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THE NATIONAL UNIVERSITY OF IRELAND, CORK
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Assessment of a Novel Computer Aided Learning Tool in Neuroanatomy Education

Thesis presented by

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Under the supervision of

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For the degree of

Doctor of Philosophy

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Department of Anatomy and Neuroscience

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Declaration

The submitted thesis is my work and has not been submitted for another degree at University College Cork or elsewhere.

Author contribution:

The author conducted all the work in this thesis except for Ms Margaret Cole, UCC and Ms Shelly Chakraborty, UCC who provided statistical assistance for analysing the data acquired from the Neuroanatomy Education Questionnaire (Chapter 2).

Where the work of others has been used to augment my thesis, it has been referenced accordingly.

Signed: _______________ Date: _______________

Dedication

Dedicated to my parents for their prayers and to my loving wife and son for their love, time and moral support.

Acknowledgments

First and foremost, I would like to express my sincere gratitude to my supervisors, Dr André Toulouse, Dr Harriet Schellekens and Prof. John F. Cryan for their continuous support and supervision of my PhD study over the last 3 years – their patience, motivation, enthusiasm, immense knowledge and mentorship was invaluable. Their guidance helped me throughout the time of research and writing of this thesis.

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List of Publications

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- Javaid MA, Cryan JF, Schellekens H, Toulouse A. Limitations of Neuroanatomy Web-Resources – a perspective. Poster presented at: The International Horizons Conference in UCC, Ireland (Dec 2017).

- Javaid MA, Cryan JF, Schellekens H, Toulouse A. Deciphering the Limitations of Neuroanatomy Teaching Web-resources – a Perspective. Poster presented at: The Anatomists on the Edge Conference in National University of Ireland, Galway (Jun 27th – 29th, 2017).

- Javaid MA, Chakraborty S, Cryan JF, Schellekens H, Toulouse A. Understanding Neurophobia: Reasons behind Impaired Understanding and Learning of Neuroanatomy in Cross-Disciplinary Healthcare Students. Poster presented at: The International Horizons Conference in UCC, Ireland (Dec 2016).

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List of Abbreviations

1.5T:	1.5 Tesla
2D:	Two-dimensional
3D:	Three-dimensional
3DVT:	Three-dimensional Visualization Technology
ACA:	Anterior Cerebral Artery
AR:	Augmented Reality
ARS:	Audience Response System
BDS:	Bachelor of Dental Surgery
BSc:	Bachelor of Science
CAL:	Computer Assisted Learning
CF-ONLine:	Conceptual Framework for Online Neuroanatomy Learning
CNS:	Central Nervous System
Corp.:	Corporation
CSF:	Cerebrospinal Fluid
CST:	Corticospinal Tract
CT:	Computerized Tomography
DEM:	Direct Entry to Medicine
DICOM:	Digital Imaging and Communications in Medicine
DTI:	Diffusion Tensor Imaging
EFEM:	European Federation for Experimental Morphology
GEM:	Graduate Entry to Medicine
GIMP:	Gnu Image Manipulation Program
GPs:	General practitioners
HCP:	Human Connectome Project
HTML:	Hyper Text Markup Language
IBM:	International Business Machines

IFAA: International Federation of Association of Anatomists

IQ: Intelligence Quotient

MCA: Middle Cerebral Artery

MCQ: Multiple Choice Question

MRA: Magnetic Resonance Angiogram / Angiography

MRI: Magnetic Resonance Imaging

MSc: Master of Science

NLM: National Library of Medicine

NU-group: No-Use group

NY: New York

OT: Occupational Therapy

PCR: Percentage Correct Response

PET: Positron Emission Tomography

Ph. D: Doctor of Philosophy

PHP: Hypertext Preprocessor

QTVR: QuickTime Virtual Reality

RCT: Randomized-Controlled Trial

SD: Standard Deviation

SDT: Self-determination Theory

SEM: Standard Error of Mean

SLS: Speech and Language Sciences

SPECT: Single Photon Emission Computed Tomography

SPSS: Statistical Package for Social Scientists

SREC: Social Research Ethics Committee

UCC: University College Cork

UK: United Kingdom

USA: United States of America

VHD: Visible Human Dataset

VR: Virtual Reality

VRML: Virtual Reality Modeling Language

WA: Washington

α: Alpha

Abstract

Impaired understanding of intricate neuroanatomical concepts and structural inter-relationships has been associated with a fear of managing neurology patients, called neurophobia, among medical trainees. As technology advances, the role of e-learning pedagogies becomes more important to supplement the traditional dissection / prosection and lecture-based pedagogies for teaching neuroanatomy to undergraduate students. However, despite the availability of a myriad of e-learning resources, the neuro (-anatomy-) phobia – neurophobia nexus prevails.

The focus of the PhD was to investigate the difficulties associated with learning neuroanatomy and to develop and assess the efficacy of a novel e-learning tool for teaching neuroanatomy, in the context of the strengths and pitfalls of the currently available e-learning resources. Firstly, we sought to provide direct evidence of the medical and health science students' perception regarding specific challenges associated with learning neuroanatomy. The initial results showed that neuroanatomy is perceived as a more difficult subject compared to other anatomy topics, with spinal pathways being the most challenging to learn. Participants believed that computer assisted learning and online resources could enhance neuroanatomy understanding and decrease their neurophobia.

Next, in the context of the significance of e-learning for supplementing traditional pedagogies, we identified features of neuroanatomy web-resources that were valued by students and educators with regards to learning neuroanatomy of the spinal pathways. Participants identified strengths and weaknesses of existing neuroanatomy web-resources and ranked one resource above the others in terms of information delivery and integration of clinical, physiological and medical imaging correlates. This provides a novel user perspective

on the influence of specific elements of neuroanatomy web-resources to improve instructional design and enhance learner performance.

Finally, considering the data acquired from students and educators, a novel, interactive, neuroanatomy learning e-resource was developed to support teaching of the neuroanatomy of the spinal pathways. The instructional design included a discussion of the clinical interpretation of basic neuroanatomical facts to aid in neurological localization. The e-learning tool was assessed and evaluated by undergraduate medical and neuroscience students using neuroanatomy knowledge quizzes and Likert-scale perception questionnaires and compared to the previously identified best-ranked neuroanatomy e-resource. Participants' opinion regarding the usefulness of various components of the tools was also gauged. The results showed that usage of the UCC e-resource led to a significant increase in participants' knowledge of the neuroanatomy of the spinal pathways compared to students' who did not use e-resources. Moreover, the participants reported a greater interest in learning neuroanatomy with the novel tool, showing a greater appreciation for it while learning clinical neurological correlates compared to those using the best available e-resource identified earlier.

In summary, the prevailing problem of neurophobia could be addressed by enhancing student-interest. Technological e-learning pedagogies, with intelligently designed interactive user-interface and clinical correlation of basic neuroanatomical facts can play a pivotal role in helping students learn neuroanatomy and breaking the nexus between neuro (-anatomy-) phobia and neurophobia.

CHAPTER 1

General Introduction

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Part of the chapter to be submitted as a review paper to *Medical Education*

1. Anatomy Education

Human anatomy is the study of the structure and spatial relationships between different body parts. Its teaching has been regarded as foundational in the education of medical and health sciences students and practitioners. By learning anatomy, students get a first exposure to the structure of the human body, which forms the basis for their understanding of pathology and clinical problems (Arantes and Ferreira, 2016). The subject of human anatomy has been traditionally delivered at the beginning of medical education. In recent times, the conventional modalities of anatomy learning, which comprised of lectures and cadaver-dissection, are being increasingly supplemented by computer assisted learning (CAL) and e-resources.

In medical institutions, anatomy is generally taught under four sub-categories, namely gross anatomy, histology, embryology and neuroanatomy. Gross anatomy deals with the morphology and organization of structures, their shapes, size and location. Its study provides students with the opportunity to comprehend anatomical variations and correlate them with images and disease processes. Practicing clinicians and would-be doctors in their physical examination through palpation, percussion and auscultation and imagery interpretation need to have a precise understanding of normal and diseased gross anatomy (Singh et al., 2015). The subject of histology facilitates comprehension of the cellular and tissue-level organization of the body. A good knowledge of histology leads to an enhanced understanding of the histopathological effects produced by age-related changes as well as various pathogens, toxins, drugs, environmental hazards and other factors on the human body. Embryology reveals the development of embryonic tissues from conception to birth. The identification of causes and clinical course regarding congenital disorders and anomalies can be advised by having a sound knowledge of developmental anatomy (Singh et al., 2015). Lastly, neuroanatomy as a discipline is interested in the gross, histological and developmental anatomy of a single system, the nervous system. Due to the complex nature of the system and its interactions with the other body organs, it is often considered as a standalone division of anatomical sciences.

2. Neuroanatomy Education

2.1. Core Syllabus for Neuroanatomy

Neuroanatomy provides the basis for clinical neurosciences and neurology and serves as the cornerstone upon which is built an understanding of the human nervous system and associated neuropathologies. Neuroanatomy, due to the complexity of the nervous system and often abstract nature of neuroanatomical concepts, differs from the anatomy of other body systems and thus, has acquired its own place in the curriculum (Mateen and D’Eon, 2008).

There have been several commendable attempts to define a core syllabus in gross anatomy to outline the minimum level of knowledge expected of a recently-qualified medical graduate to manage patients safely (Moxham et al., 2015). However, more specialized core syllabuses, for fields such as neuroanatomy, are rare. These include a core syllabus published for the dental students (American Association of Dental Schools, 1992) and an article by Klueber (2003) which relates head and neck anatomy with neuroanatomy. Recently, Moxham and colleagues have outlined the initial parameters of a core syllabus for neuroanatomy in a medical course with the help of a Delphi Panel consisting of anatomists, scientists, and clinicians (Moxham et al., 2015).

An important feature of the core syllabus is a call for the clinical relevance of the selected neuroanatomy topics (Pabst, 2009; Moxham et al., 2011). It is becoming increasingly important to identify which elements of neuroanatomy are of greatest clinical relevance in justifying their inclusion in the syllabus. The level of detail of those elements to be learned in preclinical neuroanatomy should in turn be determined by what will suffice medical students and clinicians to practice fields such as, neurology, medicine, psychiatry and neurosurgery.

2.2. Teaching and Learning of the Neuroanatomy Curriculum

The subject of neuroanatomy has traditionally been taught from a systemic standpoint, rather than from a regional or topographical perspective, as may be the case with gross anatomy. It is currently being taught either as part of a conventional medical curriculum, where it represents an isolated course in the preclinical years of medical schools, or as part of modern curriculum approach, where it is horizontally integrated with other subjects, such as, neurophysiology, neuropharmacology, neuropathology and neuroradiology (Arantes and Ferreira, 2016). In a survey conducted by Drake and colleagues it was found that 12 of the neuroanatomy / neuroscience courses reported that they were part of an integrated approach, and 19 indicated that neuroanatomy / neuroscience was a standalone course. The total course hours reported by the participants in the survey averaged 79 (range 30-160 hours). The average number of lecture hours was 52 (range 0-150 hours) and the average number of lab hours was 15 (range 0-47 hours) (Drake et al., 2009).

In addition to the information acquired during the pre-clinical years, reviewing this previously learned neuroanatomy, in a vertically integrated fashion during the four years of the medical curriculum, has benefits associated with recalling basic and advanced neuroanatomical content (Lim and Seet, 2008). Students can regularly look up and refresh their knowledge of neuroanatomy relevant to understanding clinical neurological problems. In this context, a spiral curriculum, where material is revisited multiple times with increasing complexity, may be an alternative way of reinforcing learning (Charles et al., 1999). Lastly, a phenomenological approach that would focus first on the patient's experience and illness presentation and second on the basic science explanation and interpretation of the phenomena could be a way of demystifying neurology, shifting learning from a more passive to an active model while ensuring that the material selected is integrated and relevant (Menken, 2002).

3. Challenges Associated with Teaching and Learning of Neuroanatomy and the Emergence of Neurophobia

A sound understanding of neuroanatomy helps the students / practitioners to interpret the symptoms and signs of neurological disorders (Singh et al., 2015). The clinical relevance of neuroanatomy is most obvious in fields such as neurology, neurosurgery and psychiatry, where the goal of the neurological examination is to localize the lesion / dysfunction within the central nervous system (CNS). Being knowledgeable about the normal structure and function of nervous system components, it is possible, when malfunction is observed, to work backwards and decipher which structure is affected.

I have been teaching neuroanatomy to the medical undergraduate and health science students for a decade. Unfortunately, I have found that medical students find it hardest to grapple with the intricated details associated with learning neuroanatomy of the brain and the spinal cord versus all other topics of anatomy. In the same vein, students and practitioners find it challenging to translate their early neuroanatomy knowledge into patient care. Evidence from the literature shows that the subject is considered most difficult to learn out of the entire human anatomy curriculum (Jilwan et al., 2014; Martin et al., 2014). This perceived difficulty of neuroanatomy has been referred to as neuro (-anatomy-) phobia and has been associated with intrinsic factors, such as, the complexity of intricate neuroanatomical concepts themselves (Javaid et al., 2018). Moreover, the cognitive leap required to appreciate the relationships of spatially overlapping elements of the brain and the spinal cord within the tight confines of the skull and the vertebral column, is humungous. Because of the small size of these structures and their spatial overlapping, individual entities are difficult to isolate and visualize by conventional dissection. In addition to the complexity, the breath of the neuroanatomy syllabus frequently frightens the first / second year student whose first worry is how to address the burden of so many concepts within a short time frame, in the context of passing their exams.

The impaired understanding of the topic and the neuro (-anatomy-) phobia has contributed towards instilling a fear, among the medical students and young doctors, regarding managing neurology patients (Flanagan et al., 2007; Youssef, 2009; Giles, 2010; Sanya et al., 2010; Zinchuk et al., 2010; Matthias et al., 2013; McCarron et al., 2014; Pakpoor et al., 2014). This fear of the clinical neurology, due to the neuro (-anatomy-) phobia and the lack of integration between basic science and clinical information, was first coined in the literature as ‘neurophobia’ (Jozefowicz, 1994). Its incidence has been reported to be as high as about half of the medical students experiencing it at one point during their training.

The transition from neuro (-anatomy-) phobia during the pre-clinical years to neurophobia during the clinical years can be considered as a continuum, manifesting itself in specific forms at different stages. During the preclinical years, the attendance at basic science lectures has been found to dwindle with associated poor exam grades. While in the clinical years, students with neurophobia are often unable to perform and interpret a neurological examination and localize neurological lesions and abnormalities. This poor performance during the basic science and clinical years leads to frustration with neurological diagnoses and disinterest in neurology as a career. Being a clinical doctor and from my own personal experience, while working along with neurology residents in specialty neurology clinics and on the hospital floors in the Stroke Centers, I have also seen a similar attitude from the clinical trainees who found it challenging to exercise the basic neuroanatomical details while seeing the patients to decipher the location of neurological lesions.

The above-mentioned situation becomes even more alarming with a steady increase in the global burden of disease due to increased prevalence of mental and neurological diseases, such as stroke, dementia and neurodegenerative disorders in old age people (Vos et al., 2015). Since, the number of specialist doctors is not rising accordingly, therefore the coming times could witness a relative decline in the specialist neurologists. In these circumstances young medical doctors and general practitioners would have to face a greater number of first-encounters with neurological patients. Hence, a good comprehension of the intricate (and often abstract) neuroanatomical concepts and their associated clinical correlates will be pivotal for identifying problems and referring patients to appropriate specialist doctors; in this case, neurologists / neurosurgeons. This further highlights the importance of addressing the neuro (-anatomy-) phobia, in the context of decreasing the neurophobia.

To date, most of the existing studies investigating neurophobia, have used Likert scales which have focused on inquiring about the participants' perceived difficulty of clinical neurology compared to other medical specialties. Although an impaired understanding of neuroanatomy has been identified in the past as the major underlying reason for the prevailing neurophobia, however, this was revealed in the broader context of clinical neurology and none of the existing studies have used Likert-scales / questionnaires which inquired directly about the perceived difficulty of neuroanatomy (Table 1.1). This renders the existing scales unsuitable to gauge the neuro (-anatomy-) phobia and necessitates a need to devise a novel scale which could measure medical and other health sciences students' perception about neuroanatomy compared to other topics in basic anatomical sciences, dissect out the underlying reasons and inquire about ways to address this problem. In addition, all existing scales for neurophobia relate to surveying junior doctors and medical students in their clinical years (Table 1.1), with only one study inquiring about the opinion of practicing speech and language therapists (Martin et al., 2014). Therefore, the perceived opinion of the medical students during their preclinical years, as well as other health science students, including therapies and dental students needs to be explored.

Table 1.1: Studies Employing Questionnaires to Investigate Neurophobia

Study	Brief description
Abushouk and Duc,2006	A review summarizing neurophobia literature and presenting evidence-based recommendations and educational interventions to overcome students' fear of neurology
Fantaneanu et al., 2014 – Canada	Questionnaire results revealed that medical students confirmed having a fear of clinical neurology (24%) and academic neurosciences (32%) and perceived neurology being most difficult among various specialties (► = 46%). In addition, various non-modifiable and modifiable risk factors underlying neurophobia were identified.
Flanagan et al., 2007 – Ireland	Questionnaire results revealed that medical students and doctors had a perception that neurology was most difficult among the nine different medical specialties. *Reason identified* = ►, lack of teaching, limited patient exposure, difficult diagnosis.
Gupta et al., 2013 – India	Questionnaire submitted among medical students inquired about factors promoting or discouraging students to opt for neurology as a career. *Reason identified* = Factors promoting students to opt for neurology included intellectual challenge and logical reasoning it offered (72%), inspiration offered by teachers (63%), better quality of life (51%), scope for independent practice without expensive infrastructure (48%). Factors preventing students from opting for a neurology career included their perception that most neurological diseases are degenerative (78%), neurology being an academic specialty (40%), neurophobia (43%), lack of procedures offered (57%), inadequate exposure (31%) and resultant lack of self-confidence (75%).
Kam et al., 2013 – Singapore	Survey results revealed that neurophobia prevalence was highest among med-students (47.5%), junior doctors (36.6%) vs. other medical specialties ($P < 0.001$). *Reason identified* = ►, low interest and lack of clinical training contributed to neurophobia.
Martin et al., 2014 – Ireland	Focused interviews were conducted among eight speech and language therapists. Participants recalled their experience of learning neuroanatomy from traditional textbooks and lectures as "very, very hard and tough".
Matthias et al, 2013,SriLanka	Questionnaire revealed that neurophobia prevalence was highest compared to other medical specialties ($P < 0.001$). *Reason identified* = ►, complex clinical examination.
McCarron et al., 2014 – Northern Ireland, UK	Questionnaire results revealed that GPs reported poorer knowledge, lower confidence and interest and greater perceived difficulty of neurology compared to other clinical specialties ($P < 0.001$). *Reason identified* = ►, lack of organized clinical teaching and referral guidance.
Pakpoor et al., 2014 – UK	A survey conducted among 25–31 medical schools in UK and involving 1877 medical students, revealed that neurology was rated significantly more difficult vs. other medical specialties ($P < 0.001$). *Reason identified* = ►.
Ridsdale, 2007 – UK	A descriptive article which talks about neurophobia and suggests strategies to counter it. However, there is no mention of neuroanatomy.
Sanya et al., 2010 – Nigeria	A questionnaire results from medical students across 3 medical schools in Nigeria revealed that neurophobia prevalence was highest vs. other specialties ($P < 0.001$). *Reason identified* = ►, insufficient exposure to neurological cases (41%), complex diagnosis (32%), inadequate neurology teachers (32%).
Schon et al., 2002 – UK	A perception questionnaire revealed that GPs and House officers perceived clinical neurology significantly more difficult compared to other fields in medicine ($P < 0.001$). *Reason identified* = ►.
Youssef et al., 2009 – Caribbean	A cross-sectional survey distributed among 4^{th} and 5^{th} year medical students in the Caribbean revealed that students perceived neurology being significantly more difficult vs. other specialties and they considered themselves being least knowledgeable about the subject ($P < 0.001$). *Reason identified* = ►, complex clinical examination.
Zinchuk et al., 2010 – USA	A questionnaire submitted to 3^{rd} and 4^{th} year medical students and residents revealed that compared to other specialties, they perceived being least knowledgeable about neurology, ranking it the most difficult specialty and being least confident in managing neurology patients. *Reason identified* = ►.

► = Refers to an impaired understanding of neuroanatomy / perceived complexity of neuroanatomy / perceived need to know the basic neuroanatomical sciences, being identified as the major reason underlying the neurophobia; UK = United Kingdom; USA = United States of America; GPs = General practitioners.

4. Factors Facilitating the Transition from Traditional to Modern Pedagogies

Teaching through dissection and prosections and via conventional lectures, are still the modalities of choice in most curricula (Vázquez et al., 2007), with cadaveric material still being the most frequently used resource for teaching anatomy and neuroanatomy (Arantes and Ferreira, 2016). However, the prevailing neuro (-anatomy-) phobia, highlights the fact that the traditional pedagogies alone have not been able to ameliorate the difficulties associated with learning the intricate neuroanatomical concepts.

Cadaver dissection has the added advantages of developing important cognitive skills (Slotnick and Hilton, 2006), manual dexterity (Granger, 2004, McLachlan, 2004) and an opportunity to reinforce familiarization and respect for the body and hence, which cannot be dismissed as obsolete. Nonetheless, in context of the limitations of traditional teaching pedagogies and the changing trends across medical institutions (discussed below), it would certainly be a shame not to take full advantage of the available technology to supplement the dissection-based pedagogy (El- Moamly, 2008). Some of the factors which have facilitated the transcendence from traditional to modern pedagogies, include neuroimaging, computer assisted learning resources, three-dimensional (3D) digital brain models, for teaching and learning neuroanatomy. These will be individually discussed below in the next section.

4.1. Reduction in the Neuroanatomy Teaching Hours

Wide-ranging reductions in the anatomy teaching schedule in medical schools around the world (Drake et al., 2002; Heylings, 2002; Plaisant et al., 2004; Azer and Eizenberg, 2007;

Drake et al., 2009) has minimized the time which students can spend in the dissection rooms (Kulkarni, 2014). In places like United States, United Kingdom, Ireland, Australia and New Zealand, anatomy teaching hours have declined (Heylings, 2002; Leung et al., 2006; Sugand et al., 2010). The United States alone witnessed an 18% decrease in neuroanatomy instruction-hours from 2002 to 2009 (Drake et al., 2002; Drake et al., 2009; Drake et al., 2014), while Arantes and Ferreira found that the average number of neuroanatomy contact hours in Portugal had been reduced to a bare minimum of only 21.3 hours in institutions adopting a modern curriculum, as compared to 61 hours in institutions still abiding by the conventional curriculum (Arantes and Ferreira, 2016). The addition of new disciplines (e.g., communication skills, professionalism, and ethics) into the curriculum has further led to a reduction in the teaching of factual neuroanatomical content (Parker, 2002; Moxham and Plaisant, 2007; Rainsbury, 2007; Drake et al., 2009) despite students preferring longer anatomy courses (Holla et al., 2009). Hence, not surprisingly, many institutions have replaced dissection with prosections, plastic models and multimedia learning packages (Reidenberg and Laitman, 2002; McLachlan, 2004; McLachlan and Patten, 2006).

4.2. Loss of Qualified Neuroanatomy Instructors

The number of medically qualified anatomy teachers has dropped (Turney, 2007). One would be hard-pressed at most medical schools to find faculty members purely devoted to the characterization of nervous system structure. For instance, Arantes and Ferreira (2016) found that most faculty involved in teaching neuroanatomy in Portugal, were part-time teachers; with some unrelated to neurosciences, while full-time career anatomists were rarely involved in teaching this subject (Arantes and Ferreira, 2016). At some medical schools, neurobiologists who are familiar with human neuroanatomy are responsible for teaching preclinical medical students and they may find it harder to use examples of clinical cases that invoke the need for such neuroanatomical knowledge in practice (McCrorie, 2000).

An inadequate anatomy faculty, compressed syllabus and squeezed schedule for dissection has created gaps in anatomical knowledge of the students. For instance, surveys of clinical staff have shown that the majority perceive current anatomical education to be inadequate (Waterston and Stewart, 2005) and in a state of crisis (Older, 2004; Raftery, 2007). The situation has adversely affected training in surgery and other specialties – consequently downgrading the clinical skills of doctors for safe medical practice (Waterston and Stewart, 2005). Hence, to maximize the efficacy of the limited time spent in the labs, students need to prepare the topic, well in advance, prior to the commencement of each teaching session. Computer assisted, and online neuroanatomy learning resources could help substantially in this regard.

4.3. Increased Need to Learn Living Anatomy and Neuroimaging

In modern times, the doctors will increasingly encounter anatomy through two modalities: living anatomy and medical imaging. Cadavers and prosections might not be the best guide to living anatomy during undergraduate training, because these are by their nature non-responsive to movements and interactive clinical examination techniques, such as, palpation and percussion. In addition, the process of fixation significantly alters the color and texture of human tissues, and haptic feedback from dissection and prosections may be quite unlike, as compared to that obtained during patient-encounters. Moreover, the information gathered from a dissection does not readily translate into the cross-sectional views – presented by computerized tomography (CT) and magnetic resonance imaging (MRI) scans.

4.4. Small Size of Neuroanatomical Structures

Dissection (and prosections) are especially limited when it comes to visualization of neuroanatomical structures, such as, the nerve pathways, nuclei and neuronal connections. The computer assisted online resources can serve as useful supplementary teaching aids to help students to appreciate the inter-relationships of these structures.

4.5. Health and Safety Concerns and Cost

Other limitations accompanying human-specimens include an emotional impact, health and safety issues and legal concerns underlying handling cadaveric material, in addition to the practicalities and cost of using cadavers; their acquisition, transportation, maintenance and disposal (McLachlan and Patten, 2006).

5. Advantages of Computer Assisted and Online Resources

Since the end of the last century, technology has taken a front seat in dispersion of medical education. In a recent systematic review, evidence that online learning was equivalent, possibly superior to traditional learning in its impact on the knowledge, skills, attitudes and satisfaction of undergraduate students has been presented and its cautious adoption in the pedagogical design has been encouraged (George et al., 2014).

