NUMBER OF QUESTIONS	CORRELATION WITH SCORE (R_S)	P-VALUE
SPATIAL MCQ	59.1	±28.5	0.629	18[a]	0.23	0.016
NON-SPATIAL MCQ	74.1	±16.9	0.852	34	0.12	0.18
SHORT ANSWER	72.7	±18.9	0.832	6	0.13	0.13
PRACTICAL	58.6	±17.8	0.889	19	0.16	0.06
FINAL RESULT	69.7	±15.3	-	-	0.122	0.16

[a] Sum number of MCQ questions taken from three points during semester, n=108

MSLQ

The MSLQ means, Cronbach alpha scores and correlation with final unit scores for IGO, EGO, TV, TA are shown in Table 11 (n=112). Final unit scores were weakly correlated positively with perceived task value (r_s=0.22, p=0.016) and negatively with test anxiety (r_s= -0.29, p=0.001).

Table 11. Descriptive statistics including standard deviation (SD), internal reliability (Cronbach alpha) and Spearman correlations (r_s) of motivated strategies for learning questionnaire subsets (test anxiety (TA), task value (TV), extrinsic motivation (EGO) and intrinsic motivation (IGO)) and final unit score in neuroanatomy course (n=112).

SCALE	MEAN	±SD	CRONBACH ALPHA	NUMBER OF ITEMS	CORRELATION WITH FINAL SCORE (R_S)	P-VALUE
TA	4.50	±1.30	0.809	5	-0.29	0.001
TV	5.86	±0.76	0.811	6	0.22	0.016
EGO	5.32	±1.12	0.714	4	0.16	0.08
IGO	4.88	±0.99	0.703	4	0.07	0.45

DASS-21

There was a significant, negative correlation between the DASS-21 anxiety score and final unit scores (r_s=-0.22, n=82, p<0.05). Cronbach's alpha for neuroanatomy-specific anxiety was 0.82. There was no correlation between depression or stress related subscales and final unit score (r_s=-0.18, p=0.1; r_s=-0.05, p=0.7; n=82).

4.6 Discussion

Learning neuroanatomy is positively correlated with perceived task value, and negatively correlated with neuroanatomy-specific anxiety. Students of high spatial ability performed better in spatial MCQs. There was no correlation between spatial ability and other assessment types, although students of a superior spatial ability had a tendency to perform better in practical exams. Our knowledge of factors important for neuroanatomy teaching have been advanced and discussed separately here.

It was encouraging to see MRT results were similar to previous studies of Guimarães et al. (2019) and Pizzimenti and Axelson (2015) respectively; with similar populations (undergraduate students) and test administration methods (method of scoring MRT, small groups, age/sex of the examiner). The overall MRT was low (10.6±4.7). This was expected given the smaller timeframe given to participants to complete the task (six-minutes rather than eight). This is not to be confused with students misunderstanding the task, or improper administration of the test; highlighted by the consistency of these findings with larger samples [89]. Previous studies have found spatial ability is negatively correlated with age [116]. It was not the objective of this study to examine age related changes in spatial ability, and while in this study a negative trend was observed, it was not statistically significant. This may have been due to the negative skew in distribution of age of the population assessed.

Spatial Ability

Spatial ability was correlated only to a student's performance on spatial MCQs and not to other assessment modalities. A systematic review of spatial abilities tests and anatomy knowledge observed a positive correlation when examination is of a pictorial or spatial nature; such as in practical examination [93]. While students of high spatial ability had a tendency to perform better in the practical exam, this conclusion was not statistically significant and is contrary to previous findings. Some students had commented to the Unit Coordinator that they had not dedicated much time to reviewing spatial relationships between structures, believing this to be low-yield task and requiring significant cognitive load. Further, Allen et al. (2016) summarised that different studies may get neutral findings if questions did not require complex enough spatial consideration, which may have been the case in this report.

It remains unclear if courses requiring practical neuroanatomy assessment, such as in medical or allied health schools or for students with surgical career intentions, would benefit from targeted interventions that improve spatial ability. From Gonzales et al. (2020), greater than two hours of training with targeted interventions would be required to see an improvement in performance. However, neuroanatomy courses utilising predominantly non-spatial multiple-choice or short answer examination formats such as those in science or allied health are unlikely to benefit by targeting teaching interventions towards spatial ability, where the link is not statistically significant.

A limitation of this study was the use of a compiled list of spatial questions to increase sample size. By selecting from multiple time-points, the mean value obtained may have been artificially high, as students learn to expect the style of question and prepare accordingly. This bias may have been negated by writing an exam with a greater proportion of spatial-questions, or writing a bespoke assessment specifically designed to assess spatial learning.

There was a significant difference between male and female MRT results, consistent with previous findings [89, 116]. It should be noted that scoring out of 24 is known to increase the magnitude of the effect size [116]. Despite being well-documented, the reasons for why this difference exists are poorly understood.

Motivation

The perceived value of content plays an important role in how effectively students learn neuroanatomical content. That is, the more interesting, important, or useful the student sees neuroanatomy, the better they will learn. Utilizing digital technologies can make the process of learning more enjoyable [120]. Most recently, a study on undergraduate students using the GreyMapp AR tool versus cross sections of brains found students considered it a valuable addition to curricula and experienced less cognitive load when using the tool [37]. However, it remains largely unknown whether this is correlated to improved learning and future studies may better characterize this [18]. Further, enjoyment is a subjective experience, and some students may find it challenging for those with low spatial ability, or those experiencing side effects [34].

While not a complete list, modifiable factors that influence perceived value are degree of clinical relevance, curriculum autonomy and patient/clinical contact [121]. These factors, along with others not described here, should form the basis for selecting pedagogical approaches. Contrary to previous studies, intrinsic and extrinsic motivational sub-types were not as important in learning neuroanatomy compared to anatomy more broadly [88, 122]. Larger studies may be requiring to verify this finding.

Anxiety

As expected, there was a weak negative correlation between anxiety and neuroanatomy performance, providing quantitative evidence for the effect of 'neurophobia' [1]. Modifiable risk factors for neuroanatomy anxiety include poor teaching, complex terminology, separation of basic science teaching and clinical application [69]. This evidence suggests interventions that decrease test anxiety, such as those described in the introduction, may have a positive effect on learning neuroanatomy.

4.7 Conclusion

Students' performance in neuroanatomy is positively correlated with the value they place on the subject, and negatively correlated with the amount of anxiety they experience. Spatial ability and intrinsic/extrinsic motivation did not correlate with student's overall performance in neuroanatomy. However, spatial ability was correlated to scores on spatial MCQs. Larger data sets with cross-institutional sampling may be used to validate this study's conclusions. Targeting interventions to increase students' perceptions of the value of learning neuroanatomy and reduce anxiety will further improve student performance in this subject.

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CHAPTER 5:
Comparative Analysis of Neuroanatomy Teaching Techniques: A Randomized Control Trial Affected by COVID-19

Hamish J. Newman* [1,2], Amanda J. Meyer[1], Sandra E. Carr[2]

[1] School of Human Sciences, The University of Western Australia, Perth, Western Australia; and
[2] School of Allied Health, Health Professions Education, The University of Western Australia, Perth, Western Australia

5.1 Preface

An observation of studies comparing teaching methodologies was that few compared the performance of the methodology across multiple neuroanatomical concepts. Further, many studies assessed knowledge retention at one time point, and this was usually immediately following the intervention. An issue with these studies is they were assessing short-term memory rather than long-term retention. Neuroanatomy educators would have difficulty relating findings to their own context given the limited scope the initial studies were conducted within. An experiment was conducted with a refined methodology that compared the performance of web-based, 3D model learning to traditional cadaveric laboratories across multiple neuroanatomical concepts and assessed at varying time points. The primary aim was to determine if technology enhanced learning improved knowledge acquisition and long-term retention compared to traditional teaching, and determine if there was a relationship with neuroanatomical concept.

The intervention was planned to be run between April and June, 2020. However, mid-way through data collection, all classes were suspended due to the novel corona-virus outbreak. While my initial aims and objectives were not met, the pandemic offered important observational data regarding students’ attitudes towards modern teaching techniques during a pandemic. A secondary aim developed which was to describe student’s preference on teaching modality in response to the pandemic and offer explanations for these preferences. The limited sample size meant observational data collected was not of a standard to be submitted for publication. However, by maintaining an awareness of these limitations, interesting insights into student experiences and perspectives of a comparative analysis of traditional and digital methods of learning neuroanatomy during COVID-19 can be demonstrated and are discussed in this chapter.

5.2 Abstract

Introduction In the context of reduced teaching hours dedicated to anatomy in problem-based, integrated curricula, academics have increasingly sought modern alternatives to traditional didactic presentations and cadaveric laboratories. There has been heterogeneous translation of these modern techniques into practise. The aim of this paper was to observe and reflect on student experiences and perspectives of a randomized-controlled trial of traditional versus digital methods of learning neuroanatomy during COVID-19. **Materials and Methods** Students (n=96) were enrolled in an undergraduate neuroanatomy course at a single institution. Students were randomly allocated to either participate in a digital (2D and 3D digital computer-aided learning) or traditional laboratory (cadaveric and plastinated specimens). To compare knowledge acquisition and retention, participants completed a baseline pre-laboratory, and a one-week post-laboratory knowledge test. Originally, the trial was to be conducted over five selected laboratories. **Results** Only laboratories one, two and three were completed before in-class participation was suspended due to COVID-19. The mode of laboratory "traditional" or "digital" did not affect student retention of knowledge. There was no difference between pre- and post-laboratory test results for either control (pre-laboratory mean=6.27±1.19, post-laboratory mean=5.91±1.81, n=11, paired t-test P=0.40) or experimental (pre-laboratory mean=6.00±1.28, post-laboratory mean=5.78±1.93, n=18, paired t-test P=0.70). **Conclusion** In response to COVID-19, students tended to revert to tried and tested, traditional methods of teaching in favour of digital methods. This study offers further evidence to continue advocating for the use of cadaveric material in anatomy laboratories in the future.

Key Words: Neuroanatomy education, modern teaching methods, digital learning

5.3 Introduction

The COVID-19 pandemic has disrupted education in Universities around the world. Paradoxically, it offers a valuable learning experience, as it offers a window of insight into research conducted during a crisis. Specifically, for the scope of this paper, students' attitudes towards educational research and novel methods of teaching were examined.

Since the 1990s, there has been a paradigm shift in the way anatomy is taught in medical schools.[4] In the context of reduced teaching hours dedicated to anatomy in problem-based, integrated curricula, academics have increasingly sought modern alternatives to traditional didactic presentations and cadaveric laboratories [16]. Current evidence suggests this remains the backbone of neuroanatomy education, although integration of modern techniques has been highly variable between institutions [123].

In the last decade, there has been progressive interest in comparing these modern teaching techniques, including: mobile technology, augmented reality (AR), virtual reality (VR), and most recently artificial intelligence (AI) to the traditional lecture and laboratory classes [16]. The impression has been that digital techniques may be comparable to cadaveric specimens and dissection. For several reasons, current studies have lacked the generalizability to provide educators a framework for which techniques to use – reflected in the heterogeneous translation of research into practice [18]. First, few studies have explored the effect of teaching strategies on long-term retention and knowledge loss [18, 124, 125], known to be an issue in neuroanatomy teaching [10, 11]. Second, most interventions apply the condition across a single learning outcome/concept. That is, few studies have compared their novel method of teaching with the gold standard across a range of neuroanatomical concepts. Educators must know that a technique increases knowledge acquisition and long-term retention across many topics before straying from the method of teaching that has educated generations of successful health care professionals.

Initially, this study was a description of a novel method of conducting comparative studies of neuroanatomy teaching techniques, by doing so across numerous neuroanatomical topic areas and over a greater period of time. The primary aim was to determine if technology enhanced learning improved knowledge acquisition and long-term retention compared to traditional teaching, and determine if there was a relationship with neuroanatomical concept. Mid-way through data collection, all classes were suspended due to the novel corona-virus outbreak [126], offering important observational data about student attitudes towards modern teaching techniques during a pandemic. The pandemic has necessitated a large-scale shift towards distance learning across the world, a unique challenge requiring a range of actions by universities to provide content online [127].

The aim of this paper became to observe and reflect on student experiences and perspectives of a comparative analysis of traditional and digital methods of learning neuroanatomy during COVID-19, and offer explanations for these preferences.

5.4 Methods

Study population

This education-based, randomized-control study was approved by the Human Research Ethics Committee of The University of Western Australia (RA/4/20/5250). Out of 196 students enrolled in the 2020 ANHB2217 Human Neurobiology unit at The University of Western Australia, 96 students consented to participate in this study (49%). The unit was originally designed to be taught over 12 weeks, consisting of 12 laboratories of a traditional nature, with cadaveric specimens, models, clinical images and textbooks available for use, with demonstrators providing assistance. There were 22 scheduled mixed-method lectures, including didactic presentation and integrated use of mobile technology and formative quizzes.

Data collection

The intervention was to take place over five selected laboratories during the semester. Students were randomly allocated to either control or experimental conditions. Each lab would cover a distinct neuroanatomy concept: cortex and cerebral vasculature, brain stem, cranial nerves, deep brain structures and peripheral nervous system. Students would complete a pre-lab knowledge test, and then a second post-lab test four weeks later (schematically illustrated in Figure 4). Only laboratories one, two and three were completed before in-class participation was suspended due to the corona-virus outbreak and risk mitigation procedures initiated by The University.

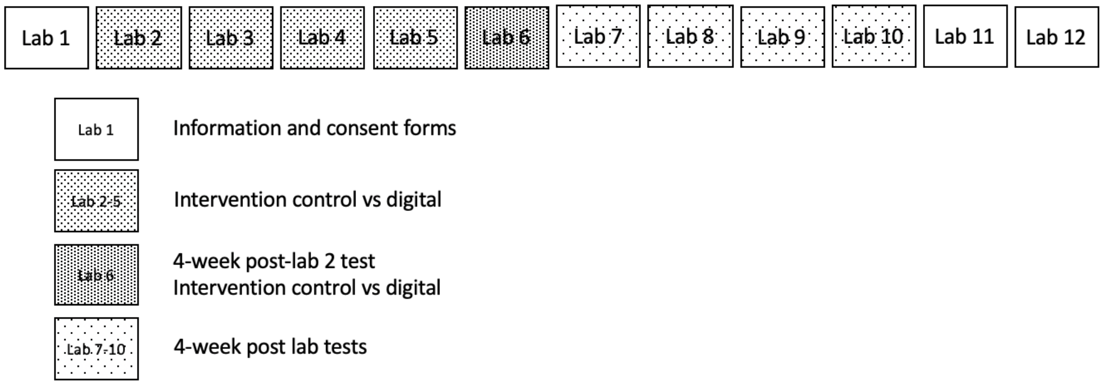

Figure 4. Graphical representation of interventions in selected laboratories for ANHB2217 Semester 1, 2020.

All students completed the relevant lectures and had access to pre-laboratory materials as per the standard unit structure. Before starting the scheduled neuroanatomy laboratory, participating students were randomly divided into two groups by randomly and blindly selecting either ‘control’ or ‘experimental’ pieces of paper out of a dish.

Both groups completed a short, ten-minute pre-laboratory knowledge test in the second laboratory class. The test included ten multiple-choice questions, covering a range of Bloom’s taxonomy level questions; level one (n=3), level two (n=3), level three (n=2), level four (n=2) [117]. The control group then completed two-hours in the traditional laboratory environment described above. The experimental group completed a digital computer-based laboratory, with access to online textbooks, lecture slides, 2D computer-based, and 3D digital neuroanatomical tools on a smart phone, tablet or laptop devices. Specific resources used included UBC Neuroanatomy® (Vancouver, Canada), Sketchfab® (New York, United States), and YouTube Osmosis® (Baltimore, Maryland). For each laboratory, the series of learning objectives were linked to relevant pages of the aforementioned resources (Table 12). Students had the opportunity to peruse these resources with access to demonstrators and other available web pages.

Table 12. Teaching technologies mapped to learning objectives for laboratory 1 and 2

Laboratory	**Learning objective**	**Teaching technology**	**Example**
Brainstem	- Identify the key features of the midbrain, pons, medulla oblongata on diagrams, specimens & clinical images. - Understand the blood supply of the brainstem. - Understand the location of the cranial nerve nuclei in the brainstem	2-D computer-based tools 3D digital tools	Osmosis – Brainstem tutorial Sketchfab – Brainstem model UBC Neuroanatomy – Interactive Modules
Cortices and cerebral vasculature	- Identify the major gyri and sulci of the brain. - Understand the histological organisation of the cerebral cortex. - Understand the function of specific areas of the cerebral cortex. - Understand the blood supply of the cerebrum, cerebellum and brainstem. - Apply your knowledge to determine the anatomical basis of infarctions.	Lecture slides 2-D computer-based tools 3D digital tools	Sketchfab – cerebral vasculature model Osmosis – cerebral vasculature tutorial (Circle of Willis and Stroke)

The post-laboratory knowledge test was completed one week later in the third (and final) laboratory class. The test was of a similar design to the pre-laboratory test; included ten multiple-choice questions, covering matched, but not identical, questions to the pre-laboratory test. Tests are provided in supplementary material A.

Observational data regarding student attitudes towards the research study, the user-interface and assessment of technical issues had by the students and responses from students withdrawing from the study were recorded by the lead researcher. The observations were collated in a spreadsheet using Microsoft Excel (Version 16.39, 2020). Recurring observations were identified and collated by the lead researcher to identify themes. These were discussed within the team to produce a final set of qualitative results. Explanations for observations and student preferences were made by the lead researcher in conjunction with published literature, discussed within the team and made by consensus.

Students who elected not to sign the consent form, who opted-out of the study at any stage or who were repeating the unit were excluded from the study.

Data analysis

Cronbach alpha values for each test were calculated as a measure of internal consistency. Descriptive statistics were applied across test results. Paired t-tests where full score sets were available were used to compare between pre- and post-test results. Statistics were performed using Microsoft Excel (Version 16.39, 2020).

5.5 Results

Quantitative

A total of 75 enrolled participants (n=34 control, n=41 experimental) completed the baseline test and laboratory two. There were 29 enrolled participants (n=11 control, n=18 experimental) that completed the baseline test and laboratory three.

Average pre- and post-laboratory test results are reported in Table 12. The randomization procedure was effective, and there was no difference in baseline test results between control (n=34, mean=5.59 ± 1.51) and experimental groups (n=41, mean=5.88 ± 1.50, unpaired t-test P=0.41). The mode of laboratory “traditional” or “digital” did not affect student retention of knowledge. There was no difference between pre- and post-laboratory test results for either control (pre-laboratory mean=6.27 ± 1.19, post-laboratory mean=5.91 ± 1.81, n=11, paired t-test P=0.40) or experimental (pre-laboratory mean=6.00 ± 1.28, post-laboratory mean=5.78 ± 1.93, n=18, paired t-test P=0.70) where complete data sets were available.

Table 13. Data presentation of full data sets for primary outcome, comparing pre-lab and 1-week post-lab test marks between conditions.

Intervention	Neuroanatomical Concept	Control vs Experimental	
		Pre-lab test % vs % (p-value)	**Post-lab test % vs % (p-value)**
Control (n=11) vs Digital (n=18)	Cerebral vasculature	62.7 vs 60.0 (0.40)	59.1 vs 57.8 (0.70)
Control vs Digital	Brainstem	Cancelled due to COVID-19	
Control vs Digital	Peripheral nervous system		

Control vs Digital	Spinal Cord	
Control vs Digital	Cranial Nerves	

Pre- and post-laboratory tests were composed of questions across multiple levels of the Blooming Anatomy Tool. Cronbach's alpha for the 10-question pre-laboratory test was 0.316 and for the 10-question post-laboratory test was 0.378.

Qualitative

Impact of the spread of corona virus on attendance

At the time of the first lab on the March 3, 2020, there were three confirmed cases of coronavirus in Western Australia, in the second lab on the March 10, 2020 there were nine, and at the time of the third lab on March 17, 2020, there were 31 confirmed cases in Western Australia.

Student attendance appeared to drop significantly as the risk of contracting COVID-19 increased. With an assumed 100% attendance in lab 1, there was approximately 80% in lab 2, and 40% attendance in lab 3.

Attitudes of students towards participation in research

Students attitudes towards the research changed as news of the pandemic spread. Of the students that withdrew from the study, the following comments were made in lab 3:

> *"… it doesn't look like we have much time left in labs, and we want to make sure we get as much time with the specimens as possible"* Student 1

> *"I'm sorry, the digital labs aren't for me. I would rather see the real thing"* Student 2

> *"I don't want to miss out on time with the cadavers…"* Student 3

> *"I think having a combination of both would be ideal. But considering we only have one lab left I would like to spend it in the other [cadaveric] lab"* Student 4

Student attitudes towards digital technology

In initial laboratories, students were excited about the prospect of using virtual reality as a teaching tool. However, there was less excitement about use of digital tools including the 2D and 3D digital reconstructions of models.

> *"The virtual reality component would be really cool, it's a shame we won't get a chance to do that part of the experiment"* Student 2

> *"… to be honest it seems like moving labs online is an easy way for the uni[versity] to make money without actually teaching, we can access online content ourselves most of the time and it usually isn't that great"* Student 5

Students appeared to be quite familiar with digital 3-D representations of the anatomy already, and there were no issues with user-interface of the various digital modalities. A subjective assessment of technical issues observed by the researchers demonstrated approximately 10% of students having issues with internet connectivity at one point during the lab, all of which were able to be resolved.

There was significantly less interaction with the demonstrators in the digital lab compared to the traditional lab, as students opted more for independent study. Further, there was less student-student interaction, with most completing the lab in silence, aside from those accessing online videos.

5.6 Discussion

This study aimed to comment on student attitudes towards educational research of modern teaching techniques during a pandemic and offer explanations for these preferences. There was a considerable impact on attendance at laboratories, and of those that attended, the majority opted to complete the laboratories in the traditional manner. While there was no community transmission of the virus at the time, it appeared that the risk of transmission of the virus balanced with the opportunity to learn in the laboratory was skewed enough to warrant staying at home for the majority. Importantly, the impact of the pandemic on individuals, their ability to adapt and learn to the shifting educational environments were confounding variables that could not be controlled for.

When presented with the choice, most students opted to spend their remaining time in the laboratory with the specimens as opposed to a structured digital laboratory. This is reflected by the significant drop out rate of the study. There was a subjective degree of regret about not being able to complete traditional laboratories throughout the semester. This may have been due to a number of factors. Around the world students are concerned that the face-to-face teaching they paid for is not adequately provided in an online format, evidenced by class-action lawsuits made by students towards universities around the world [128, 129]. Second, the preference to spend time with specimens may come from factors more difficult to measure, which has previously been summarized by Estai and Bunt (2016). For instance, learning in the laboratory may enhance active and deep learning, prepare students for clinical practice and encounters with death as well as practice of manual skills [130]. Further, being in the laboratory may help develop aspects of medical professionalism such as teamwork, stress-coping strategies and empathy [131]. Discovery of anatomical variations, rarely documented in online learning tools, bring a sense of surprize and curiosity while learning in a laboratory, which are useful emotions for prompting learning [132]. There is also a sense of fidelity of learning, with variations, details and textures appreciable to the students – not so in a digital setting

[17, 133]. These elements may all draw students towards the more traditional mode of cadaveric learning.

Cadaveric laboratories encourage collaborative (where individual progress is made in tandem with others), and distinctly, co-operative learning (progress is made interdependently) – facilitating shared knowledge accumulation and peer-to-peer learning respectively. The value of these shared learning strategies have been demonstrated elsewhere [134]. Without guidance to specifically do so, this experience demonstrated students opted for independent study when utilising digital resources, as opposed to shared learning when left independent in the cadaveric setting. The use of teamwork, stress-coping strategies and deeper learning with cadavers, and not utilised for digital learning, may be possible factors related to this [17, 135]. While these factors did not yield quantifiable differences in knowledge acquisition or long-term retention in this study, specific co-operative learning based activities may have enabled further collaboration and enhanced the digital learning experience [136].

In response to COVID-19, students tended to revert to tried and tested, traditional methods of teaching. The appeal of digital technology appears to have diminished, based on the subjective assessments of students' attitudes towards the experiment. In previous papers on the topic, authors have identified that students felt more engaged by learning with digital representations of anatomy, and using technology [18]. However, as these resources have become more widely available, and free-to-access, the initial excitement about these novel methods appears to wear off [137]. When attempting to select evidence-based methods of teaching, the relative usefulness of studies that comment on student satisfaction alone must be considered in conjunction with objective assessments of their application.

An example is the demonstration that there was no significant difference between digital and traditional methods of teaching applied in this study, consistent with previous studies [16]. However, the authors of this paper acknowledge that results of this study were affected by issues of poor sample size, and fewer than desired neuroanatomical concepts tested.

This research experience offers evidence to suggest that at this stage, digital methods of learning cannot replace the experience of a cadaveric laboratory from a student's perspective. This is obvious, although whether it should be the goal to attempt to in the first place is a matter of ethical debate. Considering the experience of these students in the face of this pandemic, it is of our belief that cadaveric learning should continue to be advocated for by neuroanatomy educators.

A secondary aim of this paper was to summarize a proposed method of comparison between traditional and digital methods of neuroanatomy teaching and present pilot data for the technique. There was not enough data gathered to offer reasonable evidence for the use of traditional vs digital methods of teaching for knowledge acquisition or long-term retention in neuroanatomy. However, without the global spread of a virus that caused nation-wide lockdowns around the world, this method would have been the among few to assess neuroanatomy teaching techniques across such a wide range of concepts. This is a valuable methodology, as it provides the educator with a more comprehensive view of when some techniques may be applied over others. The low level of internal consistency, demonstrated by the poor Cronbach alpha results of the baseline and post-laboratory tests, may explain the lack of significant differences between teaching techniques compared by this study. Future research comparing teaching techniques may apply this method to assist educators in translating this research into practice.