Whether it be PowerPoint™ slides or advanced augmented reality applications, digital and e-learning tools could lead to an improved learning of neuroanatomy in various ways. For instance, online computer applications can offer an advanced three dimensional (3D) (Cook, 2007; Pickering, 2017) and a more realistic representation of neuroanatomical structures and pathways as compared to the two dimensional (2D) illustrations used in textbooks (Juanes and Ruisoto, 2015). The online mode of learning can overcome the barriers of distance and time making education available for the entire global community through open-sourcing (Cook, 2007; Juanes and Ruisoto, 2015). Purpose-designed online learning resources can promote active student learning via interactive teaching designs, games, quizzes and active internet searches (Cook, 2007; Pickering, 2017) and the computer learning programs can be customized for individual learners (Ruiz et al., 2006). The students can visit the website repeatedly and experience a greater control over their learning environments through flexible participation timings. This will foster endurance-learning through deliberate practice and temporal spacing (Cook, 2007). Lastly, the user-friendliness of the web-interfaces and ready availability, coupled with the natural propensity and comfort of the millennial students (Generation Y) to use online tools, makes e-learning, a powerful pedagogical tool to supplement traditional neuroanatomy learning (Cook, 2007).

6. Conceptual Framework for Developing Online Neuroanatomy Learning Tools

E-learning unites two main areas, learning and technology. The process of learning incorporates the cognitive processes linked with the acquisition of knowledge while technology can serve as an effective enabler of this learning process. An important factor in any instructional initiative is the quality of its instructional design, and e-learning in no exception. Hence, I have reviewed the online instructional design literature, multiple adult learning theories (Taylor and Hamdy, 2013) and human cognitive learning theory (Mayer, 2003; Paas et al., 2003), which have provided the thesis its conceptual basis, in the broader context of incorporating best practices for online student learning. This enabled the identification of a set of instructional design principles for formulating quality online learning resources while the conceptual framework has provided theoretical underpinnings for these principles (CF-ONLine, Conceptual Framework for Online Neuroanatomy Learning, Table 1.2).

Table 1.2: Conceptual Framework for Online Neuroanatomy Learning (CF-ONLine)

Elements of CF-ONLine	Theoretical basis	References
A. Cognitive basis and avoidance of information overload	1) Reduce extraneous processing, 2) manage essential processing, 3) foster generative processing	Mayer, 2003; Paas et al., 2003; Young et al., 2014
B. Address individual differences	1) Multimodal content presentation to cater for varying learning styles and preferences, 2) Learner control (students can access content in a random / systematic fashion)	Price, 2004; Johnson and Aragon, 2003
C. Motivation	Enhance intrinsic motivation (value-driven learning). 1) SDT (based on autonomy, competence, relatedness), 2) Expectancy-valence theory. 3) Needs assessment	Sobral, 2004; Ryan and Deci, 2000; Chen and Jang, 2010; Hsu et al., 2019; Cook and Artino, 2016; Wigfield and Eccles, 2000;
D. Contextualized learning	Framing neuroanatomical facts around realistic situations, teaching clinical correlates and employing case-based studies	Greenwald and Quitadamo, 2014.
E. Social learning	Influence of social processes (community and context) on learning. 1) Situativity cognitive theory. 2) Social learning theory incorporating elements of behavioral and cognitive learning theories. 3) Humanistic (behavioral) learning theories explain learning by watching behavior of others (a mixture of behavioristic and cognitive constructivist approach).	Durning and Artino, 2011; Taylor and Hamdy, 2013.
F. Reflective learning	1) Transformative learning theory (discusses utilizing disorienting dilemmas to challenge students' thinking). 2) Experiential learning (incorporates a mixture of behavioristic and cognitive constructivist approach)	Sanders, 2009; Mezirow, 1997.
G. Feedback	An essential part of medical education and can be used to promote reflection. Experiential learning, SDT (competence)	Van de Ridder et al., 2008
H. Active learning	Enhanced user-interactivity promotes active learning. Techniques such as discovery learning, project-based learning, co-operative learning can be employed.	Prince, 2004.

CF-ONLine = Conceptual framework for online neuroanatomy learning; SDT = Self-determination theory

I contend that powerful online learning environments should address individual student differences, motivate the learners, avoid information overload, provide a clinical and real-life context, encourage social interaction, provide hands-on activities and student engagement with the content and encourage student-reflection (Table 1.2). It is to be noted that although the framework represents a synthesis of ideas from multiple perspectives, it is not all-inclusive. I have taken this theory-driven CF-ONLine as a starting point whose organizational schema will be modified considering the users' opinions; both students and educators.

The theoretical underpinnings of the conceptual framework (CF-ONLine) have been discussed below.

6.1. Cognitive basis and avoidance of information overload

The learning efficiency from online tools / resources can be enhanced by developing purposeful e-instructional designs which mirror human cognitive architecture (Mayer, 2003). Cognitive load is a central consideration in the design of e-learning resources and multimedia instruction. Meaningful learning, on one hand, involves simultaneous cognitive processing of the pictorial and the verbal representations of information, on the other hand, must avoid cognitive overload which could prevent assimilation of information by exceeding available cognitive capacity. In this context, important load-reducing guidelines can be acquired from the Mayer's theory of multimedia learning (Mayer, 2003) and the theories of cognitive load (Paas et al., 2003).

Richard Mayer suggested that the three top-level goals for designing multimedia instruction for learning included 1) reducing extraneous processing which did not support the objective of the lesson, 2) managing essential processing required to mentally represent the complicated material presented, and 3) motivating the individuals to delve deep into the content to make sense out of it (or fostering deeper learning), known as generative processing (Mayer, 2003; Young et al., 2014). Firstly, the extraneous processing can be reduced by designing a user-interface which facilitates intuitive learning, adding cues to highlight the main ideas and organization of the material (signaling principle), minimizing the need for visual scanning by placing corresponding words and graphics close to each other (spatial contiguity principle), presenting corresponding graphics and narration simultaneously rather than successively (temporal contiguity principle) and avoiding incorporating those features into the instructional design which do not contribute to learning (redundancy principle). For instance, for the latter, adult learners don’t need to have the same information presented to them in written text and audio formats (verbal text), simultaneously. Only the spoken / verbal text (audio) would suffice so that the eyes can look at the graphics. On the contrary, if both audio narration and text-captions are inserted then that might lead to a split-attention effect in the visual processing channel in the brain and the learner might miss paying attention to either some graphics or some written captions (Mayer, 2003). Secondly, the essential processing associated with learning complicated, but important, information can be managed by breaking up the information and presenting it in parts (segmenting principle) or by providing some prior training into the names and characteristics of the main concepts (pre-training principle). Lastly, if the students have the capacity to learn but they are not motivated or not interested in trying to analyze the information, relating it to their previous knowledge and trying to make sense out of it, then that implies that they are not exercising any generative processing. Any means to motivate the learner will enhance the generative processing associated with the schema construction (Mayer, 2003; Young et al., 2014).

6.2. Individual differences and multimodal learning

Individual differences specific to learning and instruction can be found in intelligence, cognitive controls, cognitive and learning styles, personality types, and prior knowledge (Table 1.2., Price, 2004). Such differences can be addressed by providing content in multiple formats and allowing for individual locus of control. Learners can be given the opportunity to be as systematic or random in accessing course material as they desire. Although the instructional design of e-learning resources should be framed along a hierarchical sequence, however, they do not have to be accessed in a specific rigid way, with students having the option to move through the course topics in random order (Table 1.2, Johnson and Aragon, 2003).

6.3. Motivation

Intrinsic motivation has been found to have a close relationship with measures of self-regulation of learning and academic success in a demanding medical program (Sobral, 2004). High intrinsic and low-controlled motivation profile of medical students has been better associated with good study hours, deeper study strategy, better academic performance and lower exhaustion from studies compared to the high extrinsically-controlled motivation profile (Kusurkar et al., 2013). Both forms of motivation; intrinsic and extrinsic, can be considered as two ends of a continuum. The extrinsically motivated behavior could be internalized by the learner when there is a sense of relatedness and can get transformed into an intrinsically motivated behavior. Internalization refers to the active attempt to transform an extrinsic motive into personally endorsed values and thus assimilate the behavioral regulations that were originally external. This concept has been endorsed by the self-determination theory (SDT) which talks about three basic needs that need to be met in order to sustain intrinsic motivation, namely 1) competence (capability; being confident to carry out a task), 2) sense of relatedness and 3) autonomy (more learner control with the participant given more options / choices) (Table 1.2., Hsu et al., 2019; Cook and Artino, 2016; Chen and Jang, 2010; Ryan and Deci, 2000). This implies that the neuroanatomy web-resources which offer intrinsically-motivated instigators to their learners will possess higher chances of success in helping students learn neuroanatomy. Students' attention can be maintained by ensuring that the course content, activities, and assignments are related to students' personal and professional goals. A sense of relatedness could be imparted to the medical students by helping them learn the clinical relevance of basic neuroanatomical facts–leading to better future clinical performance. In addition, social and environmental factors can influence competency and autonomy, such as, 'positive-feedback'–as part of an interactive instructional design, can offer a feeling of competency and enhance intrinsic motivation. Moreover, providing greater degree of control to the learner over learning content can also enhance motivation (Hsu et al., 2019; Cook and Artino, 2016; Chen and Jang, 2010; Ryan and Deci, 2000).

The drive to learn could be further understood in the context of expectancy-valence theory which describes the motivation to learn, as a product of 1) expectancy of success and 2) value of success (Table 1.2, Wigfield and Eccles, 2000). Enhancement of exam-performance through available course material, case-based teaching / usage of clinical scenarios, and highlighting relevant novel research, could enhance the value of successfully learning the content, while inclusion of success stories or peer advice could contribute to the expectancy of success upon successfully learning the material.

Motivation to learn also arises from educational needs (Table 1.2). The extent of discrepancy one perceives between his present level of ability and the desired level of ability, affects the extent to which one is motivated to learn. Hence, the gaps in knowledge and performance should be conveyed to the learners by clearly articulating the intended learning outcomes, i.e., what the learners are expected to be able to do after the activity. In such an outcome-based approach where clear goals have been set for learners, if the learners perceive a gap between their current level of ability and the goals, they will be more motivated to take part in the learning activities, if they believe the activities have been designed to help them achieve the goals (Chan and Pawlina, 2015).

6.4. Contextualized learning

Contextualized learning motivates and enhances user-interest in learning the topic (Table 1.2). The neuroanatomical content could be learnt most effectively if it is presented in the context in which it ought to be used in the future. Hence, the basic neuroanatomical facts should be framed around realistic situations and integrated with clinical neurological correlates. Case studies are an excellent way to provide the context in which new mental schemas can be developed (Greenwald and Quitadamo, 2014).

6.5. Social learning

Learning and thinking cannot be stripped off from the influence of social processes, such as community and context (Table 1.2). The situativity cognitive theory states that learning, and thinking are social activities and are influenced by the available tools and the setting in which learning takes place (Durning and Artino, 2011). Social learning theory combines elements from both behaviorist and cognitive theories and posits that we learn best by interacting with others in social settings. Behavioral learning theory contributes to social learning because people don’t learn from observation alone but through imitation and reinforcement of what they observe. Cognitive component of the social learning theory focuses on the cognitive processes involved in the observation over ones own / others’ resulting behavior, with the idea that individuals can regulate their own behavior by recognizing consequences (Taylor and Hamdy, 2013).

Although the online learning environment is limited in providing the social and communal advantage of learning, still various strategies could be employed such as, using comments sections underneath the web-pages, having discussion forums, bulletin boards and chat rooms, inserting video-recorded welcome message and user-guide, creating listservs for subscribers, and providing learners with the option of emailing the instructor or web-master.

6.6. Reflective learning

Reflective practice is a metacognitive process that occurs before, during and after situations / actions with the purpose of developing greater understanding of both the self and the situation so that future encounters with the situation are informed from previous encounters (Table 1.2, Sanders, 2009). Theories, such as, the transformative learning theory has explored how critical reflection could be used to challenge the learner’s beliefs and assumptions and potentially change them (Mezirow, 1997). In an online learning environment, reflection could be promoted by provision of extensive and timely feedback to the learners.

6.7. Feedback

Feedback refers to specific information about the comparison between a learner's observed performance and a standard, given with the intent to improve the learner's performance (Table 1.2, Van de Ridder et al, 2008). Feedback is an essential part of medical education and can be used to promote reflective learning. Some simple examples of formative assessment and feedback offered to the users as part of the web-learning activity could include multiple choice questions, interactive clinical cases or the option of turning the labels on / off on the anatomical images.

6.8. Active learning

Adults learn better through active learning which can be defined as a learning process in which the learners are engaged in meaningful activities in the classroom and are mindful of what they are doing (Table 1.2, Prince, 2004). Active learning can occur in many forms in an online learning environment by enhancing user-interactivity. This goes in accordance with the proposed connection between constructivism and adult learning theory in online learning environments (Huang, 2002). Discovery learning, project-based learning and cooperative learning are common techniques for engaging students in activities that involve considerable amounts of creativity, decision making, and problem solving and emphasize upon the importance of learning from goal-driven and activity-based experience (Johnson and Aragon, 2003).

In summary, the pedagogical construct of an effective online resource should:

1. Employ a variety of learning tools to cater for varying learning style preferences.
2. Present the information in a manner which minimizes mental workload, such as, by making design intuitive, emphasizing upon the high-yield facts (signaling principle),

positioning relevant text and graphics in close spatial proximity (spatial contiguity principle) and graphics and narrations in close temporal proximity (temporal contiguity principle), providing preliminary training (helping users getting well-worse with the interface and complicated terminologies) prior to commencement of the course, and segmenting complex information into bite-sized chunks for easy assimilation.

3. Enhance learner's intrinsic motivational drive by clear articulation of intended leaning outcomes (needs assessment), sharing peer–success' stories / experiences (expectancy of success), and pressing upon the clinical relevance, role in research and passing exams (Valence / value of success and sense of relatedness).
4. Offer the option of learning in a custom fashion, at one's own pace and preferred sequence (sense of autonomy and learning style preferences).
5. Offer interactive feedback (and sense of competency) for reflective and deeper-active learning. the latter leads to active / deeper learning.
6. Exercise the social and communal advantage of learning by incorporating comments-section, discussion forums, bulletin boards, chat rooms, video messages and user-guide, generating listservs for subscribers, and providing learners the option of emailing the instructor.

Below I have analyzed various modern technological pedagogies for neuroanatomy learning in context of the above-described conceptual framework (Table 1.2).

7. Modern Technological Pedagogies for Neuroanatomy Learning

7.1. Technology with Conventional Teaching Aids

7.1.1. Technology and Textbooks

Technology has come a long way in revolutionizing the way students interact and learn from textbooks. Books published recently are supported by complementary IT materials, such as, CDs / DVDs and subscriptions to online resources (Vázquez et al., 2007). Another development in medical education has been the e-book with multimedia components. Vasquez and colleagues, at the University of Salamanca Spain reported a compilation of neuroanatomy e-books in interactive DVD format (Vázquez et al., 2007). The multimedia components offered by these resources provide interactive learning opportunities through on / off switching of labels on illustrations and neuroradiological images, further complemented by videos, case reports and question-banks with feedback responses. For instance, the accompanying multimedia component of a neuroanatomy e-book entitled ‘Digital Neuroanatomy’ has been subjectively perceived to be appealing to beginning neuroanatomy students looking for a basic gross and histological overview of the subject, presented through various modalities including dissection images, neuro-radiographs, stained sections and interactive quizzes (Gould, 2007). However, a detailed quantitative assessment / evaluation of the efficacy of such e-resources is lacking in the literature.

7.1.2. Technology in the Anatomy Classroom

For many years, in classrooms the blackboard and hand-drawn drawings were the main bastion of anatomical teaching. With improvements in photography and the projectors themselves, slides became an essential tool that for many people rendering the blackboard obsolete. The projection of animations and videos provided anatomy with another important medium for teaching. The use of PowerPoint™ presentations to interactively present images, associated text, animations and video-clips for anatomy teaching, has been favored by the students (Carmichael and Pawlina, 2000). Moreover, the introduction of the audience response system (ARS) technology has removed the boredom from the lecture room environment by promoting active student engagement (Iskander, 2018).

Virtual classrooms have also been employed in addition to the traditional classrooms, where students can tune into an impressive array of anatomical software. These can be accessed from within the campus or from students' homes. Many of these programs are interactive and students can take advantage of these as a way of self-learning (Stewart et al., 2007).

7.1.3. Technology and Cadaver Dissection

Numerous resources are available on the web which contain an open access pool of images of prosections and videos of cadaver dissection, such as, those offered by University of British Columbia (Krebs, 2016 - http://bit.ly/UBC-Neuro) and Wisconsin University School of Medicine (http://bit.ly/WSUanatomy). These resources can be used by undergraduate students as supplementary teaching aids along with the conventional dissection and prosection-based learning of neuroanatomical spatial relationships, thus facilitating laboratory task efficiency. For instance, DiLullo and colleagues assessed the efficacy of an online digital video clip resource custom-designed for medical students in the Philadelphia College of Osteopathic Medicine. Dissection guidance was provided to the students by communicating challenging aspects of the dissection process through these visual demonstrations. Survey responses from students indicated that the videos enhanced the quality of the anatomy course as well as individual performances and enhanced student competencies in human gross anatomy (DiLullo et al., 2006). Similarly, Mahmud et al showed that despite the failure to improve the final examination scores, the 1st year medical students favored the use of dissection videos as supplementary teaching aids for the cadaver dissection (Mahmud et al., 2011).

7.2. Neuroimaging

The imaging techniques, such as, endoscopy, MRI and CT, has enlarged the discipline of living anatomy (McLachlan, 2004). Their incorporation into the curriculum offers medical students, in vivo visualization of anatomy and physiology as well as an insight into pathological processes (Gunderman and Wilson, 2005).

Grignon et al conducted a systematic review which showed that, when inquired using questionnaires, students unanimously perceived the imaging anatomy being capable of enhancing the quality and efficiency of human anatomy instruction (Grignon et al., 2016). In addition, students' exam and test scores improved after incorporation of radiological teaching sessions (Grignon et al., 2016). Earlier, in a Likert questionnaire-based study, Machado and colleagues found that second year medical students highly ranked the use of CT and MRI for the successful demonstration of anatomical structures and explanation of clinical cases (Machado et al., 2013). The study was however limited as a quantitative assessment of an increase in students' knowledge and understanding of neuroanatomy in relation to the intervention was lacking. Moreover, from a design perspective, it would have been helpful to have included a control group with no exposure to imaging anatomy (Machado et al., 2013). In a study conducted at Boston University, Lufler and colleagues showed that the first-year medical students who used cadaver CT scans to visualize structures in the anatomy lab during dissection, scored significantly higher in the practical exams and on questions testing knowledge of anatomical spatial relationships (Lufler et al., 2010). The analysis of the data acquired, was characterized by the use of multiple statistical models based on multiple outcome variables related to comparison between students' performances who used CT scans vs. those who did not use the scans and those who used scans from same cadavers they dissected vs. using different cadavers. Such multiple comparisons cannot be corrected by logistic regression analysis and thus might have resulted in the observed significant associations, by chance (Lufler et al., 2010). Lastly, the cadaver CT might not have been a correct replacement of a live CT because of various potential tissue changes occurring inside the preserved specimens. In the same context, the cadaver-age was not mentioned either (Lufler et al., 2010). In another study inquiring about first year medical students' perceptions before and after the academic year, regarding integrating radiological anatomy instruction into the curriculum, Murphy et al. found that students' opinion regarding the importance of integrating radiology in medical undergraduate teaching increased from 92.4% to 96.2% after the module. Moreover, students' ability to correctly identify anatomical structures on the radiological images significantly increased from 59.8% to 64.3% after the module ($P < 0.001$) (Murphy et al., 2015). The results were encouraging and provide a valuable insight into students' perception of radiology-based teaching of anatomy; however, at the same time, the study was limited by being carried out at a single medical school on a single class. Hence, the results might not be an accurate representation of students' opinions due to the bias introduced by the local procedures, facilities, methods of instruction-provision, local resources, and student background (Murphy et al., 2015). The participant-cohort included the direct-entry medical students only. The perceived opinion of additional student-cohorts, including graduate entry medical and other health sciences students, needed to be taken into consideration to enhance the validity of the results. Moreover, a cross-sectional study design was employed by Murphy and colleagues (2015), which lacked a comparison of the interventional radiological pedagogy (experimental group) against some standardized pedagogical measure (control group). In addition, a false enhancement of structure identification could have been observed because of the same images been shown to students in both assessments, before and after the module, and the potential introduction of various confounding factors during the extended time-gap between the two assessments; over the course of the module (Murphy et al., 2015). In an additional study, researchers at the University of Southampton, UK evaluated an X-ray-based radiological e-learning resource for the first year nervous and locomotor course (Webb and Choi, 2014). It was found that students enjoyed learning (77%), found it easy to use the e-resource (81%) and got actively engaged in the learning process (75%). 80% of students reported that the e-learning helped them revise anatomy and 69% stated that it facilitated their application of anatomy in a clinical context. The summative assessment results were in alignment with the perceptual opinion as it was found that the student knowledge of the topics covered by the radiologic e-learning resource was significantly better as compared to those not covered by the resource ($P < 0.001$). While the favorable results are encouraging, however, one cannot be oblivious of the fact that the usefulness of the XRay is limited when it comes to visualization of soft tissue parts, especially the nervous system. Moreover, students' previous experiences, background, demographics and learning style preferences were not taken into account, which could have confounded the outcome.

In general, the magnetic resolution of the conventional neuroimaging modalities, such as, the 1.5 – 3T MRI is not high enough to visualize the small neuronal structures, such as, the nerve-nuclei and the spinal and cranial nerve pathways. These topics are important part of the medical undergraduate curriculum (Moxham et al., 2015) and understanding their location, course and function is integral for clinical neurological localization. Under these circumstances, diffusion tensor imaging (DTI) tractography could be used as a pedagogical modality to visualize and learn the neuronal pathways and white matter tracts. Even though the resolution of DTI is, once again, not high enough to visualize individual nuclei and connections across the course of the neuronal pathways, the technology still has received a positive response from the students. For instance, clinical cases and neurosurgical images from DTI tractographies produced intraoperatively (MRI-DTI apparatus by BrainSuite®), when presented during second-year neuroanatomy lectures for three years in a medical school in Rome, received appreciation from the student-community and a very high number of students felt that the use of intraoperative MRI-DTI images improved their knowledge of neuroanatomical structures and their topographical inter-relationships (Familiari et al., 2013). To further reveal the 3D structural relationships of white matter tracts in the human brain, a group of researchers from Netherlands described a unique pedagogical method of combining fibre-dissection with plastination to obtain durable and easy to use 3D specimens of cerebellar white matter tracts and nuclei. Fibre-dissection is a technique that allows isolation of whole fibre pathways, and once plastinated, the specimens can be used as a tool to teach white matter anatomy and structural connectivity (Arnts et al., 2014).

In short, undergraduate neuroanatomy courses for medical students are currently being supplemented with neuroradiological lectures incorporating CT and MRI, across numerous institutions. The pedagogy has received a positive response from the students, however, limitations in the study design, evaluation-methods and analysis have risen questions regarding their validity. Still, I believe, that as the technology becomes more affordable, we will begin to see increased infiltration of other neuroradiological technologies, such as, DTI, neuroimaging-based 3D digital brain models and virtual reality (VR) simulations into the mainstream teaching curriculum. Currently, the literature lacks an account of a critical appraisal of the neuroradiology e-resources from a learning-perspective. While being optimistic about the potential advantages of these neuroradiology e- tools for learning neuroanatomy, we should also be mindful of not getting carried away by the gadgetry and lose sight of the main goal, i.e., “learning”. In this context, I believe that a serious account of the development of the neuroradiology e-learning tools and their theoretical underpinnings – from a learning perspective – needs to be highlighted in the future papers, which can subsequently better guide their evaluation. To begin with, a brief account of the CF-ONLine given in Table 1.2 can serve as a useful guideline.

7.3. Videos and Computer Animations

Video-streaming and animations are efficient modes of transmission of anatomical information to the students. Other elements, such as pictures, text, charts and illustrations, can all be synchronized with the video in question. In the context of cognitive theory of multimedia learning, animations offer potential advantages over static images as they can explicitly depict dynamic information rather than requiring the learner to infer the change between consecutive static graphic displays (Ruiz et al., 2006).

Various computer animations have been employed for teaching topics, such as, histology (Brisbourne et al., 2002), neuroanatomy and cerebrospinal fluid (CSF) physiology. Lozanoff and colleagues developed animations from plastinated brain sections to teach human neuroanatomy in the context of the differences between an epidural and a subdural hematoma in simulated clinical cases with traumatic head injuries (Lozanoff et al., 2003). Similarly, Chorney described the development of an animated module to visualize the drainage of CSF (Chorney, 1998). Warwick Medical School, recorded 3D video podcasts, called the ‘‘Coachpod’’ for anatomy teaching on the move (Padwick et al., 2014).

Students have widely endorsed the use of videos / animations for anatomy learning. For instance, when undergraduate medical and radiation therapy students were surveyed, Barry and colleagues found the vast majority had employed YouTube video-clips for their anatomy learning (Barry et al., 2016). Similarly, Jaffar and colleagues reported that out of the 86% of students visiting their human anatomy education channel on YouTube, 92% agreed / strongly agreed that the channel helped them learn anatomy (Jaffar, 2012).

While results from the above-mentioned studies allude to the perceived usefulness of videos for anatomy learning, however, one also has to be mindful of the fact that these represent a passive mode of teaching whereas active learning has been demonstrated to result in greater learning gains. Adapting the videos into interactive tutorials which may provide opportunity for feedback and the development of students' self- evaluation may further increase the efficacy of this pedagogical tool for helping students learn complicated subjects, such as, neuroanatomy (Langfield et al., 2018).

7.4. Computer Assisted Learning Web-Resources

Various e-learning modules, interactive atlases and web-applications have been employed for learning neuroanatomy. Several data-sources including the Visible Human Dataset (by the NLM) (Juanes et al., 2003), the Chinese (Zhang et al., 2006; Li et al., 2014) and the Korean (Park et al., 2006) Visible Human Datasets, neuroradiographs (CT, MRI) (Petersson et al., 2009; Werkmeister, 2015), textbook illustrations and images of cadaver material (O'Byrne et al., 2008; de Faria et al., 2016) have been processed using a wide array of computer softwares, such as, Osirix, Adobe Flash, QTVR, VR Works software, to develop interactive multimedia content for neuroanatomy e-learning. Brinkley et al. used a combination of multimodal tools, including dissection / prosection-based images, MR images and digital 3D reconstructions of brain structures for formulating an e-learning resource covering various neuroanatomy topics including spinal pathways (Brinkley et al., 1997). Computer programming languages including HTML / PHP, C++, have been used at the front end to design interactive web user interfaces for enabling the learner to use the multimedia content.

In terms of the interactive features, most neuroanatomy web-resources have offered only a basic-level interactivity to actively engage the users. This included interactive buttons for text-based description, rollover image-labelling with immediate feedback and rotation and panning of 3D models. O' Byrne and colleagues imparted a fade-through image-function, where a sliding bar could be used to serially move across sectional representations of the brain (O'Byrne et al., 2008). Interactive questions including MCQs, fill in the blanks, picking correct answers from a list of structures, had been provided by Choudhary et al. (Choudhury et al., 2010).