The initial aim of this study was to determine if technology enhanced learning improved knowledge acquisition and long-term retention compared to traditional teaching and determine if there was a relationship with neuroanatomical concept. The mode of laboratory "traditional" or "digital" did not affect student retention of knowledge when learning cerebral vasculature. However, due to the

COVID-19 pandemic, quantitative data on other neuroanatomical concepts could not be collected. Unfortunately, due to significant drop-out rates of the study and low sample size, these results did not reach significance. Larger studies may be conducted to verify these findings and identify an answer to these questions.

5.7 Conclusion

Ultimately, the Covid-19 pandemic halted the progress of this study and brought it to a premature end. However, valuable lessons were learned regardless. Students preferred to spend remaining time with cadaveric specimens, both for the learning experience they offered, and the intangible benefits of handling cadaveric material opposed to digital teaching. It offers further evidence for the role of neuroanatomy educators to continue advocating for the use of cadaveric material in anatomy laboratories in the future.

CHAPTER 6:
Discussion

Summary of findings

The study of neuroanatomy education is complex, and involves interplay between infinite combinations of factors related to the teacher, learner, environment, and technique used; making the identification of an optimal mode of learning seemingly impossible. This thesis aimed to study and compare available teaching techniques through a variety of lenses. While each had a distinct objective, a common theme was to investigate means by which neuroanatomy education may be improved.

First, a systematic review of technology enhanced teaching methods that will have a major impact on education in coming years was conducted. Thirteen quantitative studies focussing on augmented reality, virtual reality and stereoscopy were identified, articles were reported according to PRISMA guidelines, and papers' major findings were discussed. Through evidence synthesis, comparisons between studies were drawn and explanations for why technologies worked in some contexts and not others were proposed. This serves as a useful guide for educators and researchers in technology enhanced practices and their application.

Second, an electronic survey was sent to a pre-determined academic from the 22 Australian and two New Zealand Medical Schools on the content, delivery, assessment, and development of neuroanatomy education for their students. Data was collated, and an overview of neuroanatomy education in medical schools was presented. Explanations, and potential solutions, for improved translation of research into practice was proposed. Specifically, collaborative studies built on a shared curriculum.

Third, a prospective cohort study to identify the relationship between learner-based factors: spatial ability, motivation and anxiety and knowledge acquisition was conducted. Validated instruments including the Mental Rotations Test, MSLQ and DASS-21 were applied to measure, quantitatively, the correlation between these factors and students' examination scores. These correlations were presented and suggested that interventions that augment learner-based factors are a means of improving knowledge acquisition; a gateway to individualised education.

Finally, a prospective, randomised control study comparing web-based and traditional modes of teaching for a variety of neuroanatomical topics was started before COVID-19 suspended in-class activities. While disappointing that the study ended prematurely, valuable observations of students' learning preferences were made; namely, the preference to learn with cadaveric material, and the difference in collaborative versus independent learning in a laboratory and web-based learning environments respectively. A valuable methodology to compare technology enhanced learning techniques was also described and may be a useful consideration for future studies.

Implications for theory

Based on current evidence, technology enhanced teaching methods are not inferior to conventional didactic methods, although their efficacy in teaching neuroanatomy may not be delivering the results one may have hoped for initially. This is partly due to cognitive overload, and the presentation of too much information to the learner at once, or in too short space of time. Further, technology enhanced learning methods involve a learning curve for familiarising oneself with a new learning technology, which may explain a slow uptake of information by modern means.

There is utility in the use of stereoscopic images and augmented reality in particular contexts where complex spatial relationships of neuroanatomical information is required, and in advanced presentations where cognitive load must be reduced. However, there is no difference in the use of stereoscopic videos or virtual reality compared to controls. By contextualising when some interventions worked and not others, the research and evidence available allows educators to select pedagogies that optimise neuroanatomy education. This will become increasingly important as more methods are developed and tested.

There are significant differences between medical schools in neuroanatomy teaching, in terms of the content, delivery, assessment and development of their curriculum, with variable uptake of evidence-based methods and a continued reliance on didactic methodologies. Currently, adoption of technology enhanced learning methods is low and teaching techniques are mostly used as adjuncts, with the main body of knowledge taught by didactic means. A problem remains in the transfer of evidence-based strategies from research to educational practice. The body of evidence for technology-based methods is not strong enough, or descriptive enough, to allow educators to make clear plans for their incorporation into their curriculum. As medical schools continue to adjust to problem-based, integrated curricular with fewer hours dedicated to neuroanatomy teaching – this research translation will become increasingly important.

With fewer hours dedicated to teaching, a possible expectation of medical school education is to adapt to individualised education of their students. Two factors have been identified, where targeting interventions to increase students' perceptions of the value of learning neuroanatomy and reduce anxiety, both correlated to knowledge acquisition, may improve student performance in neuroanatomy. After quantifying their relative influence on knowledge acquisition, future research that is directed towards developing technologies that enhance education by augmenting these learner-based factors may improve student performance.

It is possible that the degree to which teaching techniques interplay with these learner-based factors could explain variance in student performance when these techniques are investigated. Indeed, even since the writing of this thesis, research has demonstrated spatial ability facilitates learning in mixed reality settings compared to traditional model-based approaches. That is, students with greater spatial ability may tend to learn more in mixed reality settings, but this is not the case in learning by physical models [138]. Another series of studies that examines the way neuroanatomy is taught in medical schools, on a large scale with extensive multi-variate analysis and an analysis of these factors, may delineate these relationships and advance our knowledge of the topic further.

Important observations were made about the value students place on traditional, cadaveric-based anatomy. Specifically, students tended to prefer tried and tested, traditional methods of teaching in favour of digital methods when given the choice. This is possibly because the appeal of digital technology has diminished, based on the subjective assessments of students' attitudes towards the experiment. That is, as these resources have become more widely available, and free-to-access, the initial excitement about these novel methods appears to wear off. Further, it was observed that students opted for independent study in web-based teaching sessions, where laboratory-based education encouraged collaborative learning. These were important findings demonstrating why educators should continue to advocate for cadaveric-based learning.

Future research may be conducted according to the methodology outlined in chapter five, to better illustrate the effect of teaching techniques across a range of neuroanatomical concepts, and at varying time points. This may provide educators, and students, with the evidence to support the use of modern technologies in standard pedagogical practise. While knowledge acquisition and long-term retention should be major considerations in the development and augmentation of new technologies, so too should the neuroanatomy learning experience.

Recommendations for teaching

Several key recommendations have arisen from the works of this thesis. First, the need for research translation and resource-sharing nationally. Second, evidence-based application of technology enhanced learning methods. Finally, learner-based factors to be considered by academics planning teaching.

Few medical schools in Australia and New Zealand utilise a neuroanatomy curriculum, reducing generalizability of research and hindering its translation into practise. The first recommendation is to establish a Delphi Group, or more specifically a national neuroanatomy curriculum working/research group, to facilitate collaborative teaching practises. Ideally, this group would be formed by a combination of neurologists, neurosurgeons and academics, with representatives from all major institutions around Australia and New Zealand. A primary goal of this entity would be to establish a national neuroanatomy curriculum. With interested researchers and partners, secondary aims could be research output in optimising teaching methods including publication of guidelines in the use of technology enhanced pedagogy. Groups such as these could collaborate internationally and draw on global experience/research.

Technology-enhanced teaching methods offer highly realistic learning experiences supportive of complex learning and transfer and can be used in place of, or complimentary to, traditional learning methods. The second recommendation is appropriate use of technology enhanced teaching methods for specific types of neuroanatomy being taught. There are two main areas when pedagogies like stereoscopy, augmented and virtual reality are most useful, including when complex spatial relationships of neuroanatomical information is required, and in advanced presentations where cognitive load must be reduced. Further, the specific tool is also relevant for educators. For example, stereoscopic 3D video tools made no difference to overall knowledge acquisition compared to 2D videos of the same content. Student's learning by stereoscopic views of 2D images had mixed performance relative to students learning by 2D images alone, but this was possibly related to the degree of learner-content interaction that instructors used to facilitate learning. Finally, provided the technology is relatively intuitive, or there is appropriate orientation to the methods, AR reduces cognitive load and may improve performance. A trend of the review was that specific application of technology enhanced learning methods was important, and neuroanatomy educators should consider using these technologies in complex, or abstruse spatial concepts.

As the body of literature grows on learner-based factors relevant to neuroanatomy education, the environment and teaching strategy may be changed to enhance learning. It was demonstrated here that perceived task value was weakly positively correlated with final unit score, and anxiety was negatively correlated. Academics planning teaching should consider running interventions that increase students' perceptions of the value of learning neuroanatomy such as case-enhanced learning and reducing anxiety, including team-based learning and clinical exposure. Future research may develop new, or augment existing, technologies with these theories in mind.

Limitations of the thesis

Various limitations concerning research methodology and results are identified in the respective chapters. A major limitation consistent across all papers were that results were obtained from a single institution, and one region. Despite having reasonable sample sizes, the heterogeneity in the student populations around the world limit the reliability of these studies findings. Multi-institutional and multi-national trials and reviews taking diversity into consideration are important in sustaining the collaborative environment of researchers advancing neuroanatomy education.

The final study ended prematurely due to COVID-19, disappointingly. This chapter would have yielded interesting data comparing web-based versus traditional learning across a range of neuroanatomical concepts, which is missing from the broader literature and the discussion of the value of technology enhanced learning. When in-class activities return to more conventional practise, the opportunity may arise to investigate this further.

Implications for future research

While this thesis was directed at identifying gaps in the literature, elements of this research reflect the current trends in literature on the topic and are broadly discussed here. Namely, the rapid increase in publications on neuroanatomy education, the mixed incorporation of technology-enhanced teaching strategies into practise and a focus on learner-based factors as a means of personalising education.

First, this research reflects the growing body of literature on the topic. That is, neuroanatomy education is a fast-moving area of research with an accelerating expansion in the volume of published literature available for educators, particularly in the last 5-10 years. Researchers and teachers alike are recognising the pressures of finding space in the curriculum, and the design of technology enhanced methods of teaching has been identified as a part of the solution. Even since completion of data collection, much research has been done that adds to discussion of what has been discussed here. Regular reviews on the topic, running commentaries and evidence synthesis will play an increasingly important role for educators hoping to stay up to date with modern trends.

The COVID-19 pandemic has been a clear incentive/catalyst for educators to adapt their teaching practices, and adopt technology enhanced teaching methods if they had not already done so. The move to distance-based learning with even less dedicated teaching time may have necessitated this approach, but also reflects the growing body of literature supporting the use of these methods as an adjunct to traditional teaching. While at this stage, the findings of this thesis are like that of the broader literature that there are no silver bullets in technology-enhanced teaching strategies, the technologies are certainly not inferior in content delivery and may be substituted where appropriate. On a broader note, selection of teaching tools is left to the discretion of the academic at respective institutions, and it is not surprising the adoption of these strategies is particularly variable; a consistent finding across anatomy teaching more broadly [123]. Collaborative approaches to research and resource-sharing are important strategies for facilitating research translation in this area.

The importance of learner-based factors and their interplay with the teaching method employed, and ultimately knowledge acquisition, is of increasing interest to educators. Research is incorporating factors such as engagement, motivation and student confidence into assessments of new technologies, recognising the relationship between these factors and student performance. Anxiety and elements of motivation that are correlated to student performance have been identified, and further research is being conducted into other relevant learner-based factors such as spatial ability. Moving towards individualised education, these will play an increasingly important role.

Conclusion

In this thesis, original studies have been presented that further our understanding of how neuroanatomy education may be enhanced and demonstrated the promising space modern technologies may play a part. Further, it has offered explanations for why technologies such as AR and VR work in some settings and not others. Further, it identifies factors such as anxiety, and spatial ability, that are correlated to knowledge acquisition and may be used by educators to target these factors to improve student performance.

While an early objective of this thesis was to identify an optimal mode of teaching neuroanatomy that enhances knowledge acquisition and long-term retention, it was made clear that it is a far more complex issue than that. As the breadth of our scientific knowledge expands, neuroanatomy forms a smaller part of developing medical curricular; but retains its importance for the education of future medical professionals. Educators face the challenge of overcoming reduced teaching hours in the context of integrated, problem-based curricular changes. Future research that builds on the work of others will facilitate a more precise, individualised, and impactful application of these technologies, while preserving the wonder and experience of learning neuroanatomy.