The clinical application of basic neuroanatomical facts is imperative for addressing the prevailing neurophobia. The clinical contextualization of basic neuroanatomical information can be helpful for learning neuroanatomy (and alleviating neurophobia) by motivating the students through helping them associate a sense of relevance with the learning content (self-determination theory) and consequently fostering generative processing (Mayer, 2003), as mentioned in the CF-ONLine earlier (Table 1.2). Unfortunately, only a single web-resource could be identified which had focused on applying the basic neuroanatomical information for localization of lesion along the course of facial nerve in the brain (Lewis et al., 2011).

Many of the e-resources have been evaluated in an educational setting, by comparing them against a traditional pedagogical tool / resource as part of a typical experimental-control study design. Both qualitative (survey / questionnaire-based) and quantitative assessments have been conducted to inquire about participants' perception about the teaching tool and to acquire objective evidence of the efficacy of the resource to improve student learning of neuroanatomy, respectively. Still many lacked a comprehensive evaluation as part of their experimental design. For instance, Petersson and colleagues (Petersson et al., 2009) only employed a survey questionnaire to acquire students' perception for assessing their e-resource, while lacking a quantitative assessment of learning-gain. There were several potential limitations associated with the evaluative design of the study, for instance, the population study size was too small, and the hours spent using the software were too few to allow reliable generalizations. Although, the study design incorporated a random generation of experimental and control groups, however, the participants in both groups completed the evaluation during different times (fall vs. spring semester), hampering controlling various possible confounding factors. Moreover, the e-tool was limited to cerebral vasculature only and it was not incorporated into the curriculum at the time of evaluation, thus questioning the reliability of the results acquired in a real-life setting. Unlike Petersson and colleagues (2009), de Faria et al. (de Faria et al., 2016), Stewart et al. (Stewart et al., 2007) and Werkmeister et al. (Werkmeister, 2015) did employ a quantitative assessment by gauging students' performance scores but they were deficient in acquiring students' perceptual opinion/s. O' Byrne et al. (2008) and Choudhary et al. (2010) conducted a quantitative comparison by comparing the performance scores of participants with students from previous years and hence their experimental designs were limited in terms of normalizing across the participants' IQ, baseline knowledge and learning preferences, thus adding potential confounds to the results. Lastly e-neuroanatomy resources from Brinkley et al (1997) and Li et al. (2014) were not evaluated at all.

In the commercial sector, various popular resources such as Acland's Video Atlas of Human Anatomy (http://aclandanatomy.com/), 3D Human Anatomy Software by Primal Pictures (https://primalpictures.com/) and Anatomy TV website (https://www.anatomy.tv/) could help in neuroanatomy learning. Lately, there has been an explosion of large-scale initiatives and projects addressing mapping, modeling, simulation and atlasing of the human brain, including the BRAIN Initiative®, Human Brain Project® (Markram et al., 2011), Human Connectome Project® (HCP), Big Brain® (Amunts et al., 2013), Blue Brain Project®, Allen Brain Atlas®, Brainnetome®, among others, all of which hold potential for being employed as useful neuroanatomical pedagogical tools (Nowinski, 2017). However, the relationship between the instructional design of these resources and consequent enhancement of learning needs to be assessed.

To conclude, there is a plethora of online resources available, which are potentially beneficial for learning neuroanatomy, however, the reliability of the conclusions could be challenged due to lack of control of various confounding variables and limitations of the evaluative paradigm employed. Much work is left to be done both in developing and evaluating new instructional systems which could impart a greater level of interactivity and focus on the clinical application of the basic neuroanatomical facts. The development of the instructional design needs to be discussed in the context of the theoretical underpinnings offered by the adult learning theories and cognitive learning theories, such as, those summarized in Table 1.2 (CF-ONLine).

7.5. Mobile Applications for Neuroanatomy

With continuous advancements in technology, mobile and tablet-based neuroanatomy applications have gained students' and educators'-interest, alike. In a recent review, Lewis and colleagues talked about mobile-based 3D applications from developers for human anatomy, such as, 3D4Medical Ltd., Visible Body Inc. and Pocket anatomy which allow students to visualize and manipulate complex anatomical structures using detailed 3D models (Lewis et al., 2014).

In reviewing the field, Cohen and colleagues provided a comprehensive list of mobile medical applications in the field of neurology, many of which can be useful for neuroanatomy learning (Cohen et al., 2013). For instance, some of the neurology mobile applications offer highly useful views of surface and cross-sectional brain anatomy, such as, 3D Brain, iSurfBrainView, and Brain & Nervous System Pro III: NOVA Series Collection. Several advanced apps focus on neuroanatomy, but with neuroradiological images. These include e-Anatomy and other similar apps (BrainMRI and Brain MRI Atlas) which allow the user to scroll through multiplanar MRI sections. A similar app, NeuroRad, also provides various means to view vessels and vascular territories. They allow the user to electively label specific structures, such as sulci, gyri, ventricles, cisterns, brainstem, or vessels. 3D Brain & Nervous System Anatomy and 3D Muscular Premium Anatomy allow users to dynamically explore 3D models of the brain. The structures of interest can be isolated and viewed from any angle, which is useful in understanding the neuroanatomical spatial relationships. A set of apps using the Modality platform (Netter's Neuroscience Flash Cards, Netter's Concise Radiologic Anatomy, Netter's Advanced Head & Neck Flash Cards, Imaging Atlas of Human Anatomy, Sylvius MR: Atlas of the Human Brain, and Thieme: Atlas of Anatomy) provide numerous neuroanatomic plates of drawings and radiology. Inkling has the "Essentials of Clinical Anatomy," which includes an interactive approach to basic neuroanatomy.

The principles central to the use of mobile technology in medical education draw from the behaviorist and cognitive theoretical underpinning of socio-cultural theories (Durning and Artino, 2011) and reflective learning offered by online communication and feedback. Evidence in the literature has demonstrated that students value the integration of mobile applications and devices into traditional neuroanatomy teaching methods (Vafa and Chico, 2013; Morris et al., 2016). However, one has to be mindful of the limitations associated with the subjective reporting from voluntary respondents. Thus, a comprehensive quantitative assessment of the mobile technology, following its incorporation into the learning environment, is required in a randomized-controlled trial (RCT) setting. In the same vein, the study conducted by Morris and colleagues (2016) lacked an experimental and control group comparison and the data was acquired from students over an extended time span of 3 years, which could have added various potential confounds to the results and thus challenging the validity of the impact reported on the learning outcomes.

7.6. 3D Modelling and 3D Display Technologies

3D models and 3D visualization technology (3DVT) has shown to increase students' knowledge of neuroanatomical facts, the spatial inter-relationships, coupled with an increase in user satisfaction and learners' perception of the effectiveness of the learning tool (Yammine and Violato, 2015; Azer and Azer, 2016).

In the simplest form, 3D models may provide the ability to manipulate and visualize structures from many different angles, transcending the limitations of traditional static images. In the more complex cases, a user may be able to select components for closer study, move them about and examine supplementary data such as labels, radiographs and animations. At the highest levels, users may interact in a natural way with the model, by grasping it with the hands or altering it by cutting or drilling with a tool, thus providing an immersive learning environment. Incorporation of various types of 3D display technologies, such as, monoscopy, stereoscopy, autostereoscopy and augmented reality, into neuroanatomy educational settings, can offer a richer learning experience by further improving neuro-visualization.

Base-datasets of CT and MRI DICOM files have been extensively subjected to various post-processing imaging techniques to create 3D digital brain models (Tam, 2010). For instance, Nowinski and colleagues employed 3T MRI and MRA scans to create a 3D digital model of cerebral vasculature (Nowinski et al., 2009a; Nowinski et al., 2009b; Nowinski et al., 2009c). Various other groups have also reconstructed 3D brain models using MRI and / CT scans from live humans (Schnack et al., 2001; Pitiot et al., 2004; Anil et al., 2007; Howden et al., 2008; Giesel et al., 2009; Howden et al., 2011; Drapkin et al., 2015; Palomera et al., 2014; Settapat et al., 2014; Cui et al., 2017), cadavers (Nicholson et al., 2006; Adams and Wilson, 2011) and patients with strokes (Liu et al., 2010; Liu et al., 2009). In addition, cryosection images from the VHD have proven instrumental for the development of 3D digital brain models (Chariker et al., 2011; Yeung et al., 2011; Brewer et al., 2012; Chariker et al., 2012; Palomera et al., 2012; Ruisoto et al., 2012; Pani et al., 2013; Naaz et al., 2014; Pani et al., 2014; Allen et al., 2016), while Zhu and colleagues presented an interactive web-based navigation system based on high-resolution Chinese Visible Human dataset (Zhu et al., 2014b). A wide variety of softwares have been used for modelling and rendering the digital brain models, such as, Adobe Director & Flash, Unity, Amira, Osirix, VRML, QTVR, MicroView softwares, Web-based X3D player and Cinema4D XL Studio Bundle. Visual C++, HTML / PHP, Java and Lingo were among the common languages employed for the front-end development programming associated with the interactive web user-interface of the model.

Consequently, various state-of-art 3D models of the brain and its components have been created, which can be integrated into neuroanatomy e-learning resources, while the instructional design of these online educational settings could be better informed by the conceptual framework for e-learning, briefly outlined in Table 1. These include models of cerebral vasculature (Nowinski et al., 2009a; Nowinski et al., 2009b; Cui et al., 2017), ventricles (Adams and Wilson, 2011), various cortical and subcortical structures (Gould et al., 2008; Chariker et al., 2011; Pani et al., 2013) and 3D models-based videos to explain neuroanatomical structures (Brewer et al., 2012). Learning the 2D sectional neuroanatomy is important as medical students will have to localize neurological lesions by looking at the 2D axial, coronal and sagittal sections of the central nervous system. Hence, to better integrate 3D spatial coordinates of the cortical and subcortical structures with the 2D sectional representations of the brain, the 3D models have been overlaid onto 2D MRI (Drapkin et al., 2015), PET / SPECT scan-images (Palomera et al., 2014) and cryosection-images (Palomera et al., 2012). This dual visualization technique overcomes the cognitive leap required to jump from 3D to 2D space.

Various 3D models related to the anatomy of neuronal pathways, such as, the cranial nerves have been developed as well (Glittenberg and Binder, 2006; Yeung et al., 2011; Nowinski et al., 2012; Nowinski et al., 2013; Nowinski et al., 2015). However, a comprehensive, high-resolution resource capturing 3D relationship of neuronal pathways, including cranial and spinal nerves, along with their tracts and nuclei, is lacking.

The user-interfaces associated with almost all 3D models described above offer only limited interactive features for learning, such as, rotation, zooming in / out, panning, individually selecting / removing structures (for virtual dissection), immediate feedback via on / off interactive labelling for naming and localization of neuroanatomical structures. The 3D interactive atlas from Nowinski and Chua (Nowinski and Chua, 2013) provides the option of cutting the 3D brain in various directions to have a tri-planar display, while Palomera et al. (Palomera et al., 2014), overlaid 3D models onto PET scan slices, thus offering users the opportunity to not only apply functional plane cuts and learn spatial relationships, but also visualize functional brain activation areas. The ventricular model by Adams and Wilson provides linear measurements between any two points / structures selected on the model (Adams and Wilson, 2011).

Only a very few 3D models / atlases had focused on teaching the clinical correlates of neuroanatomy to the students, including the localization of neurological lesions. For instance, Nowinski and Chua have developed a 3D interactive atlas of neurological disorders with 144 synthesized lesions, created over the 3D brain model; each labelled with the resulting disorder and associated clinical presentation (Nowinski and Chua, 2013). Lack of provision of clinical correlates decreases the chances of contextualizing the information which could have otherwise been learnt more effectively by motivating the students and through instilling in them a sense of relatedness (Self-determination theory, Table 1.2; CF-ONLine) and appreciation of the value of the content-learned (Expectance valence theory, Table 1.2; CF-ONLine).

It has been suggested that additional research is needed to assess the value of computer-based instruction in biomedicine (Ruiz et al., 2009; Tam et al., 2009). Many of the 3D neuroanatomical tools have not been evaluated in educational settings (Nowinski et al., 2009a; Nowinski et al., 2009b; Adams and Wilson, 2011; Nowinski and Chua, 2013). Out of those which have been evaluated, some lack objective or quantitative evidence as most of the evidence revolves around subjective student / learner perception and satisfaction (Gould et al., 2008; Palomera et al., 2012; Palomera et al., 2014), which alone is insufficient to inform us about the impact of the incorporation of technology resources into anatomy education

(Clunie et al., 2017). On the other hand, some 3D models, such as that of the cranial nerves, did not increase student knowledge of neuroanatomy as compared to the traditional text and image-based materials, despite students' preference for using the 3D models (Yeung et al., 2012).

Various commercial companies have created large web-based 3D atlases for human anatomy learning, including Biodigital Human Ltd., Visible Body, Zygote body, Google Body, Anatronica, and many more (Frasca et al., 2000). However, their 3D brain models are limited in terms of the accuracy of spatial relationships and resolution of the microcosmic neuroanatomical structures.

Some additional important limitations associated with the usefulness of 3D reconstructed models for neuroanatomy learning are as follows:

1) Low resolution slice thickness is not suitable for visualizing small neuroanatomical structures, such as, arachnoid granulations. From a resolution-perspective, the Nowinski's model could be criticized as there is a sparseness of microvascular images and the content of the vascular model is incomplete. In addition, some small vessels in the vascular bed (e.g. ophthalmic artery, perforating arteries at the brain-base) have smaller lengths than those cited in the literature, while others are completely missing, including the choroidal arteries and cavernous sinus (Nowinski et al., 2009a). Moreover, the model has been based on a single specimen which raises questions regarding its validity.

2) Nicholson et al. (2006) and Adams and Wilson (2011) used cadavers as a source for developing their 3D brain models. However, one has to be cognizent of the fact that age-related structural changes in the images acquired from cadavers potentially raise a red-flag

for a less accurate representation of neuroanatomical structures (Fjell and Walhovd, 2010). It has been observed that the brain shifs and settles after death, altering the original shape of the spaces inside. In addition, embalming of the cadaver, using the arterial and venous system to perfuse the body with embalming fluid, could have an effect on the shape of the ventricular system as fluids are pushed through vessel walls of the choroid plexus into the ventricles. In an MRI study, Dashner (2003) showed that unembalmed postmortem brains had higher soft tissue contrast and greater image sharpness than images obtained from embalmed brains. This was because the water content of the recently deceased brain was similar in form to that of the living brain, and MR signal intensities are based on differences in water, specifically the hydrogen concentrations between anatomical structures. The water content of the embalmed brain would be different than the live or unembalmed brain due to the perfusion of tissues with formalin during the embalming process (Dashner, 2003).

3) From a development perspective, the limited interactivity and anatomical subdivision of the components of the brain model because of automatic image-processing segmentation techniques, is an additional drawback, as it prevents separating out structures which have similar tissue characteristics and thus will be segmented together as one object, preventing them from being visualized separately from surrounding structures. This also hinders interactivity by preventing virtual-dissection (Adams and Wilson, 2011).

4) Lastly, the large file size of the 3D digital brain models could hinder a smooth experience at the user-end.

7.7. Augmented Reality in Neuroanatomy Education

Augmented reality (AR) is a hybrid technique that overlays digital information onto the real-world objects to enhance user-experience of the real world (Berryman, 2012). Its use in health education has enhanced learning and the users of AR seek to continue using it in the future (Zhu et al., 2014a).

Küçük et al. evaluated the effectiveness of a mobile AR application on neuroanatomy learning and found that 2nd year medical students reported a greater learner satisfaction and a lower cognitive load, coupled with a corresponding increase in their academic scores (Küçük et al., 2016). The results seem encouraging, however, they should be accepted with caution, as the 'out-of-class time'–when students were engaged in using the augmented reality Magic Book–had not been gauged. Therefore, more controlled RCTs need to be employed in the future to test the reliability of the results acquired. Similar positive results were acquired when Westwood (2016) imparted enhanced functionalities to the pages of a clinical neurology review book by a mobile AR application, "The Gunner Goggles". Medical students felt that the AR application improved the quality of the textbook chapters and suggested that a completed Gunner Goggles product would have been a viable alternative to their shelf exam review (Westwood, 2016). A quantitative assessment of the Gunner Goggles AR application is however missing.

7.8. Virtual Reality and Neuroanatomy Learning

Unlike AR, which focuses upon enhancing the reality, the virtual reality (VR) creates a totally digital or a computer-generated environment. The immersive visualization offered by the VR can greatly increase learners' perception of the spatial relationships between neuroanatomical structures.

Various important data-sources have been used as substrates to generate 3D models for an immersive virtual learning environment. Some of the research groups have resorted to cryosectional images from the Visible Human Dataset (Kockro and Hwang, 2009; Armstrong et al., 2014; Kockro et al., 2015), while others have employed CT and / or MRI neuroimages (Kockro and Hwang, 2009; Hochman et al., 2014; Kockro et al., 2015; Stepan et al., 2017), to develop virtual 3D models of the brain, temporal bone, 3rd ventricle and other neuroanatomical structures.

The VR can provide a highly interactive environment to enhance the neuroanatomy learning experience through active engagement and provision of haptic feedback in a 3D world. For instance, Armstrong and colleagues developed a 3D brain model where the users could identify and reposition different parts of the brain into their correct anaomical locations in a virtual environment. A magnetically tracked wand was used as a 3D input device and its movement corresponded to the movement of a cursor within the rendered scene for moving the objects (Armstrong et al., 2014). Hochman and colleagues segmented the CT images to develop a 3D digital model of temporal bone. It was rendered in an in-house software, that when connected with Microsoft Kinect®, allowed the user to extract specific anatomical structures-of-interest from the model, move and rotate them in all planes, using hand-movements / gestures (Hochman et al., 2014). “Touch-simulator” (resembling a brain) with touch sensors, developed by Panchaphongsaphak et al., was designed to record and process the sensory information from the user’s hands and audiovisually display it. It allowed the user to visualize and manipulate graphical information of the brain surface of different cross-sectional slices by a finger-touch on the simulator (Panchaphongsaphak et al., 2007).

Virtual endoscopy, which has been used in preparation for neurosurgical procedures, can provide an interactive, noninvasive, 3D visual inspection of anatomical cavities & vessels in a VR environment (Neubauer and Wolfsberger, 2013). Karaman, in their M.Sc. thesis (https://dspace.ucalgary.ca/handle/11023/2845) at the University of Calgary, has described a live virtual tour of a 3D brain museum, as well as a standalone application to recreate elements from the museum for a similar desktop experience. Using the Brain Slice Explorer, a sliced replica of a human brain can be taken apart and studied, while corresponding QR codes provide access to a web application with further information and details (Karaman, 2016). Lastly, software generating a 'Second Life Environment' can be universally used as a virtual platform for online didactic lectures and live streaming demonstrations with prospect of global participation. For instance, 'the cranial nerve skywalk; a virtual anatomy platform' containing 3D models of cranial nerves 3, 5, 7, 9 and autonomic pathways, provided a fully immersive 2nd life environment for learning (Richardson- Hatcher et al., 2014).

Although the VR applications increase the learner immersion and engagement, however, the potential headache, dizziness or blurring of vision associated with using the head-mounted display equipment could be physically debilitating (Moro et al., 2017). Moreover, the lack of enhancement of students' knowledge of neuroanatomy when using the VR applications has been highlighted in various studies (Moro et al., 2017; Stepan et al., 2017). Students, however, have appreciated the use of VR tools in educational settings. For instance, the 3D model of temporal bone, 3rd ventricle and related structures (with selectable middle & inner ear, cranial nerves, vessels, brainstem components) created by Kockro and Hwang, when stereoscopically projected through Dextrobeam, was rated superior to the 2D teaching methods by students in context of spatial understanding, application in future anatomy classes, effectiveness and enjoyableness (Kockro and Hwang, 2009; Kockro et al., 2015). Positive feedbacks were also obtained from students regarding the “touch simulator” and the “cranial nerve skywalk” VR tools (mentioned above).

Despite the fact, that the application of VR applications into mainstream neuroanatomy education seems to be in its nascent stage, still we predict that as the technology becomes further advanced and the cost of various sophisticated modalities, which employ the VR technology, drops down, we will see their increased incorporation into mainstream neuroanatomy education at medical undergraduate level. Having said that, we should not get carried away by using technology solely for sake of using technology, and turn a blind eye to the main reason why the technology was instilled into education in the first place, that is, to enhance the learning process.

7.9. Social Media and Neuroanatomy Education

Students are increasingly willing to merge their online presence on social media with their degree programs for sharing knowledge. For instance, Jaffar and colleagues (2014) reported that most students perceived “Human Anatomy Education”; a Facebook-page, effective for learning and favored the self-assessment posts (Jaffar, 2014). Students also find Facebook™ as a useful learning tool for their summative anatomy assessments’ preparation and in increasing their confidence and reducing anxiety (Pickering and Bickerdike, 2017). Hennessy and colleagues used a questionnaire to evaluate the use of Twitter™ as a way of supporting students’ learning on a neuroanatomy module. They found a correlation between exam scores and students’ viewing frequency. Twitter™ facilitated communication, relieved anxieties and raised morale, which was valued highly by students and aided engagement with neuroanatomy. Twitter™ was successful in creating and providing a support network for students during a difficult module (Hennessy et al., 2016).

The significance of interacting with others in social settings cannot be undermined in learning and thinking. This encompasses both behavioristic learning (with people imitating others and reinforcing what they observe) and cognitive learning (mental processing involved in the observation over the resulting behavior and regulating their own behavior by recognizing consequences) (Taylor and Hamdy, 2013). While the social and communal context is important for learning, the presence of an instructor who simply guides the learning process (by acting as a guide by the side) and when required, steers it, based on his experience, is essential as well.

7.10. Gamification of Neuroanatomy Education

The world of gaming has been intertwined with the world of education for a long time. In the future we would see an increased application of game-design elements in non-game contexts, such as, education. Many published studies suggest possible benefits from using gamified media in medical curriculum. McCoy and colleagues reviewed various gamified training platforms including education games, medical mobile applications, and virtual patient simulations for medical education and clinical training (McCoy et al., 2016)**.**

This is a rapidly growing field. More research is required to rigorously evaluate the specific educational benefits of these interventions and to answer the question ‘if gamification will be the future of education’.

8. Hypothesis and Aims of the Thesis

Although modern technological pedagogies can serve as useful supplementary teaching aids for learning neuroanatomy neurophobia still persists and students and doctors continue to link it with their impaired understanding of neuroanatomy. In this context, this thesis sought to investigate the potential limitations of existing online and technological pedagogical tools and the pedagogical construct of these resources, to address the prevailing neuro (-anatomy-) phobia.

8.1. Hypothesis

We hypothesized that a novel, interactive neuroanatomy e-learning resource, which is rooted in the principles of instructional design based on cognitive and adult learning theories and the users' opinion, will be effective in significantly improving participants learning and understanding of neuroanatomy.

8.2. Research Aims

8.2.1. Aim 1: Understanding Neurophobia: Reasons Behind Impaired Understanding and Learning of Neuroanatomy in Cross-Disciplinary Healthcare Students (Chapter 2)

Students' perception regarding the difficulties associated with learning neuroanatomy, among a broad cohort of medical, dental, occupational therapy, and speech and language sciences students will be assessed. Questionnaire will be formulated to inquire about the students' perceived difficulty of anatomy topics from systems and regions-based perspectives (Appendix 1). In context of the nexus between the impaired understanding of neuroanatomy and the neurophobia, various factors contributing to this perceived difficulty will be explored as well. In addition, an inventory of conventional and non-conventional technological pedagogical tools regarding their usefulness for learning neuroanatomy and the perceived efficacy of a purposefully designed computer assisted learning CAL resource will be inquired (Appendix 1).

8.2.2. Aim 2: Evaluation of Neuroanatomy Web-Resources for Undergraduate Education – Educators' and Students' Perspectives (Chapter 3)

A detailed search will be conducted to decipher the limitations of existing neuroanatomy web-resources. A panel of educators will analyze and rank a selection of resources, focusing on the features influencing their usefulness in learning the anatomy of the spinal pathways. The evaluation-grid (Appendix 5) will be formulated based on evidence available in the literature regarding the usability and web user-interface features, principles of adult educational learning theories (Taylor and Hamdy, 2013) and the cognitive learning theory (Mayer and Moreno, 2003; Young et al., 2014). A panel of undergraduate students will subsequently evaluate the top three web-resources to assess how specific features aid in their learning of the subject (Appendix 6). The results will provide us with a novel perspective about features of neuroanatomy web-resources that are valued by both educators and users with regards to their pedagogical construct. It will inform us about measures which can be taken to improve the pedagogical construct and enhance learner performance.

8.3.3. Aim 3: Neuroanatomy of the Spinal Pathways: Evaluation of an Interactive Multimedia E-Learning Resource (Chapters 4 and 5)

A novel, interactive, neuroanatomy learning e-tool will be designed, whose pedagogical construct will be informed by students' and educators' opinion acquired earlier in UCC. The educational efficacy of UCC e-learning resource will be compared against the available best-ranked online neuroanatomy resource. Undergraduate medical and health science participants will be randomized into experimental and control groups. They will be provided 2 weeks-long online access to the UCC e-learning tool and the best-ranked available resource, respectively. Participants' knowledge of neuroanatomy will be assessed using 24-item neuroanatomy quizzes (quiz-1 and 2; Appendix 9 and 10); before and after exposure to the online tool, respectively. Lastly, participants' opinion regarding usefulness of various components of the tools will be gauged using a Likert scale-based questionnaire (Appendix 11).

Likert scale ratings and the neuroanatomy quiz scores for control and experimental group participants will be compared to investigate if the pedagogical construct of the UCC e-learning tool presents a significantly higher chance of breaking the perceived nexus between the neuroanatomy-phobia and the neurophobia, as compared to the already available top-ranked neuroanatomy learning online resources.

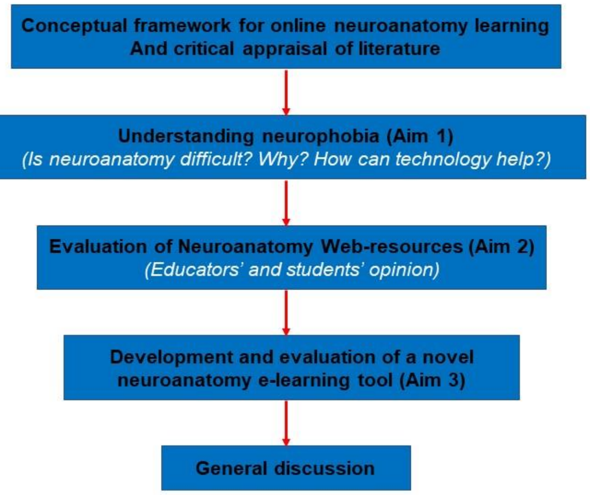

Figure 1.1: Operational Flow of the Thesis.