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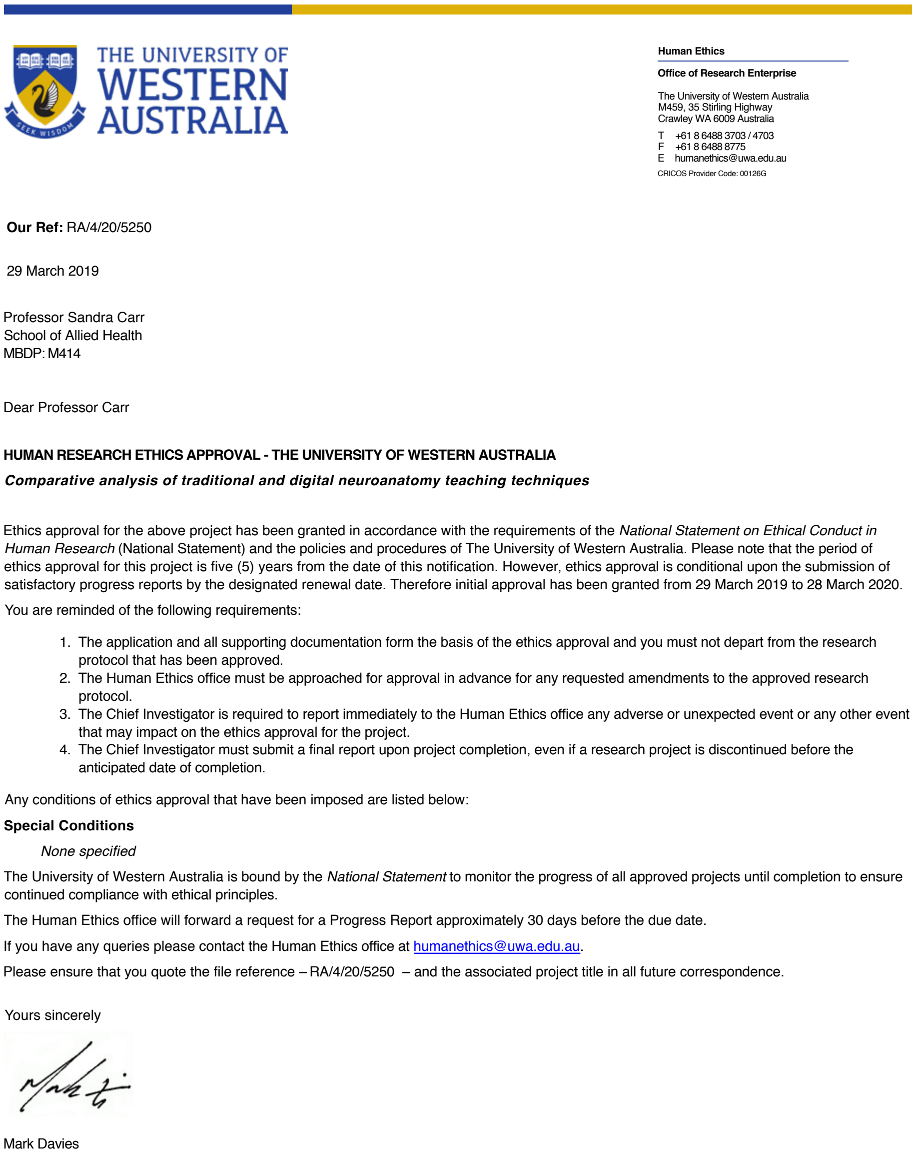
APPENDICES

Appendix A: Ethics Approval



THE UNIVERSITY OF WESTERN AUSTRALIA

SEEK WISDOM

Human Ethics
Office of Research Enterprise

The University of Western Australia
M459, 35 Stirling Highway
Crawley WA 6009 Australia

T +61 8 6488 3703 / 4703
F +61 8 6488 8775
E humanethics@uwa.edu.au

CRICOS Provider Code: 00126G

Our Ref: RA/4/20/5250

29 March 2019

Professor Sandra Carr
School of Allied Health
MBDP: M414

Dear Professor Carr

HUMAN RESEARCH ETHICS APPROVAL - THE UNIVERSITY OF WESTERN AUSTRALIA

Comparative analysis of traditional and digital neuroanatomy teaching techniques

Ethics approval for the above project has been granted in accordance with the requirements of the *National Statement on Ethical Conduct in Human Research* (National Statement) and the policies and procedures of The University of Western Australia. Please note that the period of ethics approval for this project is five (5) years from the date of this notification. However, ethics approval is conditional upon the submission of satisfactory progress reports by the designated renewal date. Therefore initial approval has been granted from 29 March 2019 to 28 March 2020.

You are reminded of the following requirements:

1. The application and all supporting documentation form the basis of the ethics approval and you must not depart from the research protocol that has been approved.
2. The Human Ethics office must be approached for approval in advance for any requested amendments to the approved research protocol.
3. The Chief Investigator is required to report immediately to the Human Ethics office any adverse or unexpected event or any other event that may impact on the ethics approval for the project.
4. The Chief Investigator must submit a final report upon project completion, even if a research project is discontinued before the anticipated date of completion.

Any conditions of ethics approval that have been imposed are listed below:

Special Conditions

None specified

The University of Western Australia is bound by the *National Statement* to monitor the progress of all approved projects until completion to ensure continued compliance with ethical principles.

The Human Ethics office will forward a request for a Progress Report approximately 30 days before the due date.

If you have any queries please contact the Human Ethics office at humanethics@uwa.edu.au.

Please ensure that you quote the file reference – RA/4/20/5250 – and the associated project title in all future correspondence.

Yours sincerely

Mark Davies

Manager, Human Ethics

Name	***Faculty / School***	***Role***
Professor Sandra Carr	School of Allied Health	Chief Investigator
Dr Stuart Bunt	School of Human Sciences	Co-Investigator
Dr Amanda Meyer	School of Human Sciences	Co-Investigator

Student(s): Hamish Newman

The University of Western Australia
Crawley WA 6009 Australia

T +61 8 6488 3703 / 4703
F +61 8 6488 8775

E humanethics@uwa.edu.au
CRICOS Provider Code: 00126G

Appendix B: Data Collection Instruments

1. Australia and New Zealand Medical Schools Neuroanatomy Survey

THE UNIVERSITY OF
WESTERN AUSTRALIA

Teaching of Neuroanatomy in Australian and New Zealand Medical Schools

1. Welcome

In 2010, UOW Academics performed a study on anatomy teaching in Australian and New Zealand medical schools. The first accurate representation of national collated data, the research has been cited over 160 times and greatly influenced discussion about delivery of anatomy to medical students.
This is an invitation to participate in a study endorsed by the Royal Australasian College of Surgeons that aims to specifically characterize neuroanatomy teaching of medical students in Australia and New Zealand medical schools. Research implicates poor anatomy knowledge of medical graduates, particularly of the central and peripheral nervous systems, as an important issue. Results of this survey will provide the basis for improved understanding and delivery of neuroanatomy teaching in medical schools. It is anticipated this study will have a substantial impact both to the academic environment, and the future of neuroanatomy teaching research.

The potential benefits of participation are that Individual participants (Universities) will be able to gauge their performance across a number of criteria with respect to national averages for neuroanatomical curricula delivery within Australasian medical schools. There are no identified risks to participation and the participant’s burden is limited to the time taken to complete this single survey (approx. 20mins). Participation is voluntary and each participant is free to withdraw from the study at any time by exiting the Qualtrics survey. Any data entered by the participant prior to exiting will be available to the researchers. Participants can contact Dr Amanda Meyer on (08) 6488 2671 or via email Amanda.meyer@uwa.edu.au should they wish to have all data removed from the study.

We aim to present the findings of our project at the 2020 Neurosurgical Society of Australasia Annual Scientific Meeting and to publish the findings in peer reviewed medical education journals. Participant’s confidentiality will be maintained through the use of averaged data and no individual participant will be identifiable in any form of disseminated research outcomes.

This study has been reviewed by the UWA Human Research Ethics committee. If you have any concerns or complaints about the way this research is conducted you can contact the Ethics Manager on (08) 6488 8775 or email humanethics@uwa.edu.au.

Yours sincerely,

Mr Hamish Newman
Dr Amanda Meyer
Professor Sandra Carr

THE UNIVERSITY OF
WESTERN AUSTRALIA

Teaching of Neuroanatomy in Australian and New Zealand Medical Schools

2. Demographic Information

Q1 This question is optional. The information provided will be used for correspondence only should the researchers require further clarification on any text answers.

Name: ________________________________

University: ________________________________

Address Line 1: ________________________________

Address Line 2: ________________________________

City: ________________________________

State: ________________________________

Postal Code: ________________________________

Country: ________________________________

Email address: ________________________________

Position: ________________________________

THE UNIVERSITY OF
WESTERN AUSTRALIA

Teaching of Neuroanatomy in Australian and New Zealand Medical Schools

3. Section 1: Course Details

Q2 Is your course:

- ○ Traditional
- ○ Problems Based
- ○ Systems Based
- ○ Integrated

Other (please specify) ______________________________

Q3 Is your course:

- ○ Undergraduate entry
- ○ Postgraduate entry
- ○ Combined

Other (please specify) ______________________________

Q4 What is the length of your course:

- ○ 4 years
- ○ 5 years
- ○ 6 years

Other (please specify) ______________________________

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Teaching of Neuroanatomy in Australian and New Zealand Medical Schools

Section 1: Course Details cont.

Q5 Approximately how many hours of face-to-face teaching does your course offer in each year of the course? This question refers to all teaching within the curriculum.

- ○ Year 1 ____
- ○ Year 2 ____
- ○ Year 3 ____
- ○ Year 4 ____
- ○ Year 5 ____
- ○ Year 6 ____

Q6 Mark, using the sliding scales, an approximate position of your course on the SPICES model continuums

	0	10
Student-centred (0) to teacher-centred (10)		
Problem-based (0) to information-gathering (10)		
Integrated (0) to discipline-based (10)		
Community-based (0) to hospital-based (10)		
Electives (0) to standard programme (10)		
Systematic (0) to apprenticeship-based/opportunistic (10)		

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Teaching of Neuroanatomy in Australian and New Zealand Medical Schools

Section 2: Gross Neuroanatomy Teaching

Q7 During which year is neuroanatomy taught in your course?

○ Year 1
○ Year 2
○ Year 3
○ Year 4
○ Year 5
○ Year 6

Q8 Approximately how many hours of gross neuroanatomy teaching are offered in each year of your course (including practicals, lectures and tutorials)?

○ Year 1 ____
○ Year 2 ____
○ Year 3 ____
○ Year 4 ____
○ Year 5 ____
○ Year 6 ____

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Teaching of Neuroanatomy in Australian and New Zealand Medical Schools

Section 2: Gross Neuroanatomy Teaching cont.

Q9 In which years are the following session types used to teach gross neuroanatomy in your course?

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Wet Practicals	☐	☐	☐	☐	☐	☐
Dry Practicals	☐	☐	☐	☐	☐	☐
Lectures	☐	☐	☐	☐	☐	☐
Others (e.g. imaging)	☐	☐	☐	☐	☐	☐

Q10 What is the approximate duration of the following gross neuroanatomy teaching sessions in your course?

	30 min	60 min	90 min	120 min	150 min	>150 min
Wet Practicals	○	○	○	○	○	○
Dry Practicals	○	○	○	○	○	○
Lectures	○	○	○	○	○	○
Others (e.g. imaging)	○	○	○	○	○	○

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Teaching of Neuroanatomy in Australian and New Zealand Medical Schools

Section 2: Gross Neuroanatomy Teaching cont.

Q11 How often are the following resources used to teach gross neuroanatomy?

	Every session	Most sessions	Some sessions	Rarely	Never
Prosected human material	○	○	○	○	○
Dissection	○	○	○	○	○
Plastinated specimens	○	○	○	○	○
Models	○	○	○	○	○
Computer generated images	○	○	○	○	○
Imaging	○	○	○	○	○

Q12 Has your anatomy department/laboratory invested in classroom teaching technologies (tablet device, eBooks, HoloLens, VR, 3D software, etc.)?

- ○ Yes
- ○ No
- ○ If yes, please specify the type of technology: ______________________________

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Teaching of Neuroanatomy in Australian and New Zealand Medical Schools

Section 2: Gross Neuroanatomy Teaching cont.

Q13 How often are the following teaching technologies used to teach gross neuroanatomy?

	Every session	Most sessions	Some sessions	Rarely	Never
University supplied tablet devices with apps	○	○	○	○	○
HoloLens	○	○	○	○	○
Virtual Reality	○	○	○	○	○
eBook Anatomy Manual	○	○	○	○	○
3D software to display CT/MRI images	○	○	○	○	○
Haptic Systems	○	○	○	○	○
Virtual dissection tables	○	○	○	○	○
Other (please specify)	○	○	○	○	○

Q14 Do you use an established neuroanatomy curriculum to select content to be taught?

- ○ Yes
- ○ No
- ○ If yes, please specify which curriculum: ______________________________

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Teaching of Neuroanatomy in Australian and New Zealand Medical Schools

Section 2: Gross Neuroanatomy Teaching cont.

Q15 Does your course adjust the teaching method to suit neuroanatomical content?

○ Yes

○ No

○ If yes, please elaborate on how ____

Q16 Does your course offer dissection experience?

○ Yes

○ No

○ If yes, please comment on the method (i.e. directed with a manual, student directed or donor medical condition direction). Please also comment on the duration and curriculum timing of delivery (i.e. which year) ____

Teaching of Neuroanatomy in Australian and New Zealand Medical Schools

Section 3: Integration of Neuroanatomy and Other Subjects

Q17 Is neuroanatomy teaching integrated with other subject content (i.e. clinical skills)?

○ Yes

○ No

○ If yes, with what type of subject content and how often does this occur?

____

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Teaching of Neuroanatomy in Australian and New Zealand Medical Schools

Section 4: Assessment

Q18 Which formats are utilised to assess gross neuroanatomy comprehension

○ Formative assessment
○ Summative assessment
○ Short answer questions
○ Multiple choice questions
○ Modified essay questions
○ Extended matching questions
○ Practical based identification (MCQ)
○ Practical based identification (SAQ)
○ Practical based viva/oral questions
○ Other (please specify) ____

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Teaching of Neuroanatomy in Australian and New Zealand Medical Schools

Section 5: Course Development

Q19 Has neuroanatomy teaching changed in the last 5 years (e.g. content, assessment, teaching method)?