CHAPTER 2

Understanding Neurophobia: Reasons Behind Impaired Understanding and Learning of Neuroanatomy in Cross-Disciplinary Healthcare Students

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Abstract

Recent studies have highlighted a fear or difficulty with the study and understanding of neuroanatomy among medical and healthcare students. This has been linked with a diminished confidence of clinical practitioners and students to manage patients with neurological conditions. The underlying reasons for this difficulty have been queried among a broad cohort of medical, dental, occupational therapy, and speech and language sciences students (Appendix 1). Direct evidence of the students' perception regarding specific difficulties associated with learning neuroanatomy has been provided and some of the measures required to address these issues have been identified. Neuroanatomy is perceived as a more difficult subject compared to other anatomy topics (e.g., reproductive / pelvic anatomy) and not all components of the neuroanatomy curriculum are viewed as equally challenging. The difficulty in understanding neuroanatomical concepts is linked to intrinsic factors such as the inherent complex nature of the topic rather than outside influences (e.g., lecture duration). Participants reporting high levels of interest in the subject reported higher levels of knowledge, suggesting that teaching tools aimed at increasing interest, such as case-based scenarios, could facilitate acquisition of knowledge. Newer pedagogies, including web-resources and computer assisted learning (CAL) are considered important tools to improve neuroanatomy learning, whereas traditional tools such as lecture slides and notes were considered less important. In conclusion, it is suggested that understanding of neuroanatomy could be enhanced and neurophobia be decreased by purposefully designed CAL resources. This data could help curricular designers to refocus attention and guide educators to develop improved neuroanatomy web-resources in future.

Keywords: Neuroanatomy education, neuroscience education, medical education, undergraduate education, computer assisted learning, web-resources, neurophobia, case-based teaching.

Introduction

Increasing concerns have been expressed by the health sciences community regarding the regression of anatomical knowledge among graduates and young practitioners. This regression has highlighted an unmet and urgent need to address the underlying causal issues to ensure safe patient care (Waterston and Stewart, 2005; Raftery, 2007; Fillmore et al., 2016). Poor understanding of neuroanatomy has been documented as a major hindrance in the successful translation of basic neuroscience knowledge to clinical situations. For example, the incorrect administration of inferior alveolar nerve block by dental students and interns due to their lack of understanding of the possible neuroanatomical variations has led to major complications (AlHindi et al., 2016). Insufficient neuroanatomical understanding and a resulting lack of confidence when treating neurology patients has been identified among general practitioners (Schon et al., 2002; McCarron et al., 2014) and medical students across various countries including the United States (Zinchuk et al., 2010), Ireland (Flanagan et al., 2007), the United Kingdom (Schon et al., 2002; Ridsdale et al., 2007; Pakpoor et al., 2014), Australia (Hudson, 2009), Singapore (Lim and Seet, 2008; Kam et al., 2013), Caribbean countries (Youssef, 2009), Nigeria (Sanya et al., 2010), Sri Lanka (Matthias et al., 2013), and India (Gupta et al., 2013).

Difficulties in retaining neuroanatomical knowledge were identified when second-year medical students were re-tested with questions from an end of term assessment they had completed eleven months earlier (D'Eon, 2006). Results showed a lower retention of neuroanatomical knowledge compared to physiology and immunology, re-affirming the difficult nature of the subject. Similarly, in face-to-face interviews practicing speech and language therapists specifically labeled their experience of learning neuroanatomy from textbooks and traditional lectures as "very, very hard and tough," especially compared to other disciplines (Martin et al., 2014). Overall, neuroanatomy is consistently cited as one of the most challenging portions of the anatomical sciences curriculum by medical students and junior physicians alike (Jilwan et al., 2014). Further evidence from the literature suggests that this poor understanding of neuroanatomy leads to a dislike or fear of the subject in clinicians and trainees (Schon et al., 2002; Flanagan et al., 2007; Ridsdale et al., 2007; Lim and Seet, 2008; Hudson, 2009; Youssef, 2009; Sanya et al., 2010; Zinchuk et al., 2010; Gupta et al., 2013; Kam et al., 2013; Matthias et al., 2013; Fantaneanu et al., 2014; McCarron et al., 2014; Pakpoor et al., 2014; Abushouk and Duc, 2016). The term "neurophobia" was first coined by Jozefowicz to describe this fear of the neural sciences and their clinical application in neurology (Jozefowicz, 1994).

In the course of the last century, there has been a curtailment in the curriculum space allocated to anatomy, particularly as health sciences programs develop integrated learning approaches. As for other anatomical disciplines, neuroanatomy was integrated horizontally with other basic sciences and vertically with clinical disciplines, leading to a marked reduction in the number of dedicated teaching hours (Drake et al., 2009). While adoption of competency-based and patient- and learner-centered approaches have been deemed useful in health sciences education, they have also pressurized the faculty to justify place of basic neuroanatomy in the curriculum (Hazelton, 2011); a situation that is not conducive to resolving neurophobia.

A brief overview of the pedagogical framework for neuroanatomy in the Republic of Ireland illustrates that the pressures described above also apply nationally. While the core knowledge is based on recognized curriculum (Moxham et al., 2015), the mode of delivery varies between institutions. Four of the five medical schools in Ireland follow a hybrid approach in which the traditional pedagogies (lectures and dissection room) are supplemented by computer assisted learning (CAL) whereas teaching is anchored into a problem-based learning paradigm in the fifth institution. For other health sciences such as occupational therapy, speech and language sciences and dentistry, an overview of the Irish institutions revealed that neuroanatomy is generally delivered as part of other anatomy or human biology courses and that while only selected portions of the curriculum are being taught, time constraints have also affected these programs.

Despite the perception that neuroanatomy is a difficult subject, the reasons underlying the perceived difficulty of “neuroanatomy” have not been fully dissected. Previous studies focused mainly on clinical neurology and alluded to an impaired understanding of neuroanatomy in the broader context of difficulties associated with practicing clinical neurology. In particular, Fantaneanu and colleagues identified a number of modifiable (such as timing of delivery) and unmodifiable (such as past exposure or preconceptions) risk factors associated with the onset of neurophobia and suggest acting on modifiable ones to reduce its prevalence (Fantaneanu et al., 2014). Moreover, while a comprehensive survey revealed very few positive outcomes (McColgan et al., 2013), potential strategies to reduce neurophobia have started to emerge from systematic studies (McColgan et al., 2013; Abushouk and Duc, 2016). While some progress has been made, the development of effective educational programs and tools is hampered by a relatively poor understanding of the underlying causes of neurophobia. In particular, the learning difficulties linked with impaired understanding of "the basic sciences such as neuroanatomy" have not been directly studied. In an attempt to bridge this gap, a broad anonymous survey was performed among medical, dental, and health sciences students at University College Cork (Ireland) (Appendix 1). This research is novel in its approach as it has aimed to identify the student's perception of neuroanatomy and specific areas of difficulty within the subject. Moreover, the reasons making neuroanatomy difficult and possible solutions in the context of computer-aided learning have been investigated.

It was hypothesized that neuroanatomy would be perceived by the students as a difficult topic to learn compared to all other topics of anatomy and that intrinsic factors, such as the complexity of the topic significantly contribute to this perceived difficulty. The hypotheses are supported by the results from the present study which suggest that appropriately designed online web-resources could be important pedagogical tools in addressing the challenges associated with learning neuroanatomy.

Materials and Methods

Institutional Neuroanatomy Teaching Framework

The pedagogical framework for neuroanatomy at University College Cork (UCC) is primarily lecture-based with support from prosection-based tutorials and CAL (Anatomy and Physiology REVEALED, McGraw-Hill Higher Education, New York, NY). Neuroanatomy is taught by multiple faculty members and is anchored in a systems-based teaching design. The groups surveyed in this study included medical students from two separate programs, undergraduate entry medicine (DEM) and graduate entry medicine (GEM), Bachelor of dental surgery (BDS), occupational therapy (OT), and speech and language sciences (SLS) students. The duration of each program is 4 or 5 years (Table 2.2). There are variations in the timing of delivery with medical students (DEM and GEM) taking classes in their second year while BDS students receive neuroanatomy lectures in first and second years. The neuroanatomy curriculum for dental and medical students comprises the list of topics presented in the survey. The medical curriculum is horizontally integrated with the relevant physiology and biochemistry. Lectures content is oriented toward descriptive neuroanatomy with supporting examples of pathological dysfunctions. The neuroanatomy curriculum is covered in the Autumn semester with 18 hours of lectures and four 2-hour long prosection-based tutorials. Bachelor of dental surgery students do not attend these tutorials as their content is interspersed within their head and neck topographical anatomy. Occupational therapy and SLS students receive the bulk of their neuroanatomy teaching in the second and third years of their degree. The neuroanatomy curriculum is covered in the Autumn semester with 18 hours of lectures focusing on clinical pathways, followed by clinically relevant case-based examples (e.g., multiple sclerosis, Parkinson’s disease). The lectures are supplemented with two (for OT and SLS) 2-hour long prosection-based tutorials. Despite variations in the delivery, all the students surveyed receive the same overall content. In addition, students from the five programs are exposed to clinical scenarios as part of other modules. All programs are assessed by a summative end-of module assessment and are supported by the University's web-based learning portal, which allows students to access lecture / tutorial notes and other learning resources.

Survey Design

A 25-item anonymous questionnaire was designed. The survey was comprised of open- and close-ended questions with Likert scale rankings inquiring about perceived areas of difficulty in learning anatomy, factors contributing to the difficulty and the means to address such challenges in the context of CAL (Table 2.1, Appendix 1). The questions were pre-evaluated by a panel of seven medical educators at UCC; four neuroanatomists and three clinical practitioners. The survey was proofread for clarity and checked for inclusion of equal number of positive and negative statements and leading sentences, reducing the total number of questions from 33 originally to a final 25. To ensure suitability and clarity, the questionnaire was piloted with ten volunteer participants who were not part of the eventual data acquisition process. Ethical approval was obtained from the institutional Social Research Ethics Committee (Appendix 2 and 3). The survey was distributed in print and online, among the medical students (DEM, N = 480 and GEM, N = 240), BDS (N = 160), OT (N = 50), and SLS (N = 50) students that have completed the neuroanatomy training at UCC. The survey was distributed to students in their second, third, fourth or fifth year of training, and as described above, neuroanatomy teaching is completed in the second or third year of training. Therefore, a serial effect may have been imparted on the results as some students completed the survey immediately after teaching concluded while third year medical and dental students filled the survey a year after completing their neuroanatomy. This lag was increased to 2 years for fourth year students and 3 years for final year students in these programs. Fourth year OT and SLS students filled the survey 1 year after completing their neuroanatomy module. Bi-weekly reminder email notifications were sent to students. Data acquisition was completed in 4 months (September–December, 2015).

Table 2.1: Structure of the Survey

Question no.	Subject of inquiry
Q1 to Q5	Participants' characteristics (Gender, program of study, current study year, prior qualification)
Q6 to Q11	Perception of level of difficulty, knowledge and interest in anatomy topics: a) Systems-based context (cardiovascular, gastrointestinal, genitourinary, musculoskeletal, pelvic and reproductive, upper and lower respiratory systems) b) Regions-based context (abdominal, head and neck, lower limb, pelvic, thoracic, upper limb)
Q13	Perception comparison of overall ease or difficulty of neuroanatomy compared to other anatomy topics
Q14	Factors making neuroanatomy difficult: (1- access to neuroanatomy information online, 2- access to neuroanatomy textbooks, 3- appreciation of 3D relationships, 4- complexity of topic, 5- lecture duration, 6- memorization of neuroanatomical terminologies, 7- time spent in dissection room, 8- understanding clinical aspects of neuroanatomy, 9- visualization of structures on prosections of CNS)
Q15	Difficulty learning the following neuroanatomy lecture topics: (CNS vasculature, auditory pathway, autonomic nervous system, basal nuclei, brainstem, cerebellum, cerebral cortex, cranial nerve nuclei and nerves, spinal cord, limbic system, meninges and ventricles, motor pathways and lesions, neurohistology, sensory pathways and lesions, trigeminal system, vascular brainstem lesions, vestibular system, visual pathways)
Q16	Usefulness of the following teaching aids in understanding neuroanatomy: (Anatomical models, bedside tutorials, CAL, dissection, laboratory practicals, spot examinations, peer learning, power point slides, lectures, web-resources, prosections, radiology, textbooks, tutorials, board drawings)
Q20	Effect of case-based teaching on the level-of-interest in neuroanatomy
Q21 Q22 Q23	Efficacy of a purpose-designed CAL resource in addressing problems linked with neuroanatomy learning Usefulness of the following components of a prospective neuroanatomy web-resource in learning (Blogs, animations, games, quizzes, atlas' images, neurology examination-clips, videos of neurological and neurosurgical procedures, online discussion forums, PDF lecture notes, podcasts, power point slides, radiology; 2D and 3D, snapshots of prosections, models, coronal and horizontal sections of CNS, video lectures) Role of purpose-designed neuroanatomy online web-resource in addressing challenges enumerated in Q14

CNS = Central nervous system, 2D = Two-dimensional, 3D = Three-dimensional, CAL = Computer assisted learning.

The first five questions pertained to participants' characteristics (gender, program of study, current year of study, prior qualification, year of completion of neuroanatomy classes, Table 2.1; Q1–Q5, Appendix 1). The participants were subsequently asked to rank different areas of anatomy in terms of their perceived degree of difficulty, level of interest, and their knowledge of the topic (Table 2.1; Q6–Q11, Appendix 1). The subsequent sections of the survey inquired specifically about neuroanatomy. Briefly, the participants were asked to rate specific factors making neuroanatomy a difficult subject on a Likert scale (Table 2.1; section Q14, Appendix 1) and rank each of the 21 lecture topics taught as part of the neuroanatomy curriculum at UCC in terms of their learning difficulty (Table 2.1; Q15, Appendix 1). The survey inquired about the perceived usefulness of various teaching aids in enhancing understanding of neuroanatomy (Table 2.1; Q16, Likert-scale rankings, Appendix 1). Finally, the participants were asked to rate the efficacy of computer assisted learning (CAL) resources in addressing the challenges they identified in previous questions (Table 2.1; Q21–Q23, Appendix 1).

Statistical Analysis

All statistical analysis was carried out using the Statistical Package for Social Sciences, SPSS, version 22 (IBM Corp., Armonk, NY). Where appropriate, descriptive statistics were provided (mean ± standard error to the mean (SEM), median, range). Friedman's paired ranking test was used to analyse potential differences in the participants' perceived difficulty between various anatomy topics. The opinion of participants was on a Likert scale (ordinal) and they ranked the difficulty of individual anatomy topics. The first comparison used two groups (neuroanatomy v. cardiovascular, neuroanatomy v. gastrointestinal, etc.) moving to three groups (neuroanatomy v. cardiovascular v. musculoskeletal, etc.) and finally moving to all the groups together (neuroanatomy, cardiovascular, gastrointestinal, genitourinary, musculoskeletal, pelvic and respiratory).

The Likert scale scores returned for the neuroanatomy difficulty factors (Table 2.1, section 14, Appendix 1) were combined into intrinsic and extrinsic factors and Cronbach's alpha was used to assess if factors included in each category were closely related (internal consistency). To test if the intrinsic scores were different from extrinsic scores a Wilcoxon's paired rank test was conducted. Nonparametric data was collected using Likert scales (ordinal data) as students were asked to rank all contributing factors rendering these dependents on others. Finally, a Mann–Whitney test was used to compute differences between the perception of the preclinical and clinical students with regards to the usefulness of various teaching pedagogies and the responses were independent of each other.

Results

Participants' Characteristics

A total of 383 students responded (272 females, 111 males, 39.1% overall response rate), of which 60.1% were DEM, 16.2% were GEM, 7.3% were SLS, 11% were OT, and 5.5% were BDS students. The majority of participants entered their degree program after completing a secondary level education (279/383, 72.8%) and the remaining students (104/383, 27%) held third level qualifications prior to their current studies (Table 2.2). The distribution and characteristics of the participants are detailed in Table 2.2.

Table 2.2: Characteristics of Participants

Variable	Direct entry medicine	Graduate entry medicine	Occupational sciences	Speech and language sciences	Dentistry
	(No.) %	(No.) %	(No.) %	(No.) %	(No.) %
Group response rate[a]	230 (47.9)	62 (25.8)	42 (84)	28 (56)	21 (13.1)
Gender Male	78 (33.9)	24 (38.7)	2 (4.8)	1 (3.6)	6 (28.6)
Female	152 (66.1)	38 (61.3)	40 (95.2)	27 (96.4)	15 (71.4)
Current phase of study Pre-clinical	97 (42.2) (year 2)	42 (71.2) (year 2)	-	-	8 (38.1) (year 2)
Clinical	133 (57.8) (years 3,4,5)	17 (28.8) (years 3,4)	42 (100) (years 3,4)	28 (100) (years 3,4)	13 (61.9) (years 3,4,5)
Highest qualification achieved Leaving cert. /A levels	202 (87.8)	1 (1.6)	37 (88.1)	24 (85.7)	15 (71.4)
BSc (biological)	7 (3.0)	32 (51.6)	-	-	2 (9.5)
BSc (non-biological)	-	7 (11.3)	1 (2.3)	2 (7.1)	1 (4.8)
MSc (biological)	-	12 (19.3)	-	-	1 (4.8)
MSc (non-biological)	-	1 (0.4)	3 (4.8)	-	-
Others	20 (8.7)	7 (11.3)	4 (9.5)	2 (7.1)	2 (9.5)

[a]Five-year long program, [b]Four-year long program, [c]Group response rate refers to the proportion of students in each group who participated in the study out of the total number of students in that group, BSc = Bachelor of science, MSc = Master of science.

Perceived Difficulty of Various Anatomy Topics

The assessment of the perceived difficulty of the various areas of anatomy showed that neuroanatomy is considered to be more difficult than other areas, both in systems and region-based anatomy teaching designs (Figure 2.1A, B). The degree of difficulty of neuroanatomy was compared to other anatomical systems, including the pelvic-reproductive, musculoskeletal, genitourinary, gastrointestinal, cardiovascular, and respiratory using a nonparametric Friedman’s test (Figure 2.1A). Neuroanatomy was repeatedly and significantly perceived as more difficult by the participants compared to other topics in anatomy. The Friedman’s mean difficulty rank was 5.93 for neuroanatomy as compared to pelvic-reproductive (4.39), musculoskeletal (4.23), genitourinary (3.86), gastrointestinal (3.49), cardiovascular (3.17), and respiratory (2.93) (χ^2 = 418.05, P = 0.0001).

In the context of region-based anatomy the perceived degree of difficulty of neuroanatomy was compared to abdominal, head and neck, lower limb, pelvic, thoracic, and upper limb anatomy (Figure 2.1B). When neuroanatomy was compared with all the other regions using a nonparametric Friedman’s test, the mean rank difficulty score for neuroanatomy was 5.77 compared to head and neck (4.68), pelvic (4.22), upper limb (3.66), lower limb (3.34), abdominal (3.18), and thoracic (3.15) anatomy (χ^2 = 409.60; P = 0.0001). The results from both instructional designs show that neuroanatomy is consistently being perceived as a more difficult topic compared to other areas of anatomy.

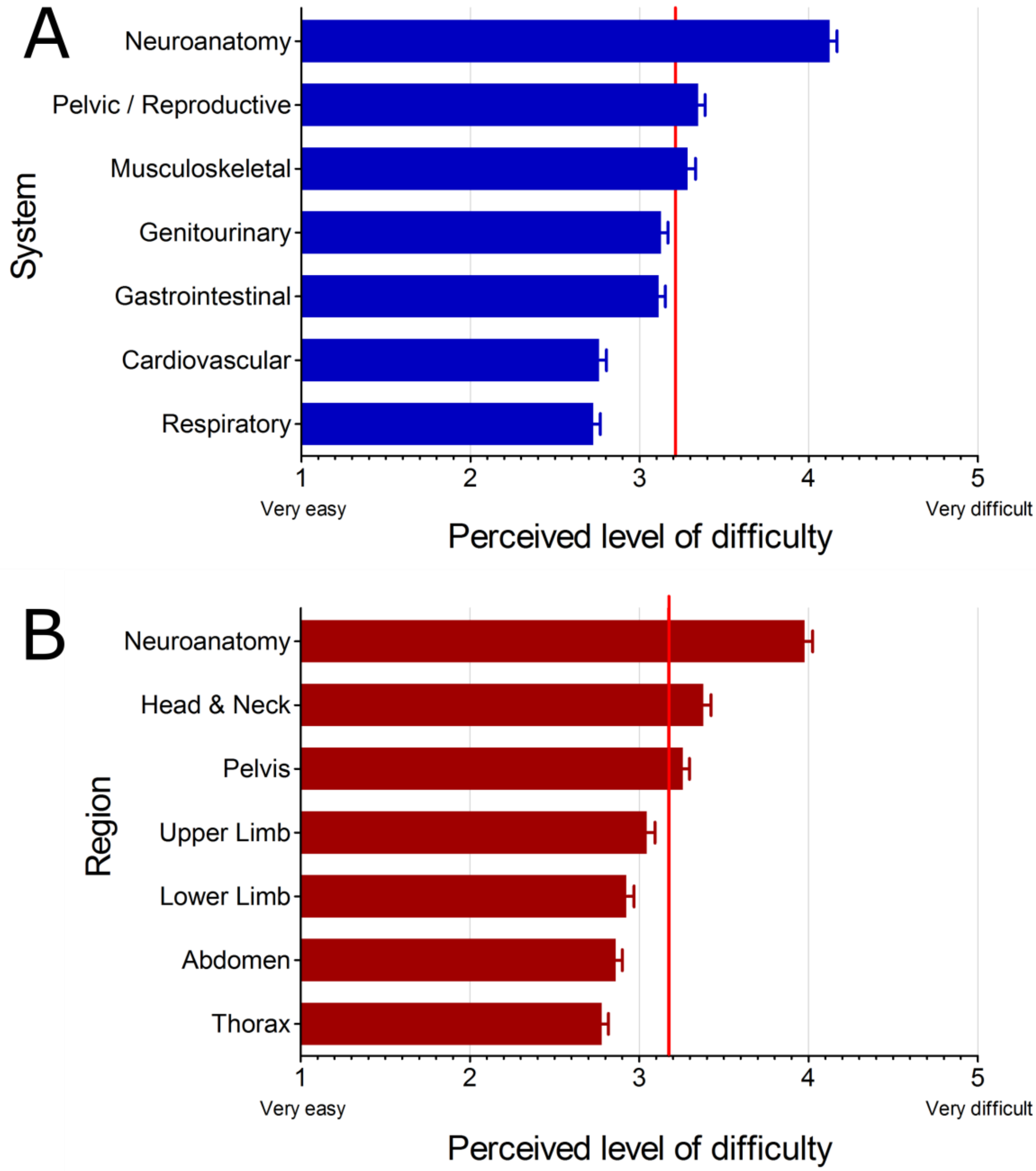

Figure 2.1: Perceived level of difficulty of neuroanatomy. A, Compared to other systems; B, Compared to other anatomical regions. The participants were asked to rank the difficulty associated with learning each topic on a 5-point Likert scale (1 = very easy, 5 = very difficult). Data are presented as mean ± SEM, for responses acquired from all participants. Each horizontal bar represents the mean difficulty level for an individual topic. The vertical red bar indicates the average level of difficulty for all topics.

Separate analysis of the various academic cohorts demonstrated that 82.6% DEM, 75.4% GEM, 92.8% SLS, 95.2% OT, and 66.7% BDS students ranked neuroanatomy as either "difficult" or "very difficult" (Figure 2.2A). Furthermore, 73.1% DEM, 73.3% GEM, 81.5% SLS, 95.2% OT, and 47.6% BDS students for a total of 74.8% of the participants perceived neuroanatomy to be either "difficult" or "very difficult" in a region-based teaching design (Figure 2.2A). Head and neck anatomy was ranked as difficult as neuroanatomy by the GEM students (not shown). No additional difficulty was reported by the BDS students in learning neuroanatomy compared to other topics when taught in a region-based manner, but system-based neuroanatomy was perceived as increasingly difficult. Moreover, the participants were specifically asked if neuroanatomy is difficult compared to other anatomy subjects (Table 2.1, Q13, Appendix 1). The majority ranked neuroanatomy specifically compared to other topics as either "difficult" or "very difficult" including 82.4% of DEM students, 78.7% of GEM students, 96.4% of SLS students, 95.1% of OT students, and 52.4% of BDS students (Figure 2.2A).

The participants' interest and perceived knowledge levels in the various systems and regions described above were also gauged using Likert scales. No difference was found between the various anatomy topics in the frequency analysis results (data not shown); however, observing that neuroanatomy is consistently considered a difficult subject, a correlation analysis was carried out to investigate the relationship between "perceived difficulty," "interest level," and "perceived knowledge status" of the students in neuroanatomy. The perceived degree of difficulty was shown to be inversely related to the level of interest in neuroanatomy from both system-based (r = -0.27; P < 0.01) and region-based perspectives (r = -0.22; P < 0.01) (Figure 2.2B). The data was further analyzed for a possible correlation between the perceived degree of difficulty and the perceived knowledge of the topic. A negative correlation was observed from both system-based (r = -0.35; $P < 0.01$) and region-based perspectives (r = -0.39; $P < 0.01$). A positive correlation was also obtained between the level of knowledge and level of interest in neuroanatomy when compared from system-based (r = 0.38; $P < 0.01$) and region-based perspectives (r = 0.46; $P < 0.01$) (data not shown). The negative correlation between perceived degree of difficulty and level of interest and level of knowledge was strongest for system–based methods of neuroanatomy teaching.

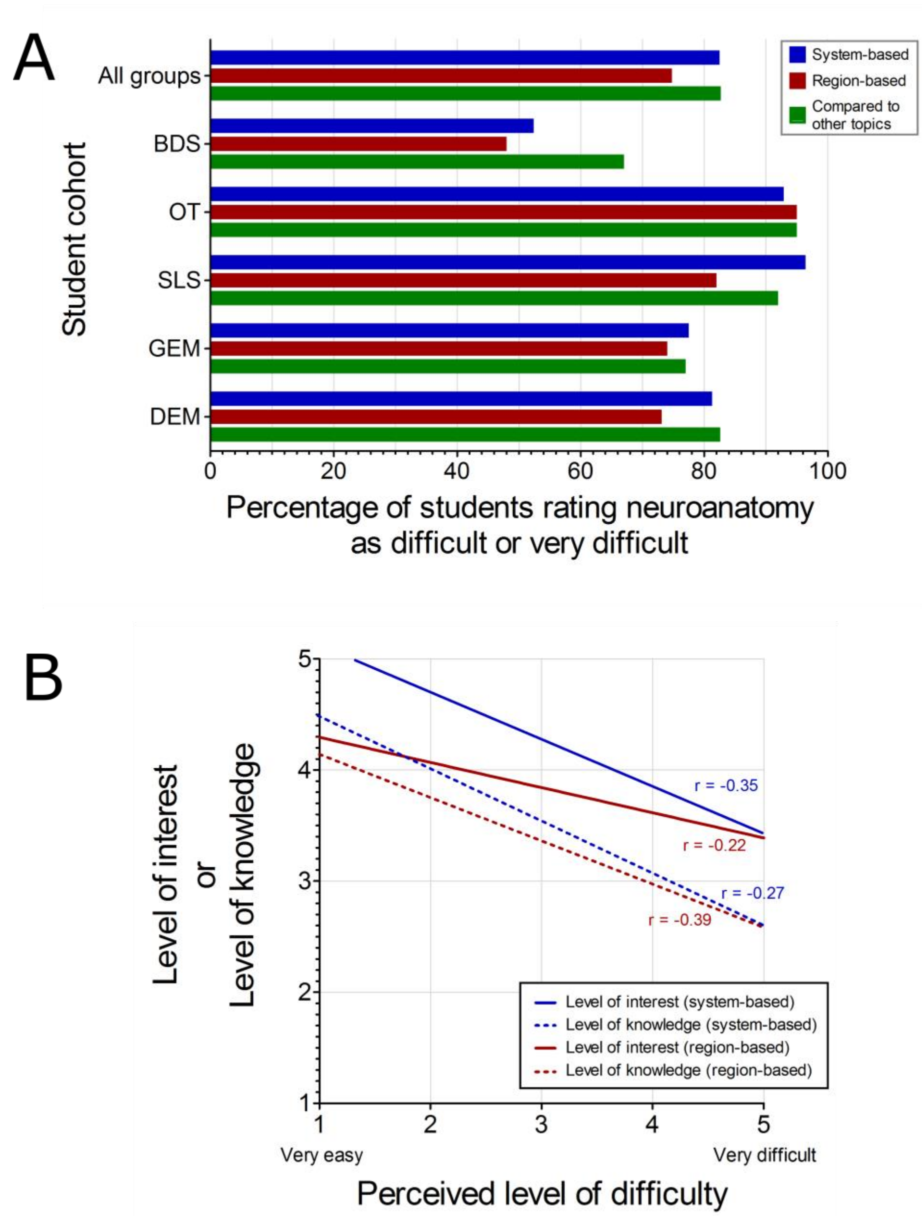

Figure 2.2: Perceived level of difficulty of neuroanatomy. A, Percentage of participants rating neuroanatomy difficult or very difficult to learn in a system-based (blue bars) or region-based (red bars) curricular design and in comparison to other anatomy topics (green bars). Data is presented as the percentage of respondents from each of the student cohorts as well as a combined group; B, Correlation between the perceived level of difficulty of neuroanatomy with the level of interest or the level of knowledge in the topic. The participants were asked to rank all three variables on a 5-point Likert scale (for difficulty level, 1 = very easy, 5 = very difficult; for interest level, 1 = very low, 5 = very high; for knowledge level, 1 = very limited, 5 = very good). Data are presented as the linear regression curve of responses from the 323 participants that had completed the six questions for system-based (blue lines) and region-based (red lines); r = Spearman's correlation coefficient.

Perceived Challenges Associated with Neuroanatomy

Having determined that neuroanatomy is considered a difficult subject, Likert scales were used to identify various factors that may contribute to the participants' difficulties with neuroanatomy (Tables 2.1 and 2.3). For analysis, the potential contributing factors were categorized into two groups; factors that are extrinsic to the subject, including lecture duration and access to information and intrinsic factors such as anatomical terminology (Table 2.3). Composite frequency scores were computed for each group and Cronbach's α was used to estimate the reliability of those scores (0.698 for intrinsic and 0.674 for extrinsic composite scores). A frequency analysis of the Likert responses revealed that a relatively small proportion of participants find that extrinsic factors influence the degree of difficulty whereas a greater proportion find that the intrinsic factors play a role in making neuroanatomy a difficult subject (Table 2.3). For each participant, the composite score was calculated by averaging the response scores for all individual factors included in the intrinsic and extrinsic groups. Wilcoxon's signed-ranks test was used to test the null hypothesis that intrinsic and extrinsic factors contribute equally to the difficulties in neuroanatomy. The intrinsic factors were shown to impart a significantly higher challenge when learning neuroanatomy compared to the extrinsic factors ($Z = 215.12$; $P < 0.0001$), implying that the innate complex nature of the topic was perceived to be the biggest hurdle in understanding neuroanatomical concepts.

Table 2.3: Participants Perception of Factors Contributing to the Difficulty of Neuroanatomy

Contributing factor	Factor grouping	Proportion of participants rating factor as important contributor (%)
Access to neuroanatomy textbooks	Extrinsic	5.1
Access to neuroanatomy information online		5.4
Lecture duration		13.9
Time spent in dissection room		19.8
Memorization of neuroanatomical terminologies	Intrinsic	30.9
Appreciation of 3D relationships		33.3
Visualization of structures on prosections of CNS		33.5
Understanding clinical aspects of neuroanatomy		37.7
Complexity of the topic		47.7

CNS = Central nervous system, 3D = Three-dimensional

In support of this, the questionnaire contained an open-ended question to inquire further about the factors making neuroanatomy challenging to learn. Three main impediments to learning were identified by a thematic analysis:

Complexity of the Topic:

- "Neuroanatomy itself is a very broad topic which required solid fundamental understanding of each part involved from a cellular level all the way to the organ level. It is challenging as most parts are interlinked in their functions"
- "It is hard to understand localizing the level of the lesion"
- "Difficulty in linking everything. I find it difficult to have the whole picture clearly"
- "Mainly lots of terminologies, not enough time to adjust to the words before it is assumed that you know them well"
- "Very complex, need more than a semester to really understand concepts very well"

Vastness of the Curricular Content:

- “Too many topics need to be covered in a short period of time”
- “A lot of information to cover in a short period of time while also studying for other modules. Maybe try to spread it out more over second/third year and not just one semester in third year”
- “Very hectic in a very short time span, there is a lot of detail”
- “A lot of content squashed into one semester”

Difficulty in Visualization of Neuroanatomical Structures:

- “I guess it is difficult because it is hard because you can’t really see the tracts in the brain”
- “Learning content on paper/in textbooks makes it hard to learn, perhaps 3D would be much more effective”
- “Visualization of 3D structures is quite difficult”

Relative Difficulty of Various Subtopics of Neuroanatomy

The participants were asked to rank 21 subtopics taught as part of the neuroanatomy curriculum at University College Cork, in terms of their learning difficulty (Table 2.1, Q15, Appendix 1). Data analysis shows that the combined difficulty level for all topics was 3.39 on a 5-point Likert scale (1 = least difficult to 5 = most difficult, Figure 2.3). The results illustrate that the perception of difficulty is not homogenous across the neuroanatomy curriculum and suggest that difficulties could be addressed with approaches targeting individual topics rather than the discipline as a whole.

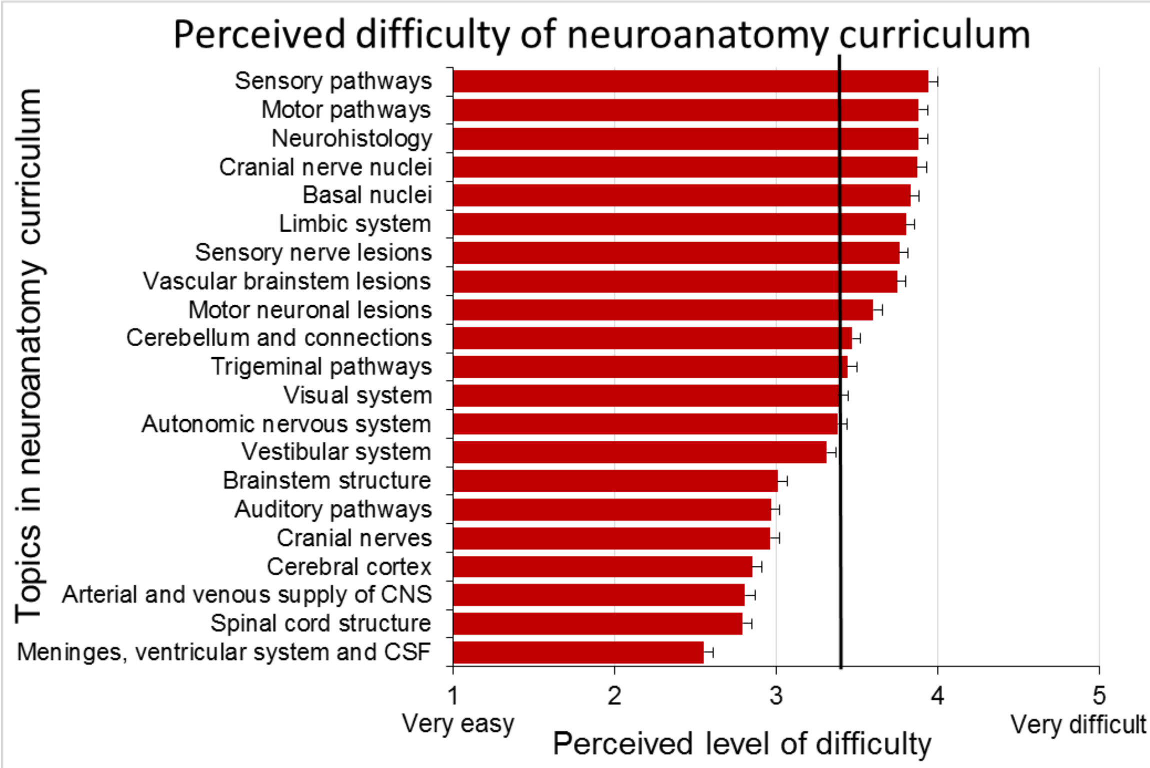

Figure 2.3: Comparison of the perceived level of difficulty across various topics in the neuroanatomy curriculum. The participants were asked to rank the difficulty associated with learning each topic on a 5-point Likert scale (1 = very easy, 5 = very difficult). The vertical bar indicates the average level of difficulty for all curriculum topics. Data are presented as mean ± SEM. CNS = Central nervous system; CSF = Cerebrospinal fluid.

Effect of Case-Based Teaching on Perception of Neuroanatomy

The participants were next asked, based on their experience, to rate their appreciation of case-based teaching and its effect on their interest in neuroanatomy using a 5-point Likert scale (Table 2.1, 1 = decreased interest a lot to 5 = increased interest a lot, Appendix 1). The majority of participants in each student cohort (72.73% overall) reported that case-based teaching would increase their interest in the subject (Figure 2.4). Interestingly, the participants who rated case-based teaching as increasing their interest had also reported a higher level of interest in neuroanatomy both from system- and region-based teaching perspectives ($r = 0.23$ and $r = 50.20$ respectively, $P < 0.001$, data not shown).

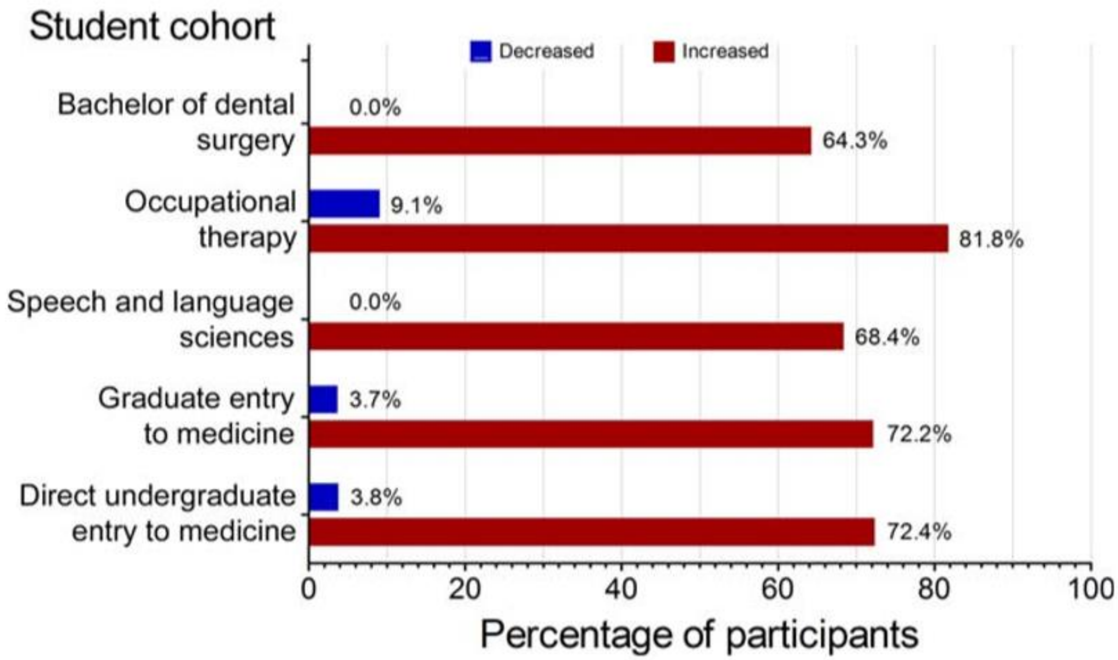

Figure 2.4: Perceived significance of case-based teaching in enhancing interest in learning neuroanatomy. The participants in each of the five student groups were asked, based on previous experiences, to rank the effect of case-based teaching on their interest level on a 5-point Likert scale (1 = decreased it a lot, 5 = increased it a lot). The participant responses on either side of the midline (point 3) were collapsed either as a decreasing effect (1 and 2, blue bars) or an increasing effect (4 and 5, red bars). The data are presented as the percentage of participants in each group.

Useful pedagogies in Neuroanatomy Teaching

When the usefulness of newer teaching pedagogies such as CAL was compared against more traditional pedagogies such as dissection room tutorials in the form of prosections and bedside teaching, data analysis showed that the perception of participants changed as they progressed in their course. Separation of the participants into pre-clinical and clinical years revealed that the usefulness of prosections was rated higher by the pre-clinical years students than the clinical year students (Mann-Whitney $U = 5840$, $P = 0.0001$, Table 2.4). Inversely, clinical students prefer CAL (Mann-Whitney $U = 5994.5$, $P = 0.003$, Table 2.4) and bedside delivery (Mann-Whitney $U = 9893.5$, $P = 0.0001$, Table 2.4) as teaching modalities compared to pre-clinical students. The results imply that students increasingly favor a clinically oriented and independent learning of neuroanatomy as they progress along their training.

Table 2.4: Perception of Teaching Pedagogies

Cohort	CAL	Prosection	Bedside teaching
Pre-clinical years[a]			
Mean	3.02	4.53	3.67
Median	3	5**	4
Clinical years[b]			
Mean	3.53	4.11	4.23
Median	4**	4	5**

[a]Second-year students, [b]Third-, fourth- and fifth-year students; ** = $P < 0.01$, Mann–Whitney U test; CAL = Computer assisted learning.

The participants were further questioned about the usefulness of neuroanatomy learning web-resources and computer assisted learning. Such resources were deemed as highly useful learning aids by the vast majority of participants (81.8%) and they either ‘agreed or strongly agreed’ that the problems associated with learning neuroanatomy could be addressed by web-based resources (Table 2.1; Q21, Appendix 1). Additional analysis showed that when asked to rank their perception of such web-based neuroanatomy resources on a five point Likert scale (1 = strongly disagree, 5 = strongly agree, Table 2.1; Q23, Appendix 1), 81.4% of participants agreed or strongly agreed that the understanding of the clinical aspects of neuroanatomy could be enhanced by using such resources. They were also of the opinion that it would further their understanding of specific neuroanatomy topics taught during lectures (82.9%) and during dissection room tutorials (85.1%), elaborate further upon the features of the central nervous system (79.4%), aid in visualization of structures on prosections (84.3%), aid memorizing neuroanatomical terminologies (72.6%) and help them better appreciate the dimensional relationships of central nervous system structures (83.4%).

Perceived Importance of Various Components of a Novel Prospective Computer Assisted Neuroanatomy Learning Web-Resource

The participants were asked to rate on a 5-point Likert scale (1 = very low to 5 = very high) their perception of the importance of various components in the design of a prospective neuroanatomy web-based resource (Table 2.1; Q22, Appendix 1). After excluding incomplete responses, a non-parametric Friedman test was carried out on the remaining 308 participants. Statistically significant differences were shown between the perceived importance of various teaching components with online discussion forums and blog posts ranking the lowest followed by traditional teaching tools such as PowerPoint™ slides and lecture notes ($\chi^2 = 1328.314$, $P < 0.001$, Figure 2.5). The questionnaire offered an opportunity to comment on the importance of various components in the design of a prospective neuroanatomy web-based resource. While some tools such as blog posts were poorly rated, the participants had nonetheless enthusiastic suggestions.

Blog Posts

- "Blog posts on specific neurological disorders, perhaps in a case-based style might be helpful"
- "Blog posts on new discoveries would be exciting"
- "Blog posts by various lecturers regarding difficult topics/updates on recent research for extra information"

Computer Animations

- "Computer animations offer better visual representation of brain structures"

- “Computer animations showing the pathways of cranial nerves highlighting the nuclei and crossing over should be used”
- “Computer animations especially for the circuitry and for understanding localization of lesions”
- “Computer animations for deep brain structures would be useful”

Games and Quizzes

- “Games and quizzes should be used to ask questions which are based on lecture material”
- “Make a few levels with explanations, from easy which is a direct question to hard which could be the application of knowledge in clinical situation”
- “Games and quizzes on matching cranial nerves to their functions”

Neurological Examination Clips

- “Neurological examination clips for the cranial nerves being examined should be shown in integration with cranial nerve being studied”
- “These would be helpful as they can be played over and over, helpful for OSCE study”

Illustrated Images from Various Anatomy Atlases

- “Illustrated images from various anatomy atlases would be helpful if they are interactive that can be zoomed into”

- “Very helpful to compare multiple pictures of same thing, for example, compare colored images from Netters with real brain images from Gray’s anatomy, side by side”
- “Real life images are more helpful”
- “Option to have labelled or not, so you can guess first”

Neurosurgical and Invasive Neurological Procedures’ Videos

- “Videos of procedures to treat neurological disorders that are relevant and expected during second year should be used”
- “More invasive, better, especially the awake procedure (touch certain area of the brain and it shows movement, etc.)”
- “Limited use for the beginners; may be simple procedures would be helpful”

Online Discussion Forums

- “Online discussion forums will need a moderator for quick response”

Video lectures (including Animated Videos)

- “Video lectures (step by step explaining complex topics, that is, tracts)”
- “Podcasts would be very helpful, lectures are fast paced and it would be amazing to be able to listen back and hear things that were missed”

Radiology: 2D and 3D Reconstruction Videos

- “I think 3D visualization should be utilized so that we could picture it much better”

- "3D radiological structures of the basal ganglia and limbic system would help the imagination"

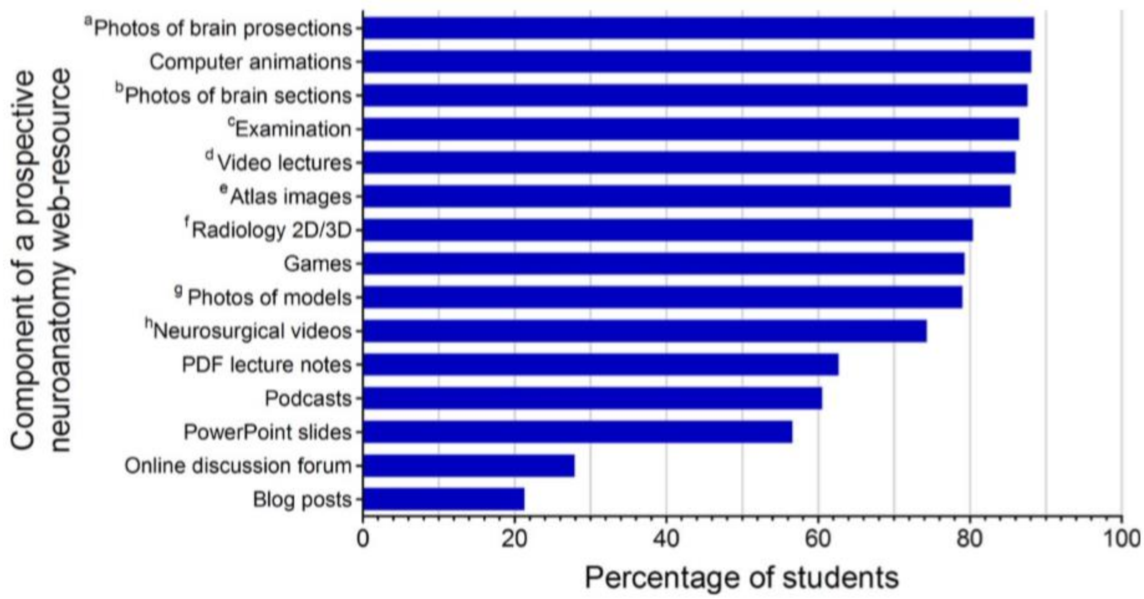

Figure 2.5: Perceived usefulness of components of a prospective neuroanatomy web-resource. The participants were asked to rank the usefulness of various components of an online neuroanatomy resource on a 5-point Likert scale (1 = very low, 5 = very highly useful). The participants' responses above the midline mark (point 3) were collapsed (4 and 5 together) and presented as a combined percentage participants' response. [a]Snapshots of brain prosections used in dissection room teaching. [b]Snapshots of brain sections (coronal, horizontal) used in dissection room teaching. [c]Neurological examination clips. [d]Including animated videos. [e]Illustrated images from anatomy atlases. [f]Radiology: 2D and 3D reconstruction videos. [g]Snapshots of models (plastic and plastinated; used in dissection room teaching). [h]Neurosurgical and invasive neurological procedures' videos. 2D / 3D, two-dimensional / three-dimensional.

Discussion

Perception of neuroanatomy

Evidence from the literature has identified a fear or difficulty with neuroanatomy among clinical practitioners and health students and points to an impaired understanding of the subject as the main cause for this neurophobia (Flanagan et al., 2007; Youssef, 2009; Sanya et al., 2010; Zinchuk et al., 2010; Matthias et al., 2013; McCarron et al., 2014; Pakpoor et al., 2014). However, further exploration aimed at identifying quantifiable causes underlying the impaired understanding of neuroanatomy is required. Such causal factors have been investigated but were limited in the level of inquiry to broad topics and in their representation of student cohorts. Several investigators addressed medical students only (Schon et al., 2002; Flanagan et al., 2007; Ridsdale et al., 2007; Lim and Seet, 2008; Hudson, 2009; Youssef, 2009; Sanya et al., 2010; Zinchuk et al., 2010; Gupta et al., 2013; Kam et al., 2013; Matthias et al., 2013; McCarron et al., 2014; Pakpoor et al., 2014; Abushouk and Duc, 2016) (Table 1.1), while Martin et al. (2014) interviewed only speech and language therapy practitioners. Most of these studies focused on clinical neurology and alluded to an impaired understanding of neuroanatomy in the broader context of the difficulties associated with learning and practice of neurology. For instance, when medical students were asked to rate their perceived level of difficulty for various clinical specialties, neurology was ranked as the most difficult (Flanagan et al., 2007; Youssef, 2009). In other studies, neurology was regarded most difficult among various medical specialties by 50% of medical students and 41.7% of non-specialist doctors (Matthias et al., 2013), and making neurological diagnoses was regarded as moderately to very difficult by 46% of medical students (Sanya et al., 2010). McCarron et al. (2014) found that general practitioners considered neurology significantly more difficult compared to other medical specialties while similar results were found by Zinchuk et al. (2010), Pakpoor et al. (2014), and Schon et al. (2002). Furthermore, Kam et al. (2013) found that the prevalence of neurophobia was 47.5% among medical students and 36.6% among junior doctors. Qualitative interviews from practicing speech and language therapists revealed that all of them expressed negative experiences with their learning of neuroanatomy during their undergraduate years (Martin et al., 2014) (Table 1.1).

While these studies point to a lack of understanding of basic neurosciences and the complexity of the topic as underlying sources for these difficulties, they did not overtly inquire about the learning difficulties linked with basic sciences such as neuroanatomy. Such tangible causes, if identified could subsequently be remedied through the use of appropriate teaching and learning strategies.

The current study is, to the authors' knowledge, the first broad scale study to provide direct evidence of students' opinion regarding difficulties associated with learning basic neuroanatomical sciences. The results have shown that the participants regarded neuroanatomy as more difficult compared with every other anatomy topic, both in system-based and region-based teaching designs and that this perception was consistent across students from various disciplines with the exception of the BDS cohort. Possible reasons for this difference in opinion include the limited exposure of BDS students to neuroanatomy, the relatively small proportion of respondents and possible limited understanding of the importance of neuroanatomy in the context of their future clinical practice (Klueber, 2003). Furthermore, the existence of a negative correlation between the student's level of interest or their level of knowledge and their perceived level of difficulty suggests that designing tools and teaching aids which enhance students' interest in the topic such as case-based teaching, could decrease their perceived difficulty and increase their knowledge of the topic.

Despite the fact that neuroanatomy has been identified as a major contributor to neurophobia, few studies have directly assessed the reasons underlying the difficulties associated with the subject. The results from the current study have shown that neuroanatomy was ranked as difficult or very difficult by most participant cohorts, and therefore suggest that the perceived difficulty may be inherent to the subject rather than the result of instructional design, delivery issues or curricular timing. It further re-enforces evidence from the literature linking impaired understanding of neuroanatomy with the innate complexity of the topic (Sanya et al., 2010; Zinchuk et al., 2010; Matthias et al., 2013; McCarron et al., 2014; Pakpoor et al., 2014). Here, this difficulty has been detailed by assessing the participants' perception of potential contributing factors. The results have demonstrated that intrinsic factors (complexity of the topic, understanding the clinical aspects of neuroanatomy, memorization of neuroanatomical terminologies, visualization of structures on prosections of the central nervous system and appreciation of the 3D relationship of structures) had a greater contribution to the difficulty associated with learning neuroanatomy compared to extrinsic factors (limitation of time spent in the dissection lab, limited lecture time, access to neuroanatomy information online, access to textbooks). The innate complexity of the subject was confirmed as the main contributing factor but the role of additional components to this difficulty was also highlighted. When the perceived difficulties associated with neuroanatomy were further explored by enquiring about individual components of the neuroanatomy curriculum, the result revealed that not all components are viewed as equally difficult; for example, the neural pathways were ranked as the most difficult subjects while the anatomy of the ventricular system was deemed easier than others. This highlights not only the intrinsic difficulty of neuroanatomy as a whole but also of specific topics within our curriculum. This data has identified areas of difficulty and should inform curricular design to re-focus attention.