- ○ Yes
- ○ No
- ○ If yes, in what ways? ____

Q20 Do you evaluate teaching methods used?

- ○ Yes
- ○ No
- ○ If yes, how? ____

Q21 Has the quality of neuroanatomy teaching increased or decreased in the last 5 years? In what ways?

____

Q22 Tell us about student engagement/motivation for learning neuroanatomy in your course. What are the major facilitators of student engagement/motivation? What are the major challenges? What opportunities exist to improve these?

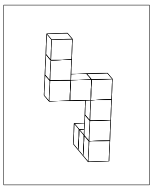
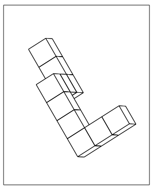
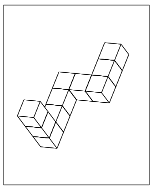
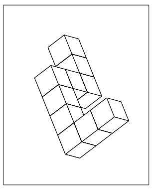
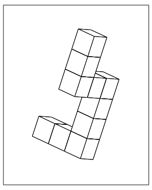
____

2. Mental Rotations Test

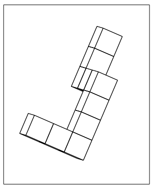
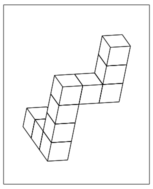
MENTAL ROTATIONS TEST (MRT-A)

This test is composed of the figures provided by Shepard and Metzler (1978), and is, essentially, an Autocad-redrawn version of the Vandenberg & Kuse MRT test.

Please look at these five figures

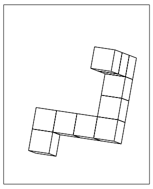
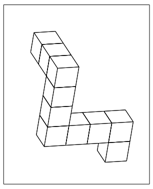
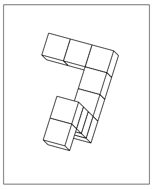
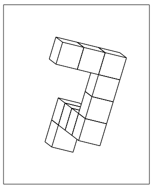
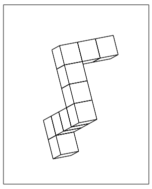
Note that these are all pictures of the same object which is shown from different angles. Try to imagine moving the object (or yourself with respect to the object), as you look from one drawing to the next.

Here are two drawings of a new figure that is different from the one shown in the first 5 drawings. Satisfy yourself that these two drawings show an object that is different and cannot be "rotated" to be identical with the object shown in the first five drawings.

Now look at this object:
1.

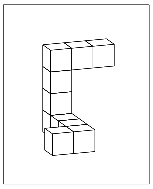
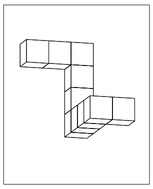
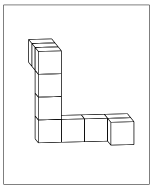
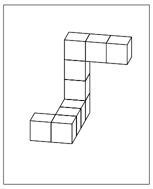
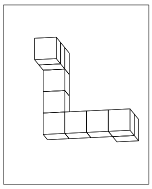
Two of these four drawings show the same object.
Can you find those two? Put a big X across them.

If you marked the first and third drawings, you made the correct choice.

Here are three more problems. Again, the target object is shown <u>twice</u> in each set of four alternatives from which you choose the correct ones.

2.a

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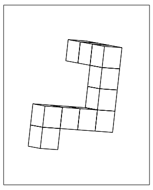
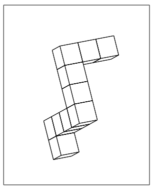
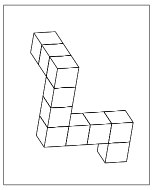
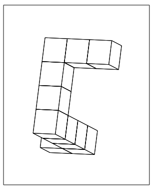
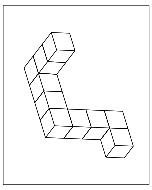

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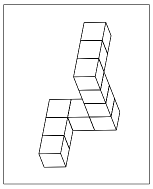
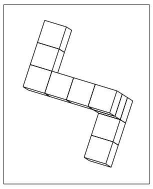
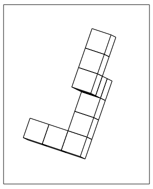
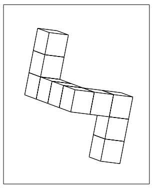
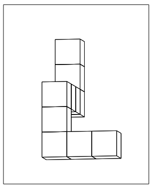
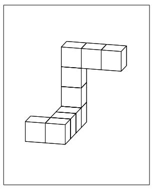
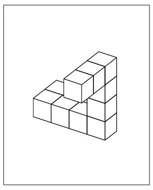
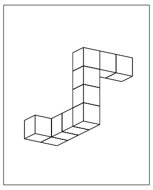
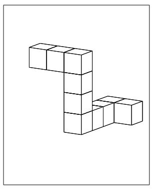
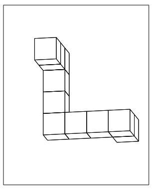






Correct Choice:	2: second and third 3: first and fourth 4: first and third

When you do the test, please remember that for each problem set there are <u>two</u> and <u>only two</u> figures that match the target figure.

You will only be given a point if you mark off <u>both</u> correct matching figures, marking off only one of these will result in no marks.

1.a

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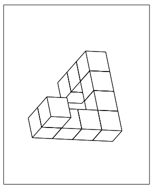
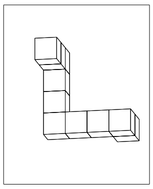
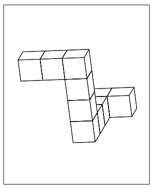
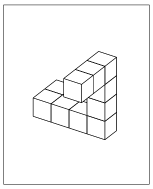
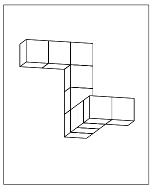

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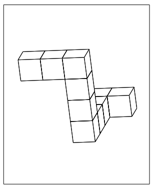
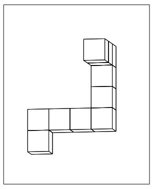
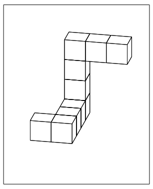
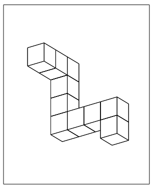
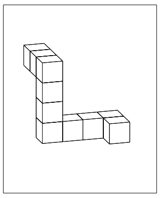

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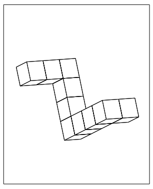
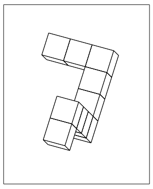
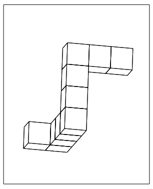
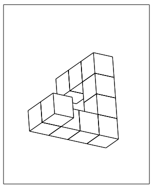
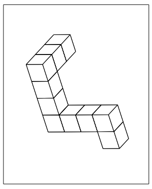

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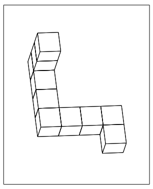
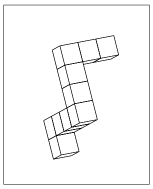
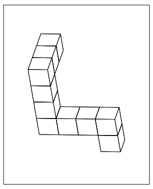
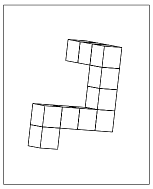
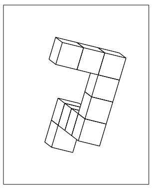

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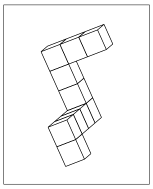
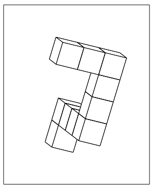
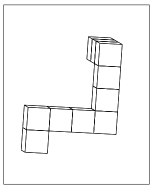
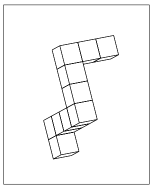
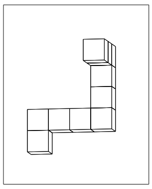

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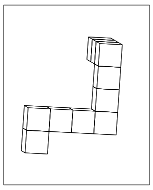
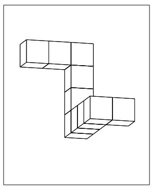
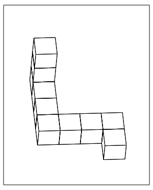
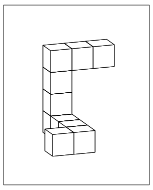
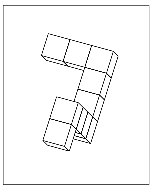

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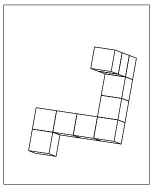
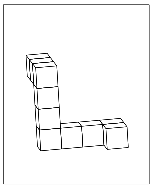
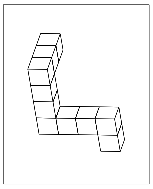
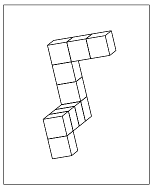
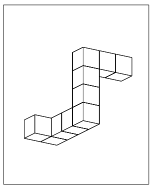

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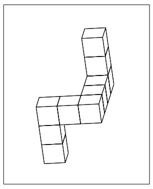
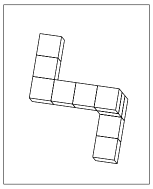
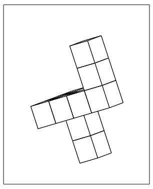
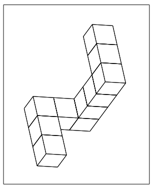
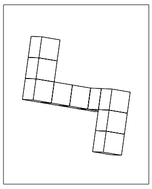

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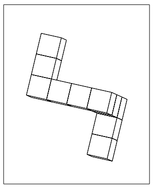
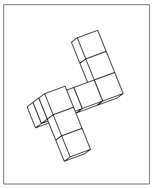
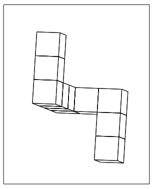
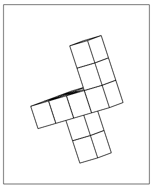
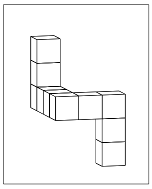

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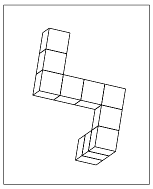
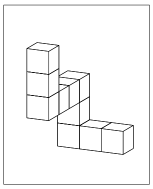
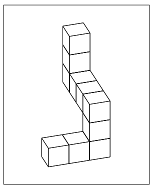
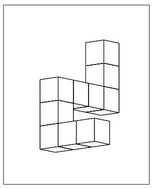
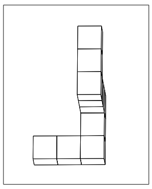

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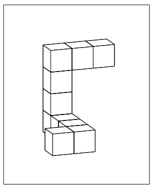
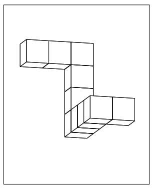
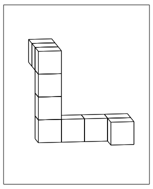
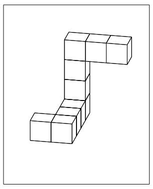
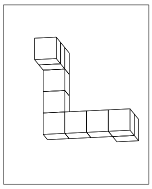

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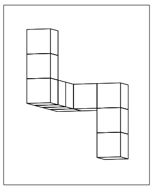
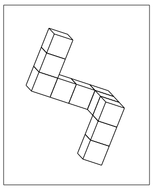
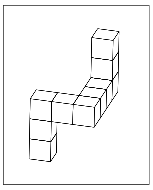
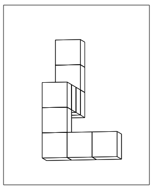
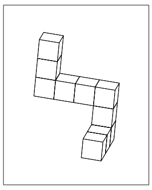

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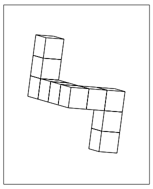
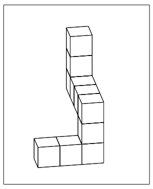
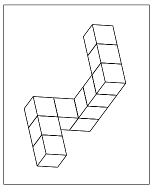
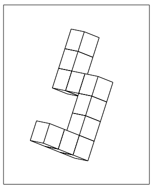
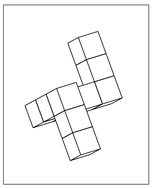

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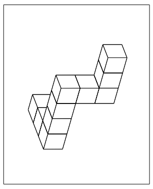
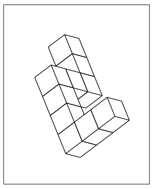
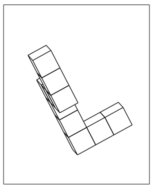
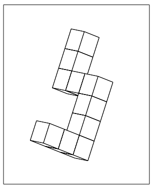
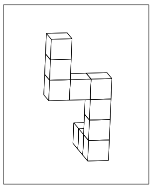

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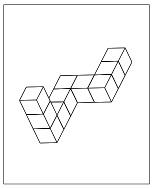
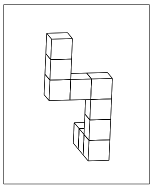
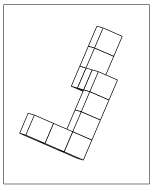
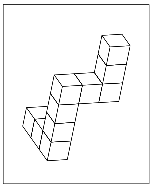
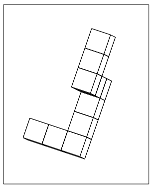

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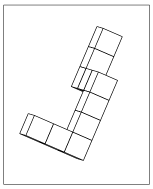
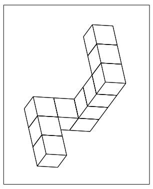
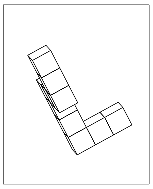
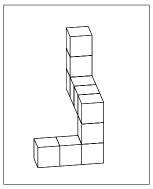
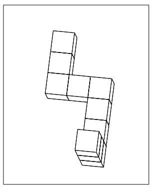

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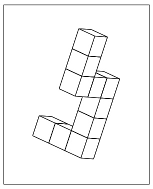
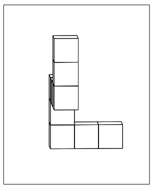
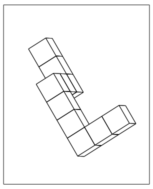
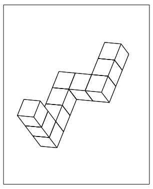
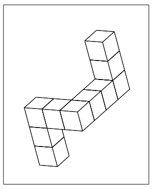

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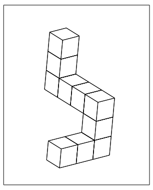
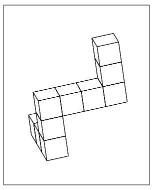
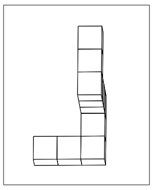
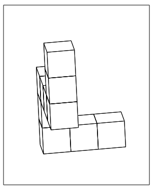
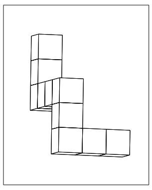

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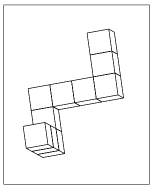
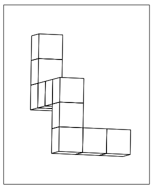
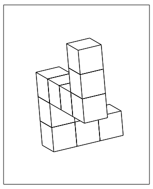
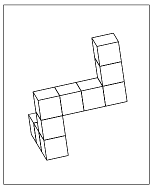
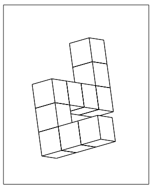

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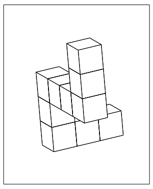
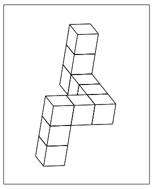
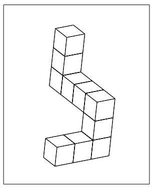
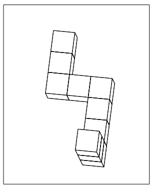
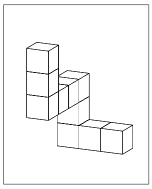

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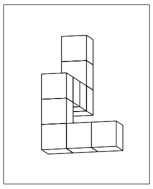
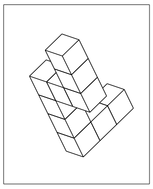
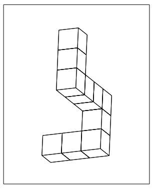
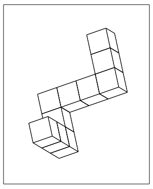
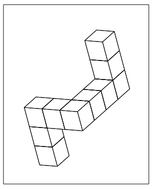

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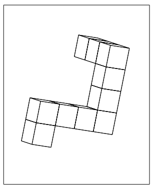
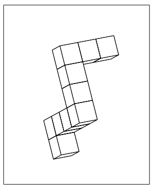
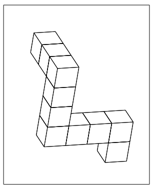
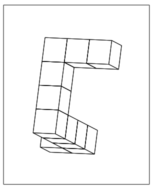
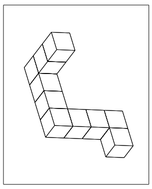

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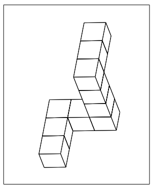
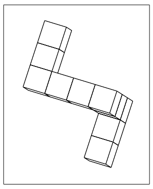
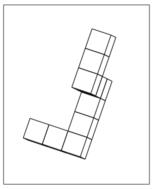
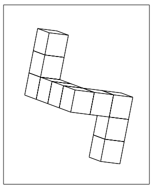
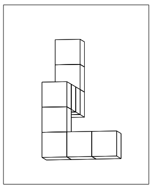
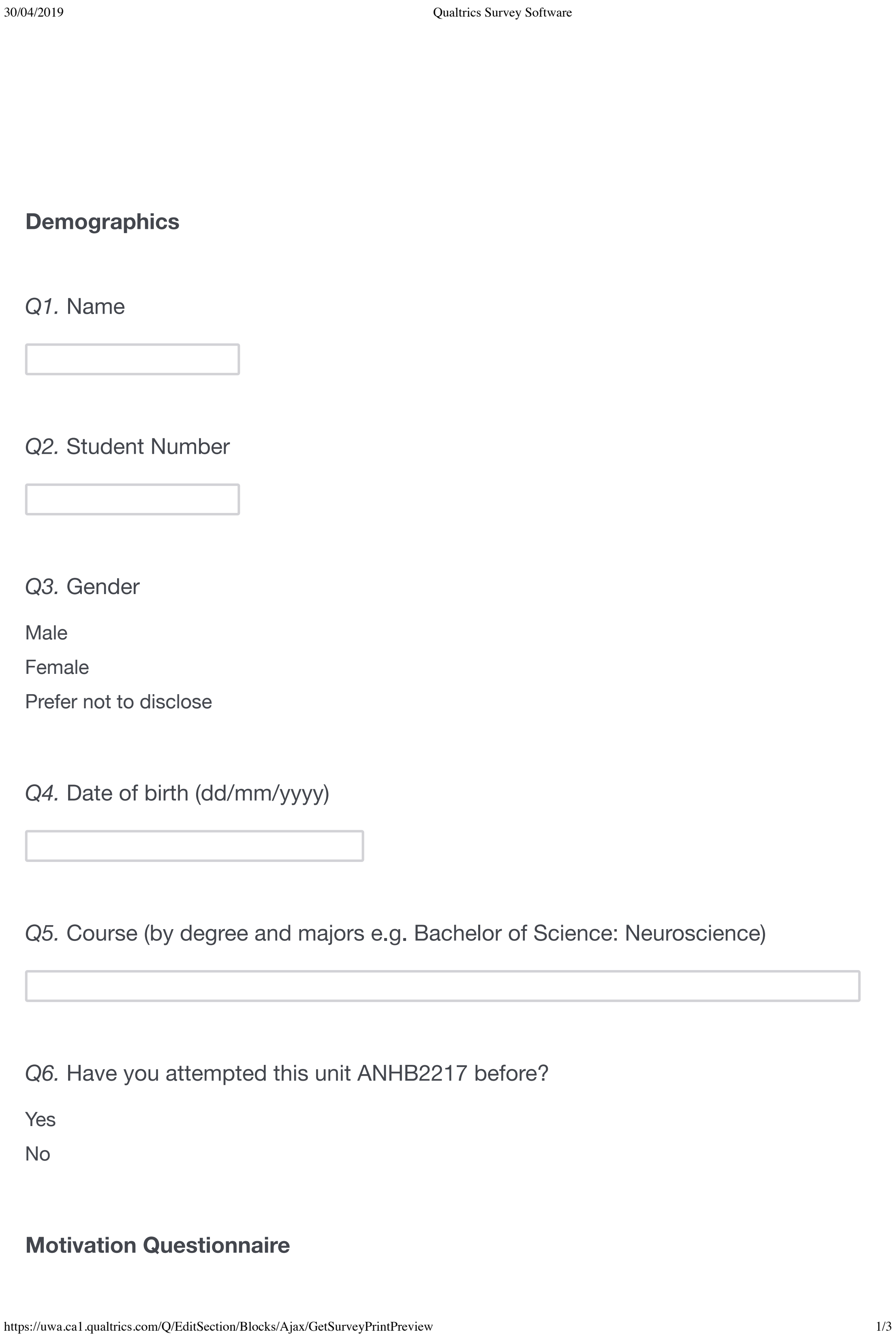






3. Motivated Strategies for Learning Questionnaire



Demographics

Q1. Name

Q2. Student Number

Q3. Gender

Male
Female
Prefer not to disclose

Q4. Date of birth (dd/mm/yyyy)

Q5. Course (by degree and majors e.g. Bachelor of Science: Neuroscience)

Q6. Have you attempted this unit ANHB2217 before?

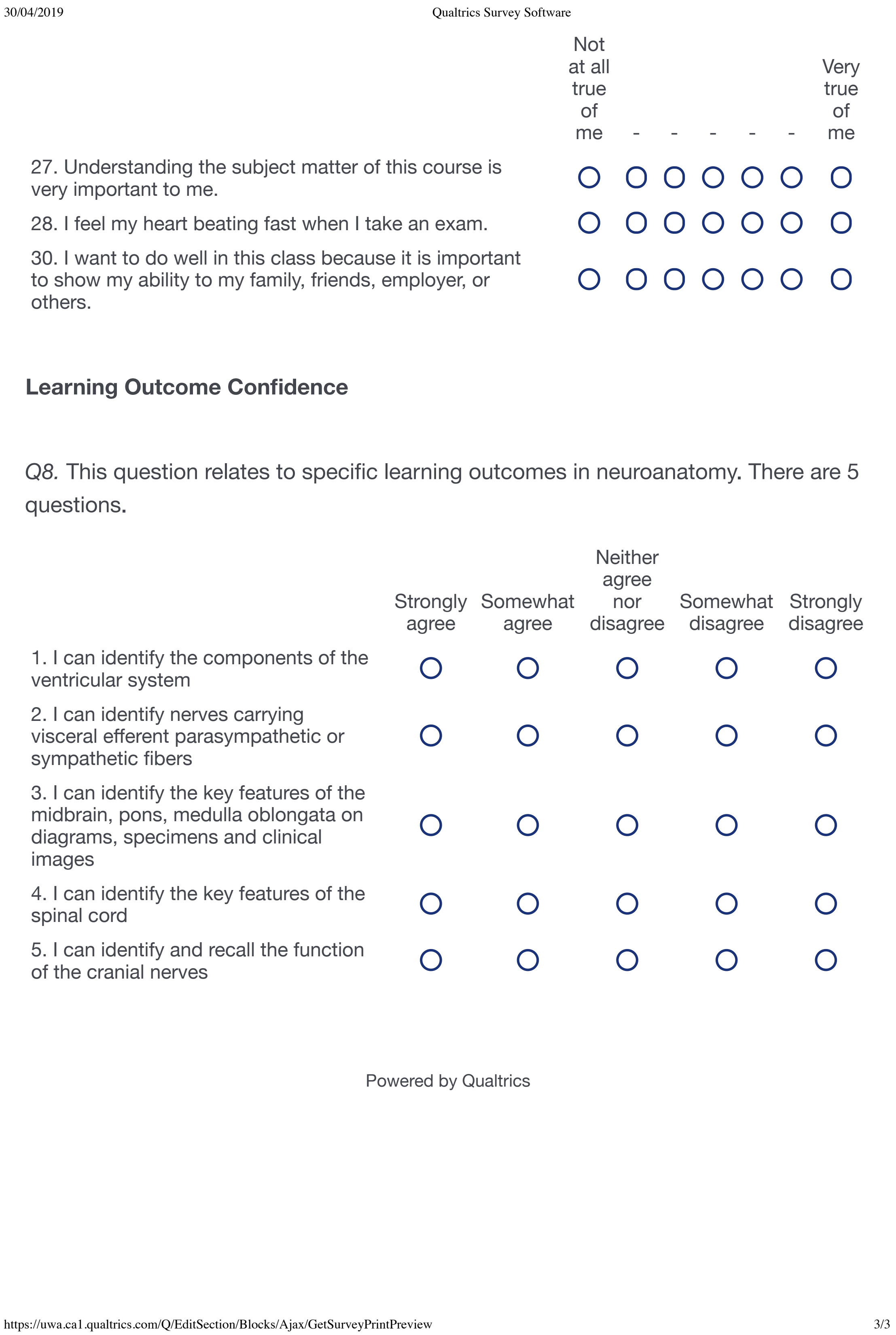
Yes
No

Motivation Questionnaire

Q7.

This question relates to learning outcomes in neuroanatomy. There are 19 questions. Some questions have been removed from the original 31-item questionnaire. Use the scale below to answer the questions. If you think the statement is very true of you, circle 7; if a statement is not at all true of you, circle 1. If the statement is more or less true of you, find the number between 1 and 7 that best describes you.