Preferred Teaching Pedagogy

In the last decades, several educational strategies have been identified to improve the neuroanatomical skills of students in clinical disciplines (Rizzolo et al., 2010). However, clarity has been lacking with regards to the preferred pedagogy to be employed (Heylings, 2002). Although study with human cadaveric material might have been traditionally considered closer to clinical medicine (Zurada et al., 2011), a nonsystematic review on the transformations in neuroanatomy teaching methodologies has shown that the majority of institutions have been using electronic tools effectively to demonstrate the topography and spatial relationships of neuroanatomical structures to the students (Sotgiu et al., 2012). For instance, the usage of a neurology case-based web-resource showed significant improvement in assessment score of medical students at Oxford University (Svirko and Mellanby, 2008, 2017). Moreover, a prospective evaluation of a neuroanatomy CAL tool for clinical therapy students showed that it helped with structure identification and was rated as beneficial and better than the traditional learning tools (Foreman et al., 2005). Case-based instructional methods use realistic narratives to actively engage learners in developing their problem-solving and analytical skills, as well as working in self-directed groups. Hudson (2009) previously reported successfully using case-based teaching to reduce difficulties associated with neuroanatomy and neurophobia.

In the current study, the majority of participants agreed that their understanding of the clinical aspects of neuroanatomy and of the topics they had studied in lectures and dissection room sessions was enhanced with the help of CAL resources. As mentioned above, the dissection room teaching includes self-directed learning using a recommended CAL resource but student may also have accessed additional undocumented resources to support their learning. Nonetheless, most of them also agreed that better visualization of the features of the central nervous system and its structures was promoted by CAL. Moreover, memorization of the neuroanatomy nomenclature and appreciation of the 3D relationship of neuroanatomical structures was aided by such resources. It is worth noting that Azer and Eizenberg showed that the preference for the teaching pedagogy could change over time, for instance, first-year students rated dissection (44%) higher than textbooks (23%) while second-year students responded by rating textbooks (38%) higher than dissection (18%) (Azer and Eizenberg, 2007). Similarly, Choi-Lundberg and colleagues found that the preclinical students ranked gross anatomy highest whereas the clinical students ranked CAL highest for reviewing/learning anatomy (Choi-Lundberg et al., 2016). When the usefulness of various teaching pedagogies was queried from a neuroanatomy standpoint, results showed that participants had a higher appreciation for traditional teaching techniques such as prosections and dissection in enhancing their understanding of neuroanatomy. However, separation of the data for pre-clinical and clinical years showed that the mean Likert-scale rankings for CAL was higher while that for prosection-based teaching was lower for the clinical year students. The results imply that despite the benefits offered by CAL students do not consider it as a total replacement for traditional dissection-based learning modality and that as students' progress in their curriculum, their preference shifts to methods offering a stronger link with clinical information. Their preference for CAL highlights its utility in reviewing the subject material after lectures and tutorials or in an autonomous manner. This dichotomy in opinion could be an outcome of the dissection-based assessment of the preclinical students that have ready access to prosections throughout the year while the clinical students lack such provision It has previously been demonstrated that structured review of information can be beneficial in medical training as it enhances the recall of relevant content (Billings-Gagliardi and Mazor, 2009). In that context, CAL may provide a useful supplement in delivering structured information that can be based on clinical information and accessed in an autonomous fashion as individuals or as groups.

Finally, the assessment of potential components of CAL tools illustrate that while there is a diversity of opinion, not all teaching instruments are perceived as useful in the context of neuroanatomy. Interestingly, the more traditional methods used in lectures such as PowerPoint™ slides, and handouts received some of the lowest rankings while more interactive methods such as computer animations and examination received higher ratings, further highlighting the link between interest, knowledge, and perceived difficulty identified above. A similar diversity of opinion has been reported in the literature. For instance, computer animations have been successfully used by medical educators for teaching anatomy and histology (Brisbourne et al., 2002), physical examination (Houck et al., 2002) and various surgical techniques (Mehrabi et al., 2000; Henderson and Ali, 2007), however, these have not always proven to be effective (discussed in Ruiz et al., 2009). Various other online pedagogical tools, which were investigated in the current survey included 2D and 3D radiological models / images, videos of lectures and surgical procedures, snapshots of plastinated models, atlas images, and podcasts have been reported to improve learning outcomes (Lozanoff et al., 2003; Estevez et al., 2010; Chariker et al., 2011, 2012; Pani et al., 2012; Bacro et al., 2013; Pani et al., 2014; Drapkin et al., 2015; Biesalski, 2016). In an era when the resources required for traditional anatomy teaching have become limited, CAL and online web-resources have huge potential to effectively support teaching and learning, however, their design and implementation must be carefully crafted. One also has to keep in mind that the benefits of various tools may also vary according to learner characteristics such as prior knowledge and spatial ability, learner control over the teaching-tool's pace, learners' ability to interact with the teaching tool, segmentation of the learning activity and the cognitive load induced by the learning tool (discussed in Ruiz et al., 2009). Further research will be necessary to ascertain when to use specific CAL tools and how to use them effectively, but the current results nonetheless offer a student perspective on their potential usefulness. The following quotation from a student summarizes it well: "It is good to have these additional learning resources but ultimately it will be ineffective if the content is not organized. A collaboration with biochemistry and physiology will also help in our understanding."

Limitations of the Study

There are a number of limitations to this study that are worthy of discussion.

Response Rate.

The overall response rate in our study was close to 40%, however, it was lower for the dental students (13.13%). It is always advantageous to have a higher response rate to represent the entire population. Relatively lower response rates could potentially be taken as the opinion of the most interested or disinterested students. The early responders might have evaluated the module more positively compared to the late and non-responders (Rudland et al., 2005). Additional comparison between such different respondent groups is lacking in our study.

Institution-Bias.

The study was conducted in a single institution (UCC) and therefore the results might not offer a representation of the student attitudes at the national and international levels.

Serial Acquisition of Data Over Several Time Points.

Although the data was acquired over a span of a few months, the information was obtained from students in various years of their programs of study imparting a serial effect to the data.

Empirical Evidence to Link Perceived Difficulty with Poor Examination Performance.

The perceived difficulty level Likert scores for various anatomy topics should be correlated with the actual examination scores to see if the subjective evidence is mirrored by the objective data. This could inform the educators if the perceived difficulty was low enough to be eventually overcome by the students enabling them to perform well on the examination or was it high enough that could not be overcome, hence requiring external help or intervention. As the survey was anonymous, such correlation could not be done.

Conclusion

In summary, neuroanatomy is perceived to be a more difficult subject compared to other areas of system-based and regional anatomy by medical, dental, and clinical therapies students. The opinion of a wide cohort of medical and health science students provided a novel perspective on the underpinnings of perceived difficulty of neuroanatomy. Data from the students' validated the significance of appropriately designed CAL and online web-resources to serve as effective pedagogical tools to aid the neuroanatomy learning, especially in times when there is a push toward limiting the anatomy teaching time in the medical and health sciences programs. However, the efficacy of an online neuroanatomy learning web-resources will only be achieved if the specific problems and difficulties in learning and understanding neuroanatomy, as identified in this study, are taken into consideration by the educators and instructional designers. The data provided here highlights the perceived areas of difficulty in neuroanatomy learning among the students. Spinal pathways was considered to be the most difficult-to-learn component of the neuroanatomy syllabus, while factors, such as, the innate complexity of the topic, impaired understanding of clinical neurological correlates and neuroanatomical spatial relationships were major contributors to the perceived difficulty. The results further informed the CF-ONLine (Table 1.2) to devise a set of guidelines / rubric for evaluating existing neuroanatomy web-resources and render it instrumental in guiding educators and instructional designers, as they embark upon developing future neuroanatomy web-resources.

CHAPTER 3

Evaluation of Neuroanatomy Web-Resources for Undergraduate Education – Educators' and Students' Perspectives

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Abstract

Impaired understanding of neuroanatomy has been linked with poor patient-care in neurology. Despite the introduction of curricular changes, the development of novel teaching strategies and the abundance of adjunct teaching web-resources, students and early career physicians continue to report difficulties in learning and clinically applying neuroanatomy. Differences in instructional design of these resources, the lack of assessment of their capacity to meet intended educational goals and a poor understanding of the user's perspective may have hindered their success in increasing understanding and retention of neuroanatomical knowledge.

To decipher the limitations of existing web-resources, an exhaustive search for neuroanatomy web-resources was performed and filtered through a strict review criterion. A panel of educators analyzed and ranked a selection of resources, focusing on the identification of features influencing their usefulness in learning the anatomy of the spinal pathways (Appendix 5). A panel of medical and neuroscience students subsequently evaluated the top three web-resources to assess how specific features aided in their learning of the subject (Appendix 6). This detailed analysis has identified features of neuroanatomy web-resources that are valued by both educators and users with regards to instructional design. One resource was ranked highest by end-users and educators in terms of clarity of explanation, step-wise teaching design, summarization of information, control of instructional-pace, integration with neurophysiology, neuroradiology and clinical correlates, deployment of pedagogical tools and factors for visualizing neuroanatomical inter-relationships. These results provide a

novel user perspective on the influence of specific elements of neuroanatomy web-resources to improve instructional design and enhance learner performance.

Key words: Neuroanatomy, anatomy, medical education, web-resources, neurophobia.

Introduction

The concept of neurophobia – a fear of the neural sciences and clinical neurology – was first described by Jozefowicz in 1994 (Jozefowicz, 1994). Reports have consistently shown that medical students and physicians feel incapacitated when required to apply their knowledge of basic neurosciences towards patient care (Flanagan et al., 2007; Youssef, 2009; Sanya et al., 2010; Zinchuk et al., 2010; Matthias et al., 2013; McCarron et al., 2014; Pakpoor et al., 2014; Arantes et al., 2017; Mullaly, 2017; Conway and Tubridy, 2018). In this context, studies have shown that the perception of neuroanatomy as a difficult subject is a significant contributor to the problem (Martin et al., 2014; Javaid et al., 2018). A recent survey has shown that medical and health sciences students rank the innate complexity of the topic, a lack of understanding of the clinical relevance of basic neuroanatomical facts and the difficult visualization of the three-dimensional inter-relationship of neuroanatomical structures as the main reasons for their difficulty with neuroanatomy (Javaid et al., 2018).

The deployment of competency-based and patient- and learner-centered teaching have contributed to renewed challenges to justify the place of neuroanatomy in the broader medical curriculum (Hazelton, 2011). While there is contradictory evidence regarding efficient teaching of neuroanatomy, as a standalone subject (Gogalniceanu et al., 2010) or as part of a vertically integrated medical curriculum (Lim and Seet, 2008; Billings-Gagliardi and Mazor, 2009), recent studies of educational interventions have highlighted the significance of focused approaches, including the implementation of team-based learning strategies (Anwar et al., 2015) and optimized three-dimensional (3D) simulators and online resources

(Abushouk and Duc, 2016), as important pedagogical tools for teaching neurological examination and reducing neurophobia.

In recent years, the increased availability of web-based teaching resources, coupled with the natural propensity of millennial students to use such online tools, has made ‘web-based learning’ a powerful pedagogical tool for supplementing traditional neuroanatomy learning (Cook, 2007). For instance, evidence has shown that online social mediums, such as, Twitter™, encouraged student engagement during the course of a neuroanatomy module (Hennessy et al., 2016). Similar opinions have been voiced by students regarding the usefulness of YouTube™ videos for learning anatomy (Jaffar, 2012; Barry et al., 2016). Svirko and Mellanby have documented improvement in the attainment of student learning outcomes with the incorporation of 3D e-learning neuroanatomy modules (Svirko and Mellanby, 2017). The significance of web-resources is further highlighted in the context of limitations of the conventional teaching in medical universities, such as, an ongoing curb in the on-campus teaching hours (Drake et al., 2009; Craig et al., 2010; Drake et al., 2014; Topping, 2014), paucity of qualified anatomy instructors, shortage of cadaver donation, and associated legal, financial and health concerns (Ellis, 2001; Demiryürek et al., 2002; Ellis, 2002; McLachlan and Patten, 2006).

Despite the benefits of computer assisted learning (CAL) and the abundance of neuroanatomy web-resources available, students continue to report difficulties in learning the subject; especially, the sensorimotor spinal pathways (Javaid et al., 2018). Furthermore, a student user-based perspective which could inform and improve the quality of instructional design of neuroanatomy web-resources has been lacking. The learning efficiency from online tools / resources can be enhanced if their pedagogical constructs and instructional design mirror human cognitive architecture (Mayer, 2003). In addition, effective online learning tools need to encompass a combination of principles, such as, addressing individual learning difference, motivating the students, avoiding information overload, presenting real-life or clinical scenarios, encouraging social interaction, active student engagement and reflection (Johnson and Aragon, 2003). Thus, there is a need to understand the breadth and determine the utility of currently available online tools for learning neuroanatomy.

In this study, a web-based search of neuroanatomy e-resources was performed and selected resources were analyzed using a novel scoring rubric inspired by adult educational learning theories (Taylor and Hamdy, 2013). Moreover, cognitive load reducing guidelines from Mayer's theory of multimedia learning (Mayer, 2003) and theories of cognitive load (Paas et al., 2003) were used to inform the scoring rubric, in order to increase its efficacy at selecting resources which promote meaningful learning. The principles offered by these learning theories suggest ways to reduce the extraneous sources of cognitive load, so that mental effort could be diverted towards the schema construction associated with learning (Young et al., 2014). A panel of anatomy educators assessed the value of selected resources with regards to their delivery of neuroanatomy of spinal pathways. A detailed opinion of students regarding what they consider most / least useful when learning neuroanatomy from the web-resources was also obtained. A quantitative analysis of educators' and students' perspectives adds strength to the results of this study. The results will inform pedagogical construct of future resources to better achieve learning outcomes for undergraduate students and reduce the prevailing neurophobia.

Materials and Methods

Study Design

This study consisted of an extensive search and review of neuroanatomy web-based tools followed by a detailed evaluation of selected resources by 5 anatomy educators (2 PhD scientists and 3 medically qualified; including 2 practicing clinicians) and 42 students at University College Cork (UCC). The student cohort consisted of 42 volunteer participants; 27 2nd-year medical students (14 females, 13 males), and 15 3rd-year B.Sc. neuroscience students (8 females, 7 males) who were undertaking a neuroanatomy module as part of their program. All participants had enrolled into their current undergraduate programs after having completed their secondary level education with no other higher qualification. This study received approval from the institutional Social Research Ethics Committee (log no. 2016-108) (Appendix 7 and 8).

Design of the Evaluation Rubrics

To design the evaluation scoring rubric used by the author (Appendix 4) and the educators (Appendix 5), various bibliographic databases such as, PubMed™ (National Institutes of Health, United States National Library of Medicine, Bethasda, MD), Google Scholar™ (Google Inc., Mountain View, CA) and other search engines, including Yahoo™ (Yahoo!, Sunnyvale, CA), WebCrawler™ (InfoSpace Holdings LLC Venice, CA), Lycos™ (Lycos Inc. Waltham, MA) and Infotopia™ (Infotopia, McAllen, TX) were searched for the existing tools and criteria for evaluation of medical, educational and health related educational websites. The following search strings were employed: 1) Quality rating instruments AND medical education, 2) (Evaluation OR guidelines OR www) AND medical education, 3) (reliability OR validity) AND (evaluation method OR questionnaire OR tool), and 4) variations and combinations of the followings: ‘quality’, ‘internet’, ‘world wide web’, ‘rating’, ‘ranking’, ‘evaluate’, and ‘assess’.

In addition, the literature was also searched for articles with topics pertaining to 1) usability and web user-interface features, 2) principles of adult educational learning theories (Taylor and Hamdy, 2013), and 3) cognitive learning theory (Mayer and Moreno, 2003; Young et al., 2014), to further inform the formulation of the evaluation rubric used by the author (Table 3.1, Appendix 4).

Table 3.1: Neuroanatomy Web-Resource Evaluation Grid Criteria Used by Author and Educators

Category	Items	Queries	Elements of CF-ONLine
Authenticity	Credibility	Content & Bibliographic accuracy – Authorship & Copyright disclosure – Target audience mentioned	
	Up-to-date	Date of last update	
	Bias	Factual information – Advertisements – Sponsorships	
	Learning outcomes	Guidelines for: Content to be learnt – Desirable depth of understanding (Bloom's taxonomy) – Context	Motivation
Feedback		Feedback acquisition from the students	
		Formative assessment	Feedback – reflection – active learning
	Online communication	Comments / Discussion section – Bulletin board –User group – Instructor availability – Search box	Social learning
Adaptability	Self-directed learning	Provision of resources / links for self-directed learning	
	Custom levels	Individualized learning database & Instructions – Custom tests / quizzes	Address individual differences
		Downloadable content	
	User control	Users can control the sequence of events	Address individual differences
Incentive to learn	Relevance to examination	Peer advice/success stories included – Advice for exam performance	Motivation
	Clinical significance	Clinical application of content – Case-based teaching	Motivation, Contextualized learning
	Relevance to research	Inclusion of neuroanatomy/neuroscience research	Motivation
	Student reflection	Are users encouraged to ask questions / reflect on improvement strategies	Reflection
	Fun	Inclusion of jokes, games, quizzes	Motivation
Learning tools	Images/pictures	Availability of: Diagrams / Illustrations – Pictures of models / prosections – Neuroradiology images	Cognitive basis to avoid info-overload – address individual differences
	Videos	Videos of: Clinical procedures – Bedside neuro exam – Cadaver dissection – Animations – Lectures – Neuroradiology	
	Notes	Text description – Lecture notes – Figure legends	Cognitive basis to avoid info-overload – address individual differences
	Audio	Included or not?	
Content presentation and interface	Content layout	Instructions/tutorial – Heading – Table of content / Site map – Formatting (bold / highlighting) – Hyperlinks – Glossary – Summary	Cognitive basis to avoid info-overload – usability interface features
	User-friendliness	Navigation features – Relevance of page title – Ease of access to information from home page – Consistent formatting – Intuitiveness of navigation – Mobile adaptability of interface – Connectivity via hyperlinks	Cognitive basis to avoid info-overload – usability interface features
	Aesthetic appeal	Appropriate choice of colour and contrast – Cluttering of pages – Blurry / Pixelated images – Readable font	Cognitive basis to avoid info-overload – usability interface features
	Language	Conversational/audience-appropriate language	Cognitive basis to avoid info-overload
	Accessibility	Accessibility via all search engines – Plug-in / username / password requirement	
	Comprehensiveness	> 50% of institutional neuroanatomy curriculum covered [a]	

[a] = Refer to Javaid *et al.* (2018) for the institutional neuroanatomy curriculum; CF-ONLine = Refers to the conceptual framework for online neuroanatomy learning (Table 1.2).

The rubric was subsequently peer-reviewed and refined by a panel comprising of the author, five anatomy educators and one senior anatomy technical staff to produce the final evaluation rubric used by the educators (Appendix 5). The items in the criterion were scaled on a dichotomous basis with a yes (score = 1; present in the resource) or no answer (score = 0; absent).

Next, a series of Likert-rating questions were formulated as part of the student evaluation rubric. These were devised in light of the detailed review of the neuroanatomy web-resources conducted by the authors and in consultation with the educators and senior anatomy technical staff. The questions were grouped into different categories based on similar or shared themes between them (Table 3.2, Appendix 6). The information not only provided insight about students' perception regarding factors which had been most efficiently employed by the available web-resources to facilitate student learning of neuroanatomy, but was also used to rank and select the best neuroanatomy learning web-resources. In addition, the student evaluation rubric contained two open-ended questions, including, what factor helped them most to learn when using a neuroanatomy web-resource and what mattered least to them when learning neuroanatomy online.

Table 3.2: Evaluation of Neuroanatomy Web-Resources by Students

Themes	Questions		Resource[a] A	Resource[a] B	Resource[a] C	Elements of CF-ONLine
Perceived value of resources	[b] Rank of the resources in order of preference		**1.4** ± 0.7	2.3 ± 0.6	2.3 ± 0.8	
	Value of the resource for learning		**4.3** ± 1.2	3.7 ± 0.9	3.6 ± 1.0	
Content description and presentation	Explanation of key principles of pathway layout		**3.8** ± 1.2	3.4 ± 1.0	3.2 ± 0.9	Pre-training principle
	Clarity of explanations		**4.5** ± 0.9	3.6 ± 1.0	3.6 ± 1.1	↓ extraneous processing
Teaching methodologies	Step by step drawings of pathways		**4.0** ± 0.9	3.4 ± 1.1	2.8 ± 1.2	Segmentation
	Summary sheets or tables		**3.4** ± 1.1	2.8 ± 1.1	2.6 ± 1.1	Repetition
	Online quizzes and feedback		**4.1** ± 0.8	3.5 ± 1.2	3.8 ± 1.1	Reflection, SDT (competency)
	Linking neuroanatomy with neurophysiology		**3.6** ± 1.0	3.4 ± 1.2	3.0 ± 1.1	Contextualized learning (horizontal integration)
	Linking neuroanatomy with neuroradiology		**3.9** ± 1.1	3.2 ± 1.1	3.2 ± 1.1	Contextualized learning (clinical correlation), multimodality, SDT (relatedness)
	Linking neuroanatomy with head, neck and scalp anatomy		**3.8** ± 1.0	3.4 ± 1.2	3.4 ± 1.2	Contextualized learning
	Linking neuroanatomy with neuroembryology		2.6 ± 1.3	**3.4** ± 1.4	2.9 ± 1.2	
	Solving neurological problems		**4.1** ± 1.0	3.2 ± 1.0	3.2 ± 1.2	Contextualized learning (clinical correlation), SDT (relatedness)
	Bedside neurological examination videos		**3.3** ± 1.5	2.5 ± 1.3	2.4 ± 1.4	
	Varying levels of detail		**3.5** ± 1.1	3.2 ± 1.0	2.8 ± 1.0	Individual learning differences, managing essential processing, imparting autonomy, SDT (autonomy)
	Control of pace of instruction		**4.1** ± 0.9	3.2 ± 1.1	3.1 ± 1.3	
Learning tools	Cross-sectional images		**4.3** ± 0.8	3.4 ± 0.8	3.6 ± 1.0	Multimodal learning, catering for individual learning preferences, enhanced visualization for relationships
	CT, MRI		**4.2** ± 0.8	2.9 ± 1.1	3.2 ± 1.2	
	Animations, videos		**4.2** ± 1.0	3.0 ± 1.2	2.8 ± 1.2	
	3D computer models		**4.3** ± 0.8	2.8 ± 1.2	3.2 ± 1.4	
	Factors for 3D visualization of neuroanatomy	Brain prosections images	**4.4** ± 0.8	3.6 ± 1.0	3.4 ± 1.2	
		Plastic models images	**3.6** ± 1.4	3.2 ± 1.3	3.0 ± 1.4	
		2D/3D illustrations	**4.3** ± 0.7	3.5 ± 0.9	3.5 ± 1.1	
		3D model softwares	**4.3** ± 0.9	3.2 ± 1.1	2.9 ± 1.3	
		Animations or video lectures	**4.4** ± 0.7	3.2 ± 1.0	2.9 ± 1.2	
		Images of sections (Horizontal, Coronal, Sagittal)	**4.5** ± 0.6	3.7 ± 0.8	3.6 ± 1.2	
		CT, MRI	**4.1** ± 0.8	3.5 ± 1.0	3.3 ± 1.2	

[a] Data presented as mean ± S.D. [b] Ranking of each resource was conducted as 1st, 2nd or 3rd best on a 3-point scale. For all other questions, values are derived from 5-point Likert scale ratings (1 = minimum, 5 = maximum). The highest ranked resource is highlighted in bold. 3D = Three-dimensional, CT = Computer enhanced tomography, MRI = Magnetic resonance imaging, SDT = self-determination theory.

The CF-ONLine (Table 1.2) and students' perception (Table 2.1, Appendix 1; Javaid et al, 2018) provided detailed insight regarding designing the evaluation rubrics. Opinions acquired from a wide cohort of medical and health science students (Table 2.1, Appendix 1; Javaid et al, 2018) revealed that neuroanatomy was considered most difficult to learn compared to all other anatomy topics. The most important factor was the complex nature of the topic, with students reporting difficulties experienced while interlinking things together and feeling hard-pressed for time while getting their heads around complicated concepts (students' comments page 74–75, Javaid et al, 2018). Consequently, the students' evaluation rubric comprised of questions inquiring about participants' perception regarding the significance of measures for managing to learn complicated concepts. Examples include, questions related to clarity of explanations and explanation of key principles of pathway layout (Table 3.2; content description and presentation theme). Such features of e-resources help reduce extraneous processing (CF-ONLine, Table 1.2) while clear articulation of key-principles and complex terminologies in the beginning provide a priori-baseline knowledge to the learner, thus making it easier to formulate complicated schemas associated with learning the intricate neuroanatomical concepts (CF-ONLine; pre-training principle). In the same vein, questions pertaining to step by step drawings of pathways and incorporating summary sheets and tables were also incorporated into the rubric design (Table 3.2; teaching methodologies theme). Elements of the CF-ONLine (Table 1.2), such as, 'segmentation' for managing the essential processing of important content and significance of 'repetition' for revising and solidifying the learnt-content, informed the formulation of these questions. Additional questions incorporated into the rubric pertained to the option of selecting from varying levels of detail and a greater learner-control over the pace of instruction (Table 3.2). While, such features cater for varying learning levels and styles, these also help manage the essential processing associated with cognitive assimilation of complicated topics, as proposed in the CF-ONLine earlier (Table 1.2). Moreover, a greater degree of control provided to the learner through custom-teaching, imparts a feeling of autonomy, thus boosting the learner motivation level (Hsu et al., 2019; Cook and Artino, 2016; Chen and Jang, 2010; Ryan and Deci, 2000) (Table 1.2; CF-ONLine). These questions were further informed by our earlier findings regarding students' opinion (Chapter 2), which revealed that students' perceived level of interest and level of knowledge were inversely correlated with the perceived level of difficulty of neuroanatomy, thus suggesting that measures geared towards motivating students to learn and enhancing their interest, will likely increase their knowledge (and reduce the perceived level of difficulty) of the topic (Javaid et al., 2018).