	Not at all true of me	-	-	-	-	-	Very true of me
1. In a class like this, I prefer course material that really challenges me so I can learn new things.	○	○	○	○	○	○	○
3. When I take a test I think about how poorly I am doing compared with other students.	○	○	○	○	○	○	○
4. I think I will be able to use what I learn in this course in other courses.	○	○	○	○	○	○	○
7. Getting a good grade in this class is the most satisfying thing for me right now.	○	○	○	○	○	○	○
8. When I take a test I think about items on other parts of the test I can't answer.	○	○	○	○	○	○	○
10. It is important for me to learn the course material in this class.	○	○	○	○	○	○	○
11. The most important thing for me right now is improving my overall grade point average, so my main concern in this class is getting a good grade.	○	○	○	○	○	○	○
13. If I can, I want to get better grades in this class than most of the other students.	○	○	○	○	○	○	○
14. When I take tests I think of the consequences of failing.	○	○	○	○	○	○	○
16. In a class like this, I prefer course material that arouses my curiosity, even if it is difficult to learn.	○	○	○	○	○	○	○
17. I am very interested in the content area of this course.	○	○	○	○	○	○	○
19. I have an uneasy, upset feeling when I take an exam.	○	○	○	○	○	○	○
22. The most satisfying thing for me in this course is trying to understand the content as thoroughly as possible.	○	○	○	○	○	○	○
23. I think the course material in this class is useful for me to learn.	○	○	○	○	○	○	○
24. When I have the opportunity in this class, I choose course assignments that I can learn from even if they don't guarantee a good grade.	○	○	○	○	○	○	○
26. I like the subject matter of this course.	○	○	○	○	○	○	○



30/04/2019 Qualtrics Survey Software

	Not at all true of me	-	-	-	-	-	Very true of me
27. Understanding the subject matter of this course is very important to me.	○	○	○	○	○	○	○
28. I feel my heart beating fast when I take an exam.	○	○	○	○	○	○	○
30. I want to do well in this class because it is important to show my ability to my family, friends, employer, or others.	○	○	○	○	○	○	○

Learning Outcome Confidence

Q8. This question relates to specific learning outcomes in neuroanatomy. There are 5 questions.

	Strongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree
1. I can identify the components of the ventricular system	○	○	○	○	○
2. I can identify nerves carrying visceral efferent parasympathetic or sympathetic fibers	○	○	○	○	○
3. I can identify the key features of the midbrain, pons, medulla oblongata on diagrams, specimens and clinical images	○	○	○	○	○
4. I can identify the key features of the spinal cord	○	○	○	○	○
5. I can identify and recall the function of the cranial nerves	○	○	○	○	○

Powered by Qualtrics

https://uwa.ca1.qualtrics.com/Q/EditSection/Blocks/Ajax/GetSurveyPrintPreview 3/3

Appendix C: Participant Information And Consent Forms

THE UNIVERSITY OF
WESTERN
AUSTRALIA

Professor Sandra Carr
Head,
Division of Health Professions Education
Faculty of Health and Medical Sciences
The University of Western Australia
35 Stirling Highway, Crawley WA 6009
Tel: 64886892
Email: sandra.carr@uwa.edu.au

Participant Information Form

Project title: **Role of spatial ability and motivation in learning neuroanatomy**

Name of Researcher: Hamish Newman (Master of Health Professions Education student).

Supervisors: Professor Sandra Carr, Professor Stuart Bunt and Dr Amanda Meyer

Invitation: You are invited to participate in a project that seeks to explore the relationships between spatial ability and motivation on a student's ability to learn neuroanatomy

You are asked to take part in this project because you are a neuroanatomy student who is participating in ANHB2217.

Aim of the Study:

To assess relationships between spatial ability and motivation on learning neuroanatomy and identify whether these are suited to particular teaching methods.

What does participation involve?

If you agree to participate in the study you will be asked to complete a short survey that will assess your visual-spatial ability, and motivations related to studying neuroanatomy. Researchers will compare results from the survey to your GPA and WAM prior to starting the unit, and ANHB2217 unit results. Therefore, you also give permission for the researchers to access these results.

You will be allocated a unique, de-identified student code which the results will be organized by.

Voluntary Participation and Withdrawal from the Study

Participation in this study is voluntary. You can withdraw from the study at any time, without reason and without consequence. Any data will be destroyed after withdrawal unless otherwise agreed.

Your privacy

Your participation in this study and any information you provide will be treated in a confidential manner. The data obtained will be coded and de-identified before being stored on a password protected computer for minimum of seven years.

Findings from this study may be published or shared at professional gatherings, however at no time will any information be presented in such a way that will reveal your identity. Your anonymity will be protected.

Possible Benefits

It is possible that there may be no direct benefit to you from your participation in this research however it is hoped that this study will guide the future support and educational needs of neuroanatomy students.

A certificate of participation will be provided for your professional portfolio.

Possible Risks and Risk Management Plan

There are no foreseeable risks associated with your participation in this research. In the event you become distressed as a result of your participation you will be offered debriefing by the researcher and given the details of a free and confidential professional counseling service.

Contacts

If you would like to participate or discuss any aspect of this study please feel free to contact Hamish on 0419 667 579. Alternatively you may contact my supervisor Professor Sandra Carr on 6488 6892 or via email at sandra.carr@uwa.edu.au.

Sincerely,

Hamish Newman
Student researcher

Approval to conduct this research has been provided by the University of Western Australia with reference number RA/4/1/xxxx, in accordance with its ethics review and approval procedures. Any person considering participation in this research project, or agreeing to participate, may raise any questions or issues with the researchers at any time. In addition, any person not satisfied with the response of researchers may raise ethics issues or concerns, and may make any complaints about this research project by contacting the Human Ethics office at UWA on (08) 6488 4703 or by emailing to humanethics@uwa.edu.au. All research participants are entitled to retain a copy of any Participant Information Form and/or Participant Consent Form relating to this research project.

THE UNIVERSITY OF WESTERN AUSTRALIA

Professor Sandra Carr
Head,
Division of Health Professions Education
Faculty of Health and Medical Sciences
The University of Western Australia
35 Stirling Highway, Crawley WA 6009
Tel: 64886892
Email: sandra.carr@uwa.edu.au

Participant Information Form

<u>Project title:</u> Comparison of traditional and digital methods of neuroanatomy teaching

<u>Name of Researcher:</u> Hamish Newman (Master of Health Professions Education student).

<u>Supervisors:</u> Professor Sandra Carr and Dr Amanda Meyer

Invitation: You are invited to participate in a project that seeks to identify differences in quality of teaching tools relevant to neuroanatomy.

You are asked to take part in this project because you are a neuroanatomy student who is participating in ANHB2217.

Aim of the Study:

To compare the use of neuroanatomical teaching techniques on knowledge acquisition and long-term retention.

What does participation involve?

You will be allocated a unique, de-identified student code which the results will be organized by.

During selected laboratories throughout the year, you will be allocated either the traditional laboratory with prosections, plastinated specimens, models and textbooks or the comparison learning experience of online textbooks, 2D computer models, 3D digital models, virtual/augmented reality demonstration. You will be asked to complete a short 5-minute pre-lab test. You will then complete one and a half hours in the allocated laboratory. This will be repeated for selected laboratories throughout the semester. Four weeks after completion of the lab, you will complete a second evaluation to explore long-term knowledge retention. This will be administered at the start of another laboratory.

Researchers will use the linked then de-identified data to compare your results from the survey and post-lab tests with your GPA and WAM prior to starting the unit, and ANHB2217 unit results. Therefore, by signing the consent form you also give permission for the researchers to access your unit mark, WAM and GPA in Callista.

Your privacy

Your participation in this study and any information you provide will be treated in a confidential manner. The data obtained will be coded and de-identified before being stored on a password protected computer for minimum of seven years.

Findings from this study may be published or shared at professional gatherings, however at no time will any information be presented in such a way that will reveal your identity. Your anonymity will be protected.

Voluntary Participation and Withdrawal from the Study

Participation (or non-participation) will not adversely affect your academic performance. However, if you wish, you can withdraw from the study at any time, without reason and without consequence. Any data will be destroyed after withdrawal unless otherwise agreed.

Possible Benefits

It is possible that there may be no direct benefit to you from your participation in this research however it is hoped that this study will guide the future support and educational needs of neuroanatomy students.

Possible Risks and Risk Management Plan

There is a small risk that students may be at a disadvantage in their learning if allocated to a condition that proves to be less effective than the other. All students will be engaged in active learning processes, and there will be equal exposure to both conditions across the cohort. Any risk is justified by the information gained within the study that may inform pedagogical approaches in the future. In the event you become distressed as a result of your participation you will be offered debriefing by the researcher and given the details of a free and confidential professional counseling service.

Contacts

If you would like to participate or discuss any aspect of this study please feel free to contact Hamish on 0419 667 579. Alternatively, you may contact my supervisor Professor Sandra Carr on 6488 6892 or via email at sandra.carr@uwa.edu.au.

Sincerely,

Hamish Newman
Student researcher

Approval to conduct this research has been provided by the University of Western Australia with reference number RA/4/20/5250, in accordance with its ethics review and approval procedures. Any person considering participation in this research project, or agreeing to participate, may raise any questions or issues with the researchers at any time. In addition, any person not satisfied with the response of researchers may raise ethics issues or concerns, and may make any complaints about this research project by contacting the Human Ethics office at UWA on (08) 6488 4703 or by emailing to humanethics@uwa.edu.au. All research participants are entitled to retain a copy of any Participant Information Form and/or Participant Consent Form relating to this research project.

THE UNIVERSITY OF WESTERN AUSTRALIA

Professor Sandra Carr
Head,
Division of Health Professions Education
Faculty of Health and Medical Sciences
The University of Western Australia
35 Stirling Highway, Crawley WA 6009
Tel: 64886892
Email: sandra.carr@uwa.edu.au

Participant Consent Form: Survey

Role of spatial ability and motivation in learning neuroanatomy

I, ________________ have read the information provided and any questions I have asked have been answered to my satisfaction. I agree to participate in this research project, realizing that I may withdraw at any time without reason and without prejudice.

I understand that all identifiable information that I provide is treated as confidential and will not be released by the investigator in any form that may identify me unless I have consented to this. The only exception to this principle of confidentiality is if this information is required by law to be released.

I have been advised as to what data is being collected, including GPA, WAM and unit results, the purpose for collecting data, and what will be done with the data upon completion of the research.

I agree that research data gathered for the study may be published or presented at professional gatherings, provided my name of other identifying information is not used.

I agree to participate in an audio and video recorded focus group.

_________________________ Participant signature

_______________ Date

Approval to conduct this research has been provided by the University of Western Australia, in accordance with its ethics review and approval procedures. Any person considering participation in this research project, or agreeing to participate, may raise any questions or issues with the researchers at any time.

In addition, any person not satisfied with the response of researchers may raise ethics issues or concerns, and may make any complaints about this research project by contacting the Human Ethics Office at the University of Western Australia on (08) 6488 3703 or by emailing to humanethics@uwa.edu.au

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THE UNIVERSITY OF
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The University of Western Australia
35 Stirling Highway, Crawley WA 6009
Tel: 64886892
Email: sandra.carr@uwa.edu.au

Participant Consent Form: Comparative analysis of neuroanatomical teaching techniques

Comparative analysis of traditional and digital methods of neuroanatomy teaching

I, ________________ have read the information provided and any questions I have asked have been answered to my satisfaction. I agree to participate in this research project, realizing that I may withdraw at any time without reason and without prejudice.

I understand that all identifiable information that I provide is treated as confidential and will not be released by the investigator in any form that may identify me unless I have consented to this. The only exception to this principle of confidentiality is if this information is required by law to be released.

I have been advised as to what data is being collected, including GPA, WAM and unit results, the purpose for collecting data, and what will be done with the data upon completion of the research.

I agree that research data gathered for the study may be published or presented at professional gatherings, provided my name of other identifying information is not used.

_________________________ Participant signature

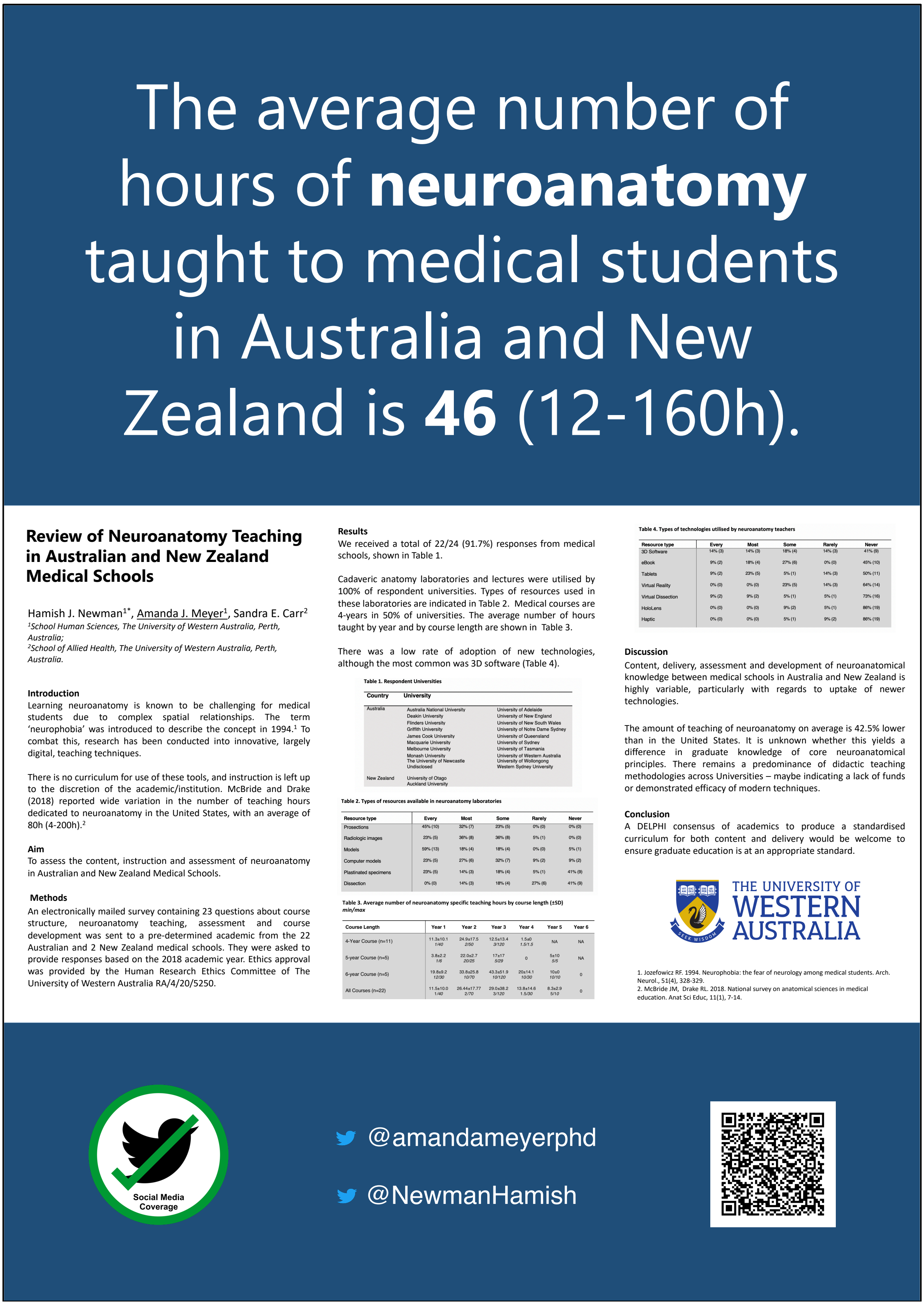
_______________ Date

Approval to conduct this research has been provided by the University of Western Australia, in accordance with its ethics review and approval procedures. Any person considering participation in this research project, or agreeing to participate, may raise any questions or issues with the researchers at any time.

In addition, any person not satisfied with the response of researchers may raise ethics issues or concerns, and may make any complaints about this research project by contacting the Human Ethics Office at the University of Western Australia on (08) 6488 3703 or by emailing to humanethics@uwa.edu.au

All research participants are entitled to retain a copy of any Participant Information Form and/or Participant Consent Form relating to this research project.

Appendix D: Research Output



The average number of hours of **neuroanatomy** taught to medical students in Australia and New Zealand is **46** (12-160h).

Review of Neuroanatomy Teaching in Australian and New Zealand Medical Schools

Hamish J. Newman[1*], Amanda J. Meyer[1], Sandra E. Carr[2]
[1]*School Human Sciences, The University of Western Australia, Perth, Australia;*
[2]*School of Allied Health, The University of Western Australia, Perth, Australia.*

Introduction

Learning neuroanatomy is known to be challenging for medical students due to complex spatial relationships. The term 'neurophobia' was introduced to describe the concept in 1994.[1] To combat this, research has been conducted into innovative, largely digital, teaching techniques.

There is no curriculum for use of these tools, and instruction is left up to the discretion of the academic/institution. McBride and Drake (2018) reported wide variation in the number of teaching hours dedicated to neuroanatomy in the United States, with an average of 80h (4-200h).[2]

Aim

To assess the content, instruction and assessment of neuroanatomy in Australian and New Zealand Medical Schools.

Methods

An electronically mailed survey containing 23 questions about course structure, neuroanatomy teaching, assessment and course development was sent to a pre-determined academic from the 22 Australian and 2 New Zealand medical schools. They were asked to provide responses based on the 2018 academic year. Ethics approval was provided by the Human Research Ethics Committee of The University of Western Australia RA/4/20/5250.

Results

We received a total of 22/24 (91.7%) responses from medical schools, shown in Table 1.

Cadaveric anatomy laboratories and lectures were utilised by 100% of respondent universities. Types of resources used in these laboratories are indicated in Table 2. Medical courses are 4-years in 50% of universities. The average number of hours taught by year and by course length are shown in Table 3.

There was a low rate of adoption of new technologies, although the most common was 3D software (Table 4).

Table 1. Respondent Universities

Country	University	
Australia	Australia National University	University of Adelaide
	Deakin University	University of New England
	Flinders University	University of New South Wales
	Griffith University	University of Notre Dame Sydney
	James Cook University	University of Queensland
	Macquarie University	University of Sydney
	Melbourne University	University of Tasmania
	Monash University	University of Western Australia
	The University of Newcastle	University of Wollongong
	Undisclosed	Western Sydney University
New Zealand	University of Otago	
	Auckland University	

Table 2. Types of resources available in neuroanatomy laboratories

Resource type	Every	Most	Some	Rarely	Never
Prosections	45% (10)	32% (7)	23% (5)	0% (0)	0% (0)
Radiologic images	23% (5)	36% (8)	36% (8)	5% (1)	0% (0)
Models	59% (13)	18% (4)	18% (4)	0% (0)	5% (1)
Computer models	23% (5)	27% (6)	32% (7)	9% (2)	9% (2)
Plastinated specimens	23% (5)	14% (3)	18% (4)	5% (1)	41% (9)
Dissection	0% (0)	14% (3)	18% (4)	27% (6)	41% (9)

Table 3. Average number of neuroanatomy specific teaching hours by course length (±SD) *min/max*

Course Length	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
4-Year Course (n=11)	11.3±10.1 *1/40*	24.9±17.5 *2/50*	12.5±13.4 *3/120*	1.5±0 *1.5/1.5*	NA	NA
5-year Course (n=5)	3.8±2.2 *1/6*	22.0±2.7 *20/25*	17±17 *5/29*	0	5±10 *5/5*	NA
6-year Course (n=5)	19.8±9.2 *12/30*	33.8±25.8 *10/70*	43.3±51.9 *10/120*	20±14.1 *10/30*	10±0 *10/10*	0
All Courses (n=22)	11.5±10.0 *1/40*	26.44±17.77 *2/70*	29.0±38.2 *3/120*	13.8±14.6 *1.5/30*	8.3±2.9 *5/10*	0

Table 4. Types of technologies utilised by neuroanatomy teachers

Resource type	Every	Most	Some	Rarely	Never
3D Software	14% (3)	14% (3)	18% (4)	14% (3)	41% (9)
eBook	9% (2)	18% (4)	27% (6)	0% (0)	45% (10)
Tablets	9% (2)	23% (5)	5% (1)	14% (3)	50% (11)
Virtual Reality	0% (0)	0% (0)	23% (5)	14% (3)	64% (14)
Virtual Dissection	9% (2)	9% (2)	5% (1)	5% (1)	73% (16)
HoloLens	0% (0)	0% (0)	9% (2)	5% (1)	86% (19)
Haptic	0% (0)	0% (0)	5% (1)	9% (2)	86% (19)

Discussion

Content, delivery, assessment and development of neuroanatomical knowledge between medical schools in Australia and New Zealand is highly variable, particularly with regards to uptake of newer technologies.

The amount of teaching of neuroanatomy on average is 42.5% lower than in the United States. It is unknown whether this yields a difference in graduate knowledge of core neuroanatomical principles. There remains a predominance of didactic teaching methodologies across Universities – maybe indicating a lack of funds or demonstrated efficacy of modern techniques.

Conclusion

A DELPHI consensus of academics to produce a standardised curriculum for both content and delivery would be welcome to ensure graduate education is at an appropriate standard.

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Social Media Coverage

@amandameyerphd

@NewmanHamish

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Review of Neuroanatomy Teaching in Australian and New Zealand Medical Schools

Hamish J Newman,[1,2] Amanda J Meyer,[1] Sandra E Carr[2]

[1] School Human Sciences, The University of Western Australia, Perth, Australia;
[2] School of Allied Health, The University of Western Australia, Perth, Australia.

Introduction

Graduate doctors' knowledge of central and peripheral nervous system anatomy is below an acceptable level.[1] To combat this, new technologies have been introduced to enhance education in the context of integrated curricula and reduced anatomy teaching hours in medical schools.

There is no curriculum for use of these tools, and instruction is left up to the discretion of the academic/institution. McBride and Drake (2018) reported wide variation in the number of teaching hours dedicated to neuroanatomy in the United States, with an average of 80h (4-200h).[2]

Purpose

To assess the content, instruction and assessment of neuroanatomy in Australian and New Zealand Medical Schools.

Methodology

An electronically mailed survey containing 23 questions about course structure, neuroanatomy teaching, assessment and course development was sent to a pre-determined academic from the 22 Australian and two New Zealand medical schools.

They were asked to provide responses based on the 2018 academic year. Ethics approval was provided by the Human Research Ethics Committee of The University of Western Australia RA/4/20/5250.

Table 1. Respondent Universities

Country	University	
Australia	Australia National University	University of Adelaide
	Deakin University	University of New England
	Flinders University	University of New South Wales
	Griffith University	University of Notre Dame Sydney
	James Cook University	University of Queensland
	Macquarie University	University of Sydney
	Melbourne University	University of Tasmania
	Monash University	University of Western Australia
	The University of Newcastle	University of Wollongong
	Undisclosed	Western Sydney University
New Zealand	University of Otago	
	Auckland University	

Results

The average number of hours of neuroanatomy taught to medical students in Australia and New Zealand is 46 (12-160h). We received a total of 22/24 (91.7%) responses from medical schools, shown in Table 1.

Cadaveric anatomy laboratories and lectures were utilised by 100% of respondent universities. Dissection was never, or only rarely used in 68% of universities. Types of resources used in these laboratories are indicated in Table 2. The average number of hours taught by year, and by course length, are shown in Table 3. There was a low rate of adoption of new technologies in 2018, with the most common being 3D software (Table 4).

Table 2. Types of resources available in neuroanatomy laboratories

Resource type	Every	Most	Some	Rarely	Never
Prosections	45% (10)	32% (7)	23% (5)	0% (0)	0% (0)
Radiologic images	23% (5)	36% (8)	36% (8)	5% (1)	0% (0)
Models	59% (13)	18% (4)	18% (4)	0% (0)	5% (1)
Computer models	23% (5)	27% (6)	32% (7)	9% (2)	9% (2)
Plastinated specimens	23% (5)	14% (3)	18% (4)	5% (1)	41% (9)
Dissection	0% (0)	14% (3)	18% (4)	27% (6)	41% (9)

Table 3. Average number of neuroanatomy specific teaching hours by course length (±SD) *min/max*

Course Length	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
4-Year Course (n=11)	11.3±10.1 *1/40*	24.9±17.5 *2/50*	12.5±13.4 *3/120*	1.5±0 *1.5/1.5*	NA	NA
5-year Course (n=5)	3.8±2.2 *1/6*	22.0±2.7 *20/25*	17±17 *5/29*	0	5±10 *5/5*	NA
6-year Course (n=5)	19.8±9.2 *12/30*	33.8±25.8 *10/70*	43.3±51.9 *10/120*	20±14.1 *10/30*	10±0 *10/10*	0
All Courses (n=22)	11.5±10.0 1/40	26.44±17.77 *2/70*	29.0±38.2 *3/120*	13.8±14.6 1.5/*30*	8.3±2.9 5/*10*	0

Table 4. Types of technologies utilised by neuroanatomy teachers

Resource type	Every	Most	Some	Rarely	Never
3D Software	14% (3)	14% (3)	18% (4)	14% (3)	41% (9)
eBook	9% (2)	18% (4)	27% (6)	0% (0)	45% (10)
Tablets	9% (2)	23% (5)	5% (1)	14% (3)	50% (11)
Virtual Reality	0% (0)	0% (0)	23% (5)	14% (3)	64% (14)
Virtual Dissection	9% (2)	9% (2)	5% (1)	5% (1)	73% (16)
HoloLens	0% (0)	0% (0)	9% (2)	5% (1)	86% (19)
Haptic	0% (0)	0% (0)	5% (1)	9% (2)	86% (19)

Conclusions

Content, delivery and assessment of neuroanatomical knowledge between medical schools in Australia and New Zealand is highly variable, particularly with regards to uptake of newer technologies. The amount of teaching time on neuroanatomy delivered to Australian and New Zealand medical students is, on average, 42.5% less than that given to their counterparts in the United States. It is unknown whether this yields a difference in graduate knowledge of core neuroanatomical principles.

It is also unknown whether neuroanatomy teaching hours/techniques correlate to differences in neuroanatomy knowledge acquisition between medical students across different universities. A national competition-based examination on a core neuroanatomy curriculum could be a useful tool to assess if these differences exist, and guide future developments in neuroanatomy education.

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