In context of the clinical contextualization of neuroanatomical facts, students reported earlier that case-based teaching would increase their interest in learning the subject (pg. 76, Javaid et al., 2018). Moreover, the clinical year students preferred a clinically oriented mode of learning for neuroanatomy (pg. 77, Javaid et al., 2018). As postulated by the self-determination theory (Hsu et al., 2019; Cook and Artino, 2016; Chen and Jang, 2010; Ryan and Deci, 2000), clinical contextualization could impart a sense of relatedness among the medical students and motivate them to learn the topic (Table 1.2, CF-ONLine). Hence, questions related to students' perceived significance of solving neurological problems and employing bedside neurological examination videos, were incorporated into the evaluation rubric-design (Table 3.2). In context of relatedness, participants were also inquired about their opinion regarding linking neuroanatomy with other relevant topics and modalities, such as, neurophysiology, neuroradiology, neuroembryology and regional head and neck anatomy (Table 3.2). The use of multiple modalities for learning, once again, caters for varying learning preferences and helps reduce the essential processing when participants are provided an opportunity to learn in their preferred learning format (Table 1.2, CF-ONLine).

Lastly, a series of Likert-scale questions included in the evaluation rubric pertained to various learning tools and students' perceived significance for learning neuroanatomy (Table 3.2). Participants' suggestions acquired earlier regarding various components of the e-learning resources (Javaid et al., 2018, Chapter 2), guided the design of such questions in the evaluation rubric (Table 3.2, Chapter 3). For instance, earlier Javaid and colleagues (2018) had shown that animations and videos were considered important for a better visual representation of deep brain structures, and pathways of cranial nerves including their nuclei and level of decussation, thus helping them to understand the localization of lesion (pg. 80, Javaid et al., 2018). Videos were deemed helpful for learning steps of clinical examination and various neurosurgical procedures and for repeatedly listening and playing back the explanation of intricate topics, at a custom pace (pg. 80–81, Javaid et al., 2018). The importance of multimodal learning and addressing varying learning style preference for online learning had also been proposed earlier in the CF-ONLine (Table 1.2, Chapter 1).

Active / interactive learning was proposed as an important proponent for meaningful and deeper learning in the CF-ONLine (Table 1.2, Chapter 1). Furthermore, Javaid et al (2018) showed that medical and health sciences students preferred the luxury of being able to interact with the illustrative images by zooming in / out and turning the labels on / off for enhancing their learning experience (pg. 80–81). Moreover, the pictorial representation of brain structures through a myriad of modalities, including illustrations, videos and prosection-images was considered helpful (pg. 80–81, Javaid et al., 2018). Consequently, both CF-ONLine (Table 1.2) and students' opinion (Javaid et al, 2018) informed the design of questions pertaining to learning tools in the evaluation rubric (Table 3.1). Lastly, the learning cannot be stripped of from the influence of social processes, such as community and context (Table 1.2). The Situativity cognitive theory (Durning and Artino, 2011) and social learning theories (Taylor and Hamdy, 2013), as part of the CF-ONLine (Table 1.2, chapter 1) inspired the incorporation of questions pertaining to online communication in the evaluation rubric (Table 3.1).

Web-Resource Selection and Assessment

A search for neuroanatomy web-resources was performed using online search engines such as Google (Google Inc. Mountain View, CA), Yahoo (Yahoo! Sunnyvale, CA), and meta-search engines, such as, WebCrawler (InfoSpace Holdings LLC Venice CA), Excite (InterActiveCorp, New York City, NY) and Infotopia (Infotopia, McAllen, TX). Custom search strings, including 1) Neuroanatomy AND web AND resources, 2) Neuroanatomy AND education, 3) Neuroanatomy AND website, 4) Neuroanatomy AND online, were entered into each search engine. The search spanned from May 1st to Aug 2nd, 2016.

A primary list of neuroanatomy learning web-resources pertaining to human neuroanatomy education, was generated. A web-resource was defined as any search outcome which can be accessed through a web-browser (websites, teaching aids, online image banks, interactive tutorials, etc.). The resulting list was filtered to exclude any of the following:

i. Repetitive results from different search engines
ii. Web-resources for disciplines other than neuroanatomy or those dedicated to non-humans only.
iii. E-textbooks, online dictionaries and glossaries.
iv. Online journals or periodicals.
v. Web-resources requiring a paid subscription or login for access.
vi. Non-multimedia web-resources that do not incorporate both text (written / audio files) and images (static pictures / dynamic videos or animations).
vii. Web-portals containing hyperlinks for external neuroanatomy resources, with no original content of their own.
viii. Web-resources containing neurohistology and / or neurocytology information only.

ix. Web-resources which lacked interactivity. Interactivity, encompassed all active and engaging forms of information-acquisition, including on / off switching of image-labelling, images with linked information, quizzes and multiple-choice questions.

x. Web-resources which covered less than 50% of the neuroanatomy syllabus taught in our institution (Javaid et al., 2018). These were excluded to avoid including incomplete resources which did not optimally address the breath of the institutional neuroanatomy syllabus. For calculating the percentage, a list of lecture-topics taught as part of the neuroanatomy undergraduate module at our institution was prepared (denominator) and compared from the list of topics covered by each individual web-resource (numerator). It is to be noted that the initial intent was to analyze the filtered web-resources for the entire neuroanatomy syllabus. However, due to time-constraints on part of the educators, and the narrow time window available during the semester when students receive the neuroanatomy lectures, it was decided to focus on a section of the syllabus that students had identified as the most difficult topic in earlier research – the spinal pathways (Javaid et al., 2018).

This exclusion sequence risks the elimination of neuroanatomy web-resources which could have addressed teaching of the neuroanatomy of the spinal pathways. To address this potential limitation, the list of 64 neuroanatomy resources was re-assessed for their information on the spinal pathways and no additional resources, other than the 22 already identified for assessment, were included in the final list for authors' review.

The remaining web-resources were analyzed and scored using an exhaustive evaluation rubric comprising the items described in Table 3.1 (Appendix 4). The sum of the item-scores formed the total score for each web-resource with a maximum possible score of 85. The scoring allowed the evaluation of its capacity to discriminate between neuroanatomy web-resources and served to establish a ranking list of web-resources for subsequent educators' evaluation.

Next, a panel of five anatomy educators involved in neuroanatomy research and teaching at University College Cork evaluated ten neuroanatomy resources using a marking grid based on the scoring rubric described in Table 3.1 (Appendix 5). The assessment was limited to the 3 top-ranked and a random selection of 7 additional resources from the authors' evaluation as it was not possible for the educators to evaluate all 22 resources due to their teaching and research commitments. The educators' evaluation grid differed from the initial evaluation rubric as it probed the usefulness of specific features of the web-resources in the context of student-learning of the sensory and motor spinal pathways. The sum of item-scores formed the total score for each web-resource with a maximum possible score of 54. A spearman correlation analysis was performed between scores attributed to the ten neuroanatomy web-resources by the authors and those attributed by the educators to investigate the inter-rubric reliability of the evaluations.

Next, the 3 top-ranked resources from the anatomy educators' panel were evaluated by the student panel, providing a users' perspective regarding their effectiveness to aid in students' learning of the spinal pathways (Table 3.2, Appendix 6).

Thematic analysis

Answers to open-ended questions were tabulated and analyzed for patterns of meaning or themes in the data. The analysis involved the following phases (Braun and Clarke, 2006):

Familiarization with the data and generation of an initial list of ideas

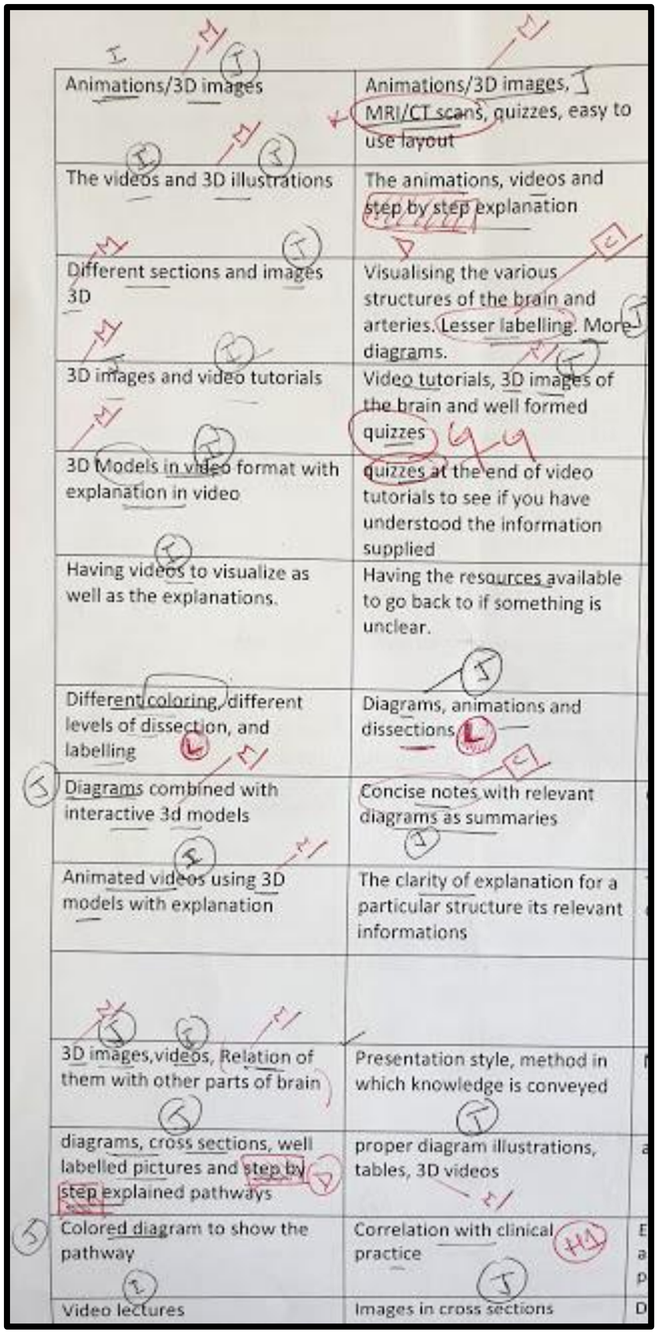
Familiarization with the depth and breath of the content was acquired through repeated reading and actively searching for meanings and patterns, prior to commencing with the formal coding process. The following initial list of ideas was generated:

- The nature of the presentation of content was perceived important, with participants pressing upon the need for the material being concise, to-the-point and without unnecessary detail.
- Various literal suggestions regarding learning complex information were found through analysis of the data, such as, breaking the complex information into bite-sized segments, clinically contextualizing the content and incorporating interactive methods for learning.
- Incorporation of various learning / pedagogical tools into the e-resources was highlighted by the participants.

Generation of codes

The data was coded by two investigators. A total of 17 and 14 codes were identified by two investigators, independently. The codes were generated by the first investigator using a manual coding method by writing down notes on the text and by using alphabetical labels to group the comments and to indicate potential patterns. These included 1) Ease of use, 2)

Clarity and simplicity, 3) Conciseness, 4) Step by step learning, 5) Repetition, 6) Summarization, 7) Assessment and feedback, 8) Clinical correlates / vertical integration, 9) Horizontal integration, 10) Videos, 11) Images, 12) Neuroradiology, 13) Dissection / Prosections, 14) 3D Visualization, 15) Authenticity / source of information, 16) Information irrelevant to the exams, 17) Functionality. Figure 3.1 shows a sample of the open-ended statements where the coding has been added in by hand using alphabetical labels.



Animations/3D images	Animations/3D images, MRI/CT scans, quizzes, easy to use layout
The videos and 3D illustrations	The animations, videos and step by step explanation
Different sections and images 3D	Visualising the various structures of the brain and arteries. Lesser labelling. More diagrams.
3D images and video tutorials	Video tutorials, 3D images of the brain and well formed quizzes
3D Models in video format with explanation in video	quizzes at the end of video tutorials to see if you have understood the information supplied
Having videos to visualize as well as the explanations.	Having the resources available to go back to if something is unclear.
Different coloring, different levels of dissection, and labelling	Diagrams, animations and dissections
Diagrams combined with interactive 3d models	Concise notes with relevant diagrams as summaries
Animated videos using 3D models with explanation	The clarity of explanation for a particular structure its relevant informations
3D images,videos, Relation of them with other parts of brain	Presentation style, method in which knowledge is conveyed
diagrams, cross sections, well labelled pictures and step by step explained pathways	proper diagram illustrations, tables, 3D videos
Colored diagram to show the pathway	Correlation with clinical practice
Video lectures	Images in cross sections

Figure 3.1. Sample open-ended statements and coding using alphabetical labels. The labels included, A= Ease of use, B= Clarity and simplicity, C= Conciseness, D= Step by step learning, E= Repetition, F= Summarization, G= Assessment and feedback, H1= Clinical correlates / vertical integration, H2= Horizontal integration, I= Videos, J= Images, K= Neuroradiology, L= Dissection / Prosections, M= 3D Visualization, N= Authenticity / source of information, O= Information irrelevant to the exams, P= Functionality.

The second investigator used NVivo™ (QSR International's NVivo 12.1 qualitative data analysis software) to generate the following codes: 1) Voice, 2) Video, 3) Time, 4) Sections, 5) Quiz and queries, 6) Prosections, 7) Proper labelling, 8) Photos, 9) Interaction, 10) Images 2D-3D, 11) Explanations, 12) Ease of use, 13) CT and MRI, 14) Control of flow.

Generation of themes

A thematic analysis using an inductive approach (Braun and Clark, 2006) was used to sort the different codes leading to the identification of overarching themes. The results of both investigators were refined and compared to reach a consensus classification under 3 themes. For instance, These included, 1) content description and presentation (incorporating the codes 1–3, namely, ‘Ease of use’, ‘Clarity and simplicity’ and ‘Conciseness’), 2) teaching methodologies (incorporating the codes 4–9, namely, ‘Step by step learning’, ‘Repetition’, ‘Summarization’, ‘Assessment and feedback’, ‘Clinical correlates / vertical integration’ and Horizontal integration) and 3) learning tools (incorporating the codes 10–17, namely, ‘Videos’, ‘Images’, ‘Neuroradiology’, ‘Dissection / Prosections’, ‘3D Visualization’, ‘Authenticity / source of information’, ‘Information irrelevant to the exams’ and ‘Functionality’. The codes which did not seem to belong anywhere, were placed underneath a separate heading called ‘miscellaneous’ for housing those codes.

A few examples of resolving potential conflict between the two investigators’ selected codes and reaching a consensus classification, have been given below:

- The code ‘voice’ was referenced three times by the data analysis software. Careful investigation revealed that each time it was used in the context of a video description of the pathways. For instance, “drawn sketches of physiological / anatomical mechanisms are useful with change in voice intonation when speaking” and “quality images help the most and a voice over explaining the pathways also helps”. Hence, it was merged with the ‘video’ category (code 10) identified by the first investigator.

- The code ‘time’ was references by the data analysis software in the context of ease of the loading time of the website. For instance, “a clean, slick website that is intuitive when minimal loading time is required to access material”. Hence, it was merged with the ‘ease of use’ category (code 1) identified by the first investigator.
- The codes ‘sections’ were references 9 times while the code ‘proper labelling’ was references once by the data analysis software. However, these were used in the context of the description of images and hence were merged with the ‘image–code’ generated by the first investigator. For example, students quoted that “diagrams, cross sections, well labelled pictures and step by step explained pathways” were perceived best by them to visualize neuroanatomical structures including the spinal pathways. In some other locations, the code ‘labelling’ was employed in the context of prosections and hence were merged into the prosection / dissection category generated by the first investigator (code–13). For example, students quoted that “labelled pictures of the real brain sections” were considered useful by them to visualize the spinal pathways.
- The code ‘interaction’ was referenced twice the by data analysis software, in the context of interactive learning. For instance, students quoted that “3D interactive models that you can manipulate yourself” and “diagrams, combined with interactive 3D models”, were perceived useful by them to visualize neuronal spinal pathways.

Since, interactive models provide immediate feedback to the learner (such as, through on / off labelling), hence, this code was merged with the ‘assessment and feedback’ category (code–7) originally identified by the first investigator.

Individual pedagogical domains within the resources were also separately rated by the students (using Likert-scale questions) in terms of their usefulness in aiding the neuroanatomy-learning experience and classified under the themes identified (Table 3.2).

One of the benefits of thematic analysis is its flexibility. It is not wedded to any pre-existing theoretical framework, rather can be used within different theoretical frameworks and can be used to do different things within them. It is compatible with both essentialist and constructionist paradigms and hence through its theoretical freedom, serves as a flexible and useful research tool for providing rich and detailed account of data (Braun and Clark, 2006). Moreover, as thematic analysis does not require the detailed theoretical and technological knowledge of approaches, such as grounded theory and discourse analysis, it can offer a more accessible form of analysis, especially for those early in a qualitative research career (Braun and Clark, 2006).

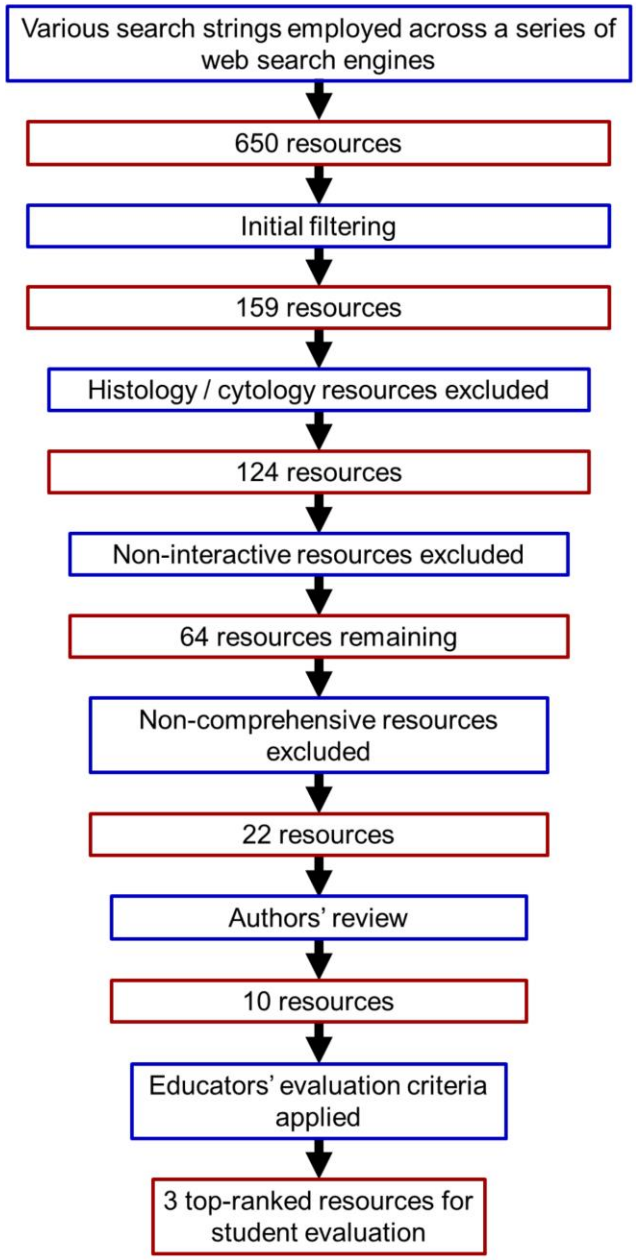


Figure 3.2. Schematic representation of the selection and evaluation of neuroanatomy web-resources. A primary list of neuroanatomy web-resources was generated using custom search strings. The search results once filtered through the inclusion / exclusion criteria generated 159 web-resources. This list was reduced to 22 resources by excluding resources which contained only neurohistology information, were non-interactive or non-comprehensive. After analysis by the first author, the top 3 resources and a random selection of 7 additional resources were submitted to an evaluation by a group of 5 educators. The 3 top-ranked resources were assessed by student users with regards to the importance of specific web-resource features in learning spinal motor and sensory pathways.

Statistical Analysis

Data were coded, anonymized and entered into Microsoft Excel 2016 spreadsheets (Microsoft Corp., Redmond, WA). Data were exported to the Statistical Package for Social Sciences (SPSS), version 24 (IBM Corp., Armonk, NY). Descriptive statistics (mean, ±SD) were used to present the data. Spearman correlation was used to analyze the relationship between authors' ranking and educators' assessment of 10 neuroanatomy web-resources. Non-parametric data was collected using Likert scales (ordinal data) as participants were asked to rank all factors rendering these dependent on others. Non-parametric Friedman's paired ranking test was used to analyze potential differences between the three selected resources (A, B and C). For those factors where a statistically significant difference was obtained between the resources (A, B and C) by Friedman. Wilcoxon's signed-ranks test was subsequently conducted for the following three paired comparisons; 1) resource A vs. resource B, 2) resource B vs. resource C and 3) resource A vs. resource C. The latter helped to identify which of the three resources employed each factor best for student learning of spinal pathways. Differences with post-hoc adjusted P values less than 0.05 were deemed statistically significant. Data from questions pertaining to the same subjects were grouped and analyzed together. Cronbach's alpha was used to measure the internal consistency of the grouped answers.

Results

An exhaustive web-resource selection and assessment process described in the methods section initially generated a list of 159 web-resources. This list was reduced in size using a step-by-step exclusion process (Figure 3.2), to eventually limit the list to 22 neuroanatomy web-resources. Analysis of these resources using the authors' evaluation rubric (Table 3.1, Appendix 4), allowed the evaluation of its capacity to discriminate between these neuroanatomy web-resources and served to establish a ranking of the 22 web-resources for subsequent educators' evaluation (Figure 3.3A, Appendix 5).

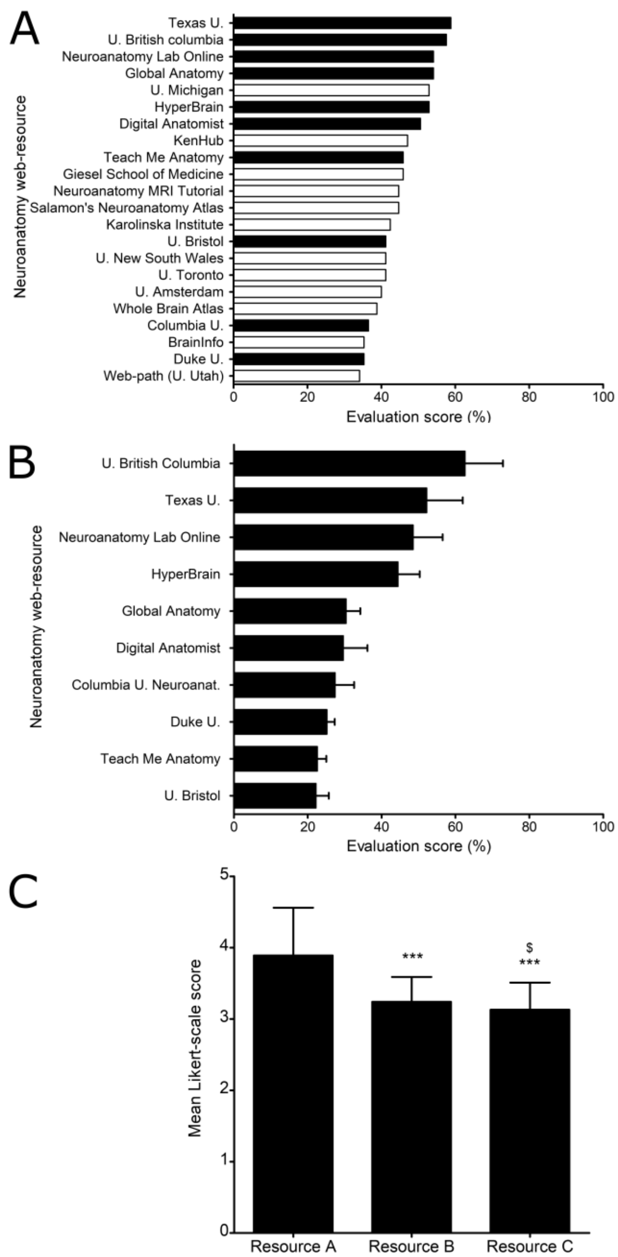


Figure 3.3. Evaluation of neuroanatomy web-resources. A, Evaluation of 22 neuroanatomy web-resources by the first author. The resources were assessed using a detailed criterion and scored individually for the presence or absence of features. The 10 resources identified in black were further assessed by the educators. The maximum total score for each resource was 85. The scores are presented as percentage. B, Assessment of 10 neuroanatomy web-resources by a panel of 5 educators. Each feature was rated for its usefulness in the context of learning of the spinal pathways. The maximum possible score was 54. The data are presented as the mean percentage ± S.D. (N=5). C, Resource A is ranked highest by student users. Results are presented as the mean Likert score from 26 questions for each resource ± S.D. ($P < 0.001$, Friedman's test with Wilcoxon's signed-rank post-hoc analysis, *** $P < 0.001$ compared to resource A, \$ $P < 0.05$ compared to resource B).

Anatomy Educators' Assessment

The top 3 ranked resources and a random selection of 7 additional resources from the panel of 22 were evaluated by a panel of 5 anatomy educators, using the final educators' evaluation rubric, for the perceived usefulness of specific features when learning neuroanatomy of the spinal pathways (Appendix 5). This grid differed from initial evaluation as it probed the usefulness of specific features of the individual web-resources in learning neuroanatomy of the sensory and motor spinal pathways. When the resources were ranked based on highest mean educators' score, results show that the top 4 resources stand apart from the remaining 6 resources as there is a 14% difference between the 4^{th} and 5^{th} ranked resources (Figure 3.3B). the Functional Neuroanatomy web resource from the University of British Columbia was ranked highest by the educators (Resource A, Figure 3.3B). A Spearman correlation analysis showed that scores attributed by the authors' evaluation and the mean scores from the educators are highly correlated for the ten resources analyzed (r = 0.831, $P < 0.01$), providing support to the reliability of the evaluation rubrics. These three top-ranked resources have been referred to as resource A (Functional Neuroanatomy, University of British Columbia, Vancouver, BC, Canada; Krebs, 2016), resource B (Neuroanatomy online, University of Texas McGovern Medical School, Houston, TX; Watson et al., 2018) and resource C (Neuroanatomy Lab Online, The University of Texas Health Science Center at Houston, Houston, TX; Daffny and Amini, 2018) in the study.

Questions in the educators' evaluation grid were grouped along six categories, based on concepts, such as, Authenticity, Feedback, Adaptability, Incentive to learn, Learning Tools, and Content presentation and interface (Table 3.1). Resource A was ranked highest in 4 / 6 categories (Adaptability, Incentive to learn, Learning Tools, and Content presentation and interface) while resource B was ranked highest in the other 2 categories (Authenticity, Feedback). When it was not first, resource A was ranked second, reflecting its position as the highest ranked overall.

Students' Assessment of the Resources

The three top-ranked resources were selected for evaluation by students to identify the features, which they believe are important when learning spinal motor and sensory pathways (Table 3.2, Appendix 6). Following collation of data, Likert-scale questions for the students' evaluation rubric were grouped into different categories based on shared themes, pertaining to i) the perceived value of the three selected resources, ii) the description and presentation of the neuroanatomy content, iii) the teaching methodologies employed, and iv) the learning tools used (Table 3.2). An observational analysis of students' illustrative quotes to questions regarding what mattered most / least to them for learning neuroanatomy from online resources, provided support for the formulation of the above-mentioned four categories.

Students' Perceived Value of the Resources

Resource A is perceived as the best neuroanatomy web-resource. On completion of the questionnaire, the respondents were asked to rank the three resources in order of preference. Resource A was ranked first by 31 / 42 participants (73.8%) while 4 selected resource B (9.5%) and 7 chose resource C (16.7%) as their top-ranked resource. A Wilcoxon signed-rank analysis provided support to the preference of the students showing that resource A is ranked superiorly to the other 2 resources (Table 3.2, $P < 0.001$ for both comparisons). When asked to rank the value of the resources when learning neuroanatomy on a Likert scale, the participants ranked resource A higher than the other 2 resources (Friedman analysis, P <

0.001) with a mean ranking of 4.3 ± 1.2 for resource A compared to 3.7 ± 0.9 for resource B and 3.6 ± 1.0 for resource C (Table 3.2, $P < 0.01$ and $P < 0.05$, respectively, Wilcoxon's signed-rank test). Analysis of the Likert scale ratings of 26 questions showed that overall resource A was ranked 1st and that there was no difference in overall rating between resources B and C (Figure 3.3C, $P < 0.0001$, Friedman's analysis with post-hoc Wilcoxon's signed rank test). Finally, participants were asked whether each resource stimulated their interest in neuroanatomy (Yes, No, Neutral answers), 31 said yes for resource A (73.8%), 16 / 42 (38.1%) for resource B and 14 / 42 for resource C (33.3%).

Content Description and Presentation

Students prefer clear and simple explanations in an easy to use interface. As illustrated below, the thematic analysis of open-ended responses revealed that the layout, intuitiveness and the clarity (and conciseness) of the description of the web-content were considered helpful by students while using online neuroanatomy resources.

- *"I prefer simple language, when material is presented in a clear and easy to use manner."*
- *"Short duration and very concise videos will be helpful."*
- *"I want to see concise notes with relevant summary diagrams."*
- *"Easy to use layout and accessibility of the web-content is important."*
- *"A clean, slick website that is intuitive when minimal loading time is required to access additional material"*

When asked to rate the resources for the clarity of their explanations, results showed that the mean Likert scores for resource A (4.5 ± 0.9) were significantly higher compared to both resources B (3.6 ± 1.0) and C (3.6 ± 1.1) (Table 3.2, $P < 0.01$ compared to resources B and C, Wilcoxon's signed-rank tests). However, the description of the key principles of the spinal pathways layout (such as, the organization of first, second and third order neurons in sensory pathways, relationship of ipsilateral / contralateral deficits with lesions below / above decussation-level, etc.) was rated better by participants for resource A (3.8 ± 1.2) in comparison to resource C only (3.2 ± 0.9, $P < 0.05$, Wilcoxon's signed-rank test). Resource A still had a higher mean score compared to resource B (3.4 ± 1.0), however, the difference was not statistically significant ($P = 0.08$, Wilcoxon's signed-rank test). Comparison of resources B and C showed no significant difference either between them in terms of clarity of the explanations or the description of key principles (Table 3.2, $P = 0.74$ and $P = 0.19$ respectively, Wilcoxon's signed-rank tests). Cronbach's alpha shows a strong inter-reliability of answers for resource A ($\alpha = 0.80$) but less so for resources B ($\alpha = 0.67$) and C ($\alpha = 0.64$).

Teaching Methodologies

Students indicate preference for a variety of learning strategies. As illustrated below, results from the thematic analysis indicate that assimilation of information in a step-by-step fashion coupled with repetition, revision and feedback quizzes are most helpful while learning neuroanatomy online. Moreover, clinically contextualization and horizontal integration are perceived to enhance interest for basic neuroanatomy. The following sub-themes were identified in this domain:

- *"Step by step explained pathways will be very useful"*

- *"Step by step learning and step by step explanation is very useful"*
- *"Repetition of learning material is helpful for learning"*
- *"I liked the way, in UBC videos, they circled again the areas with pen onscreen afterwards to make sure that you knew exactly where the area was, was really good"*
- *"Online quizzes with feedback provide the ability to test oneself"*
- *"Quizzes at the end of video tutorials to see if you understood the information supplied"*
- *"Correlation with clinical practice generates interest in neuroanatomy"*

Using Likert-scales, the participants were asked to rank a number of teaching methods with regards to their value in improving knowledge of the motor and sensory spinal pathways. The students ranked resource A highest compared to the other two resources ($P < 0.001$, Friedman's analysis) for its step-wise design giving users the opportunity to experience an incremental improvement in their knowledge (Table 3.2, $P < 0.01$ compared to resources B and $P < 0.001$ for resource C, Wilcoxon's signed-rank tests). Similarly, resource A was ranked highest compared to other two resources ($P < 0.01$, Friedman's analysis) with regards to the summarization of key information points across different neural pathways using tables (Table 3.2, $P < 0.05$ compared to resources B and $P < 0.01$ for resource C, Wilcoxon's signed-rank tests).

All three resources provided users with online quizzes and instant feedback, however, upon detailed analysis no significant difference was found between the three resources ($P = 0.094$, Friedman's analysis).

The questionnaire inquired about the usefulness of controlling the pace and level of detail in the web-resources. Resource A was ranked significantly higher compared to the other two resources in terms of providing students the ability to take charge of the pace of their learning (Table 3.2, $P < 0.01$ compared to both resources B and C, Wilcoxon's signed-rank tests). When the level of detail was analyzed, results showed that resource C was ranked significantly lower than the other 2 resources (Table 3.2, $P < 0.05$ compared to both resources A and B, Wilcoxon's signed-rank tests) and that there was no significant difference between resources A and B (Table 3.2, $P = 0.098$, Wilcoxon's signed-rank test).

In the context of horizontal integration of the curriculum, students perceived that the neuroanatomy information was better linked and integrated with neurophysiology in resource A when compared to resource C (Table 3.2, $P < 0.05$, Wilcoxon's paired-ranked test). Similarly, the data show a better link between neuroanatomy and neuroradiology in resource A than in the other 2 resources (Table 3.2, $P < 0.01$ for resource B and $P < 0.05$ for resource C, Wilcoxon's paired-ranked test). In contrast, resource B was ranked highest for its link between neuroembryology and neuroanatomy (Table 3.2, $P < 0.05$ compared to resources A and C). This is the only category where resource A was not ranked highest. Finally, the data analysis revealed no significant difference between the three resources in terms of their integration with relevant regional anatomy of the head, neck, scalp and skull areas ($P = 0.128$, Friedman's test).

With regards to the clinical correlation of basic neuroanatomical facts for learning neuroanatomy, the participants were asked to rate the usefulness of bedside examination videos and solving neurological case-based scenarios. Friedman's analysis showed significant differences between the three resources for both categories ($P < 0.001$). Wilcoxon's paired-rank testing showed that participants ranked resource A significantly higher compared to the other two resources (Table 3.2, $P < 0.01$ for both resources for both categories, Wilcoxon's paired-ranked tests). Cronbach's alpha analysis revealed strong category reliability between answers pertaining to questions related to the 'teaching methodologies category', for the three resources ($\alpha = 0.78$ for resource A, $\alpha = 0.84$ for resource B and $\alpha = 0.89$ for resource C).

Learning Tools

Students show an appreciation for a diversity of learning tools suggesting a multi-modal approach to learning the anatomy of the spinal pathways. The significance of visualizing neuroanatomical relationships in 3D and the contribution of multiple learning tools was identified in thematic analysis.

- *"Video lectures and video tutorials are good learning media"*
- *"3D models in video format with explanation in video"*
- *"Images in cross-sections with coloring of individual sections is most helpful for me to learn the pathways" and "Selecting different areas on diagrams as selectable structures helps me learn a lot"*
- *"Imaging, MRI / CT scans are good"*
- *"I really liked the UBC neuroanatomy videos that used real, pre-prepared prosections to show the various components of a system, e.g. limbic system"*

- *"Seeing images of cadaver neuroanatomy is best to help me visualize anatomical structures"*
- *"Seeking varying images from different angles and separating structures out is good for learning complex neuroanatomy structures"*
- *"Diagrams combined with interactive 3D models. 3D models are best for good understanding"*

The participants were asked to rank the usefulness of a list of teaching tools with regards to improving their knowledge of the sensorimotor spinal pathways (Table 3.2). In this learning context, the participants reported that various tools, such as, cross-sectional images, animations and videos, CT and MRI images, and 3D computer models are best employed by resource A (Table 3.2, $P < 0.001$ compared to resource B and $P < 0.01$ compared to resource C for all four tools, Wilcoxon's signed-ranks analysis) while there were no differences between resources B and C. Cronbach's alpha analysis revealed a strong inter-reliability for students' responses for the three resources ($\alpha = 0.64$ for resource A, $\alpha = 0.74$ for resource B and $\alpha = 0.78$ for resource C).

The participants also rated the usefulness of various factors to help visualize the inter-relationship between various neuroanatomical structures in the three-dimensional space. Resource A was found to be significantly better than the other resources in using images of brain prosections, CT / MRI, 2D / 3D illustrations, 3D brain models, animations and video lectures, and images of sections at various levels of the brain and spinal cord (Table 3.2, $P < 0.05$, Wilcoxon's paired-ranked tests). In the last category, images of plastic models, even though resource A was not ranked better than resource B ($P = 0.084$, Wilcoxon's paired-ranked test), it was still ranked significantly higher than the resource C ($P < 0.05$, Wilcoxon's paired-ranked test), once again reflecting the overall preference for resource A. Cronbach's alpha analysis revealed strong internal consistency between answers related to questions of various factors to help visualize the inter-relationships between various neuroanatomical structures ($\alpha = 0.79$ for resource A, $\alpha = 0.84$ for resource B and $\alpha = 0.96$ for resource C).

In addition to the three themes identified above, the thematic analysis generated a number of items that did not fit into the themes explored but that are worth mentioning. These include authenticity / popularity of the resources, the delivery of information deemed irrelevant and a confusion about what is neuroanatomy.

- *"It does not matter to me where the resource comes from/what university name is behind it"*
- *"The popularity of the website or the author matters the least"*
- *"Over explanation and too much information in one topic. Every single piece of data does not matter"*
- *"Extra unnecessary information aside from the basic"*
- *"I don't like to read information that does not relate to the course work for exam"*
- *"Explanation of the function and properties of the pathways – where do I draw a line between neuroanatomy and neurophysiology?"*

Discussion

Previous studies have suggested ways to address neurophobia in the broader context of clinical neurology practice. For instance, Fantaneanu et al. (2014) suggested that addressing modifiable risk factors that act as barriers while learning neuroanatomy, including the complex neuroanatomical terminologies and concepts, the lack of demonstrations during clinical years and the limited teaching of clinical correlates of neuroanatomy during the basic science years could help alleviate neurophobia. In addition, various evidence-based recommendations and educational interventions to mitigate neurophobia have been suggested by Abushouk and Duc (2016) and Tarolli and Jozefowiz (2018), such as the implementation of team-based and problem-based learning, improved teaching of clinical neurological examination via optimized usage of online resources and 3D simulators, increased outpatient clinical placements and recruitment of standardized patients during neurological exam training sessions. Some other proposed strategies included sustained reinforcement of basic sciences during clinical years, and the introduction of novel educational interventions into neurology teaching. However, the ways to mitigate neuro (-anatomy-) phobia, have not been discussed. A recent review of the impact of neuroanatomy teaching tools on learning has highlighted the need to consider new technologically advanced tools for neuroanatomy learning (Arantes et al., 2018). The results from this study, to our knowledge, have provided for the first time a students' (medical and neuroscience) perspective about existing neuroanatomy web-resources and have suggested ways to improve the online learning design to help address the three major problems underlying the prevailing neuro (-anatomy-) phobia, namely, the innate complexity of neuroanatomy, lack of understanding of its clinical relevance and difficulty visualizing the inter-relationships of neuroanatomical structures (Javaid et al., 2018).

A methodical approach was adopted for the selection of neuroanatomy web-resources for evaluation by educators and students. An initial broad scale assessment of existing resources identified 22 tools from which 10 were selected for review by an anatomy educators' panel. From this panel, the top 3 resources were selected for student evaluation. While students' opinion is of paramount importance, the significance of the expert-opinion cannot be undermined either. For instance, students did not consider the authenticity of the information to be important, whereas some of the educators and the author MJ found that references / bibliographies had not been employed in some instances, with one of the resources offering a hyperlink for selling its neuroanatomy textbook, raising questions about authenticity and potential information biases.

Overall, the students' results show that resource A has been ranked and valued the best by the students and the majority stated that it enhanced their interest in learning neuroanatomy. The educators also rated resource A highest in 4 out of 6 categories when evaluating a list of 10 resources. Although resource A was ranked 2nd highest by MJ, immediately behind resource B, the difference between their overall scores was relatively small. Overall, the three top-ranked resources were similar in both MJ's and educators' evaluation, adding validity to the web-resources' evaluation and selection process for student evaluation.

Innate Complexity of Neuroanatomy

Integration of new information into existing knowledge is dependent upon the neuronal computations, which can be actively processed by the working memory. Although the intrinsic cognitive load imparted by the inherent difficulty of the topic remains unalterable, the extraneous sources of cognitive load associated with the manner in which the information is presented can be influenced by the instructional design, thereby directing mental effort towards mental scheme construction (Young et al., 2014). In this context, the results suggest that students prefer easy, simple explanation of facts avoiding unnecessary detail, as reflected in the thematic analysis. Resource A was rated highest for clarity of explanation. The learning modules incorporated in this resource, provide simple explanations for neuroanatomical facts that are brief, compact and to-the-point, while resources B and C provide lengthy, text-based explanations. The anatomy educators' results have further supported this evidence as content presentation and interface features were overall rated best in resource A. These included the content layout, user-friendliness of the interface, aesthetic appeal of the resource, language used, accessibility to the resource. Thus, highlighting the importance of aesthetics and content-formatting in decreasing extrinsic cognitive load (Parrish, 2009).

The thematic analysis revealed that students favor an instructional design in which the information is conveyed in a step-by-step manner facilitating a gradual and incremental increase in their knowledge. This allows the learner to consolidate a mental scheme before adding further information. In this manner, the overall mental load remains within the confines of the working memory capacity of the learner at every learning stage. Resource A had incorporated multiple slides into its neuroanatomy learning modules. Each new slide offering incremental information, which was serially linked with the preceding one, thus giving students the opportunity to assimilate the learnt-content in a gradual, systematic manner whereas the latter two resources had the entire content condensed into one text document, making learning less accessible.

Although, all three resources put emphasis on the key elements of the spinal pathways at the start, students ranked resource A the highest. Each learning module in resource A was designed around a specific neuronal pathway, with each slide highlighting the location and description of that pathway within the respective cross-section of the CNS illustrated. This may have systematically rendered a greater emphasis on the value of learning the key principles. The educators' results have provided support to the students' opinion, as all 5 educators considered that both resources A and B had provided useful learning outcomes for learning the neuroanatomy of the spinal pathways (data not shown). We propose that the key principles should be highlighted at the beginning (within the learning outcomes) to be used as a guideline during the entire learning process. For instance, in the case of the spinal neuronal pathways, such a grid of key principles could serve as a screening guideline for the reader to ensure that he / she has not skipped important details at each learning level.

The ability to control the pace of one's own learning and to choose the level of detail in an instructional resource enables the learner to custom-titrate the intrinsic cognitive load to his working memory capacity. The results show that students felt that resource A offered the maximum flexibility in controlling the pace of instruction while educators reported that resources A and C offered appropriate learner-control features. Students also thought that both resources A and B were equally more effective in providing varying levels of detail to the learners. In this 'adaptability-context', the educators partly shared students' opinion, by acknowledging the fact that resource B provided custom / individualized test and quizzes to the learners. The authors' analysis highlighted that online quizzes were offered by all 3 resources, however, strictly speaking none offered an individualized learning database, instructions and feedback which were specific or adaptable to each learner. The discrepancy between students', educators' and authors' opinion in this regard probably reflects differences in the interpretation of the questionnaires.

In recent years, medical schools are increasingly incorporating integrated and contextual learning models into their curriculum design (Gülpinar et al., 2015), while remaining aligned with core syllabus (Moxham et al., 2015). With regards to the neuroanatomy of the spinal pathways, results show that the students rated resource A highest in terms of integrating the basic neuroanatomical facts with relevant neurophysiology (horizontal integration) and neuroradiology (vertical integration), allowing users to draw upon and integrate information from cognate disciplines to consolidate their mental scheme. Previous findings by our research group also showed that medical and other health care disciplines students reported that case-based teaching increased their interest in neuroanatomy (Javaid et al., 2018). As horizontally and vertically integrated curricula are implemented in health sciences education programs, supporting resources reflecting this process will provide added benefit to the users.

Repetition was one of the themes identified from the qualitative analysis. The summary sheets or tables and the online quizzes offer a chance to revise the same material but in a different yet similarly applicable context, thus offering the learner added familiarity with the material and reducing the perceived complexity of the topic. Students reported that resource A best employed the summary sheets to help them learn neuroanatomy.

Resource A best employed various learning tools, such as, cross-sectional images, CT and MRI, animations and videos and 3D digital computer models to help students learn neuroanatomy of spinal pathways. The effective usage of animations and neuroradiological images of MRI and CT to help learning neuroanatomy was also acknowledged by the educators`. These tools may play a dual role in providing a multimodal format to access information and providing a diverse source of information therefore maintaining the learner's interest, making resource A more effective in helping students learn neuroanatomy. In the context of instructional design, this diversification of information must be used with caution to avoid increasing cognitive load beyond the benefits achieved by its introduction.

Enhancing Learning with Clinical Contextualization of Basic Neuroanatomy

Previous results from our group have shown that clinical year students prefer a clinically oriented mode of neuroanatomy learning over dissection-based teaching (Javaid et al., 2018). The use of clinically relevant or case-based neuroanatomical information in online web-resources has been shown to significantly improve assessment scores (Svirko and Mellanby, 2017), promote active student engagement (Javaid et al., 2018) and reduce difficulties associated with neuroanatomy learning (Hudson, 2006). A positive correlation observed between the provision of clinical neurology clerkships for students during medical training and the number of students opting for neurology residency programs (Albert et al., 2015), together with the positive perception of general practice residents towards an intensive clinical neuroanatomy course (Arantes et al., 2017), suggest that students and general practitioners value clinical neurological exposure during training and could enhance their interest in neurology.

The results from the current study show that the fact, that the incorporation of neurological problem-solving, such as localization of lesions for sensorimotor deficits, contributed to the overall higher score of resource A. Quiz questions in resource A inquired about the clinical localization of neurological lesions, and thus required the learners to exercise a higher-level understanding and application of neuroanatomical facts, providing consolidating usage of acquired knowledge. The anatomy educators' evaluation provided supportive evidence by showing that all 5 educators believed that neuroradiological videos and images and videos of neurological examination had been effectively employed by resource A to explain clinical relevance of the spinal pathways' anatomy. The usefulness of clinical case-based learning in e-resources can be further enhanced through offering increased student-interaction opportunities using online social platforms and learning management systems. Such team-based learning instructional design strategy has been shown to enhance students' performance in summative assessments for complicated subjects, such as, neuroanatomy (Anwar et al., 2015).

The current study provides a wider students' perspective from medical as well as neuroscience students. The themes identified from the participants' opinion have shown that clinical correlation of basic science facts was appreciated by undergraduate medical students but that the neuroscience students did not report increased usefulness over other methods. This dichotomy in opinion could be attributed to the clinical / non-clinical orientation of the two education programs.

Visualization of Complex Inter-Relationships of Neuroanatomical Structures

Previous results from our group have shown that the students have difficulties visualizing the three-dimensional orientation and inter-relationships of sensory and motor white matter tracts (Javaid et al., 2018). The thematic analysis from the current study has shown that students supported a wide array of digital pedagogical tools to learn the complex inter-relationships and gain better spatial orientation of neuroanatomical structures. The results suggest that better incorporation of various digital tools, such as, videos and animations, diagrams, illustrations, cross-sectional and neuroradiological images and pictures of prosections – all contributed to the overall highest score of resource A. Future instructional designs should employ these to better visualize and emphasize 3D neuroanatomical relationships.

Ranked-order lists of anatomy and neuroanatomy resources have been made in the past, however, these were not specific to neuroanatomy (Kim et al., 2003) and were not comprehensive (Sharrow, 2015). The present study formulates a comprehensive list of neuroanatomy web-resources, based on a criterion rooted in the principles of cognitive and adult learning theories and web-user interface features, bridging a gap in the literature and providing a referential framework for ranking and selecting online content for incorporation into neuroanatomy curriculum.

Limitations of the Study

There are limitations of the study which could be addressed in the future. Firstly, further validation of students' perception needs to be acquired by conducting the survey in other institutions to cater for a potential institutional-bias and smaller sample size. Secondly, larger sample sizes in the future will help to decipher differences in opinion between student groups. Thirdly, participants' spatial ability should be gauged to cater for its potential confounding effect in students' opinion on three-dimensional visualization of neuroanatomical pathways. Finally, the current list of neuroanatomy web-resources needs to be revised on a continuous bass to cater for the updates offered by the e-learning resources.

Conclusion

In conclusion, this study has identified specific web-resource features that are freely available and highly rated by anatomy educators and students. Various themes and features have been identified which have further informed the conceptual framework. These could be incorporated into the instructional design of future online learning tools in the context of learning neuroanatomy of the spinal pathways. For instance, presenting the intricate concepts in a clear, simple fashion, while avoiding lengthy explanations, could avoid information overload. This could further be achieved by presenting information in bite-sized by following a step-wise teaching design, allowing students to have control over the pace of instruction and enhancing 3D visualization of complex neuroanatomical spatial relationships. Active student engagement should be encouraged through quizzes, interactive exercises and social interaction with peers on online platforms. A horizontally and vertically integrated curriculum with clinical correlates could offer better contextualization of information to motivate the students. moreover, a multimodal pedagogical approach may help to address varying learning styles. This may increase student interest in learning the topic, which could contribute to reduce their perceived complexity of neuroanatomy and enhance performance in examinations.

CHAPTER 4

Neuroanatomy of the Spinal Pathways: Development of an Interactive Multimedia E-Learning Resource

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Abstract

Neuroanatomy has always been considered the most challenging component of anatomy curriculum. The lack of understanding of basic neuroanatomical concepts during the early medical undergraduate training has rendered medical students and young doctors extremely ill-equipped to clinically apply these concepts during their hospital rotations for managing neurology patients. The situation becomes even more challenging amid the ongoing motion to reduce the on-campus teaching hours for lectures and lab-rotations, thus further limiting the efficacy of these traditional pedagogical modalities.

In the above-mentioned context, the online learning resources could act as very useful supplementary teaching aid. This study describes the development of a novel, interactive, neuroanatomy learning e-resource developed at University College Cork (UCC). Its instructional design has been informed not only by the theories of cognitive load, adult learning and Mayer's theory of multimedia learning but also by students' and educators' opinions regarding the instructional design of online neuroanatomy resources, acquired in our earlier work. The neuroanatomy e-tool was created using Microsoft PowerPoint™ 2017. The corticospinal motor pathway and the dorsal column medial lemniscal sensory tract were selected as sample-topics to design the online tool.

The tool provided information on spinal pathways through a dynamic, interactive, step-by-step incremental learning approach coupled with a discussion of the clinical interpretation of basic neuroanatomical facts to aid in neurological localization, with the aim of enhancing

students' knowledge of neuroanatomy and reducing their fear of managing neurology patients in the future.

Keywords: Neuroanatomy, anatomy, medical education, computer assisted learning, neurophobia.

Introduction

The anatomical sciences have been traditionally taught through conventional lectures coupled with exploration of anatomical spatial relationships through cadaver dissection or visualization of human prosections. The task of grappling with a gigantic lexicon of anatomical terminologies and concepts and registering an innumerable number of spatial relationships to memory is daunting in itself. The job becomes even more arduous when it comes to learning neuroanatomy, as it is difficult to appreciate the complex relationship between overlapping neuroanatomical structures within the tight confines of the cranial cavity. Many of the structures are impossible to visualize with the naked eye, including the nuclei and the neuronal tracts. Consequently, students and doctors find it difficult to study neuroanatomy (Martin et al., 2014, McCarron et al., 2014), with spinal pathways being the most difficult topic to learn (Javaid et al., 2018).

In the context of availability of a wide array of neuroanatomy e-learning resources and the natural propensity of the millennial students to use the online tools, e-learning resources can serve as valuable supplementary teaching aids to help students learn the otherwise abstract concepts of neuroanatomy (Hamza-Lup et al., 2009). However, despite the abundance of online resources, the neuroanatomy-phobia persists and students and doctors lack confidence in learning neuroanatomy and applying the basic neuroanatomical concepts to clinical neurological situations (Flanagan et al., 2007; Youssef, 2009; Sanya et al., 2010; Zinchuk et al., 2010; Matthias et al., 2013; McCarron et al., 2014; Pakpoor et al., 2014; Javaid et al., 2018). This calls for a review of the instructional design of existing online neuroanatomy resources.

Javaid and colleagues acquired a users' perspective regarding what the students considered useful in an online neuroanatomy learning resource (Javaid et al., 2019). In the context of the users' opinion and the recommendations set forth by the theories of cognitive load (Paas et al., 2003; Paas et al., 2004), adult learning (Cercone, 2008) and Mayer's theory of multimedia learning (Mayer, 2003), we describe the development of an interactive neuroanatomy e-resource for learning the spinal pathways. The tool was developed in the Department of Anatomy and Neuroscience at University College Cork (UCC), Ireland.

The motor and sensory spinal pathways were selected as the topics of choice to model the online learning tool. The topic selection was based on the results of our previous study which identified the spinal pathways as the most difficult component of the neuroanatomy curriculum by undergraduate medical and health-sciences' students (Javaid et al., 2018).

To date, an interactive resource which offers an active or hands-on opportunity to students to learn neuroanatomy of the spinal pathways in detail is missing. Spinal neuroanatomy modules by the University of Utah offer a very simplistic visual enumeration of the neurons along the course of spinal pathways with quizzes and immediate feedback (http://bit.ly/UniOfUtah). The detail offered by the neuroanatomy modules developed by the University of British Columbia (Krebs, 2016 - http://bit.ly/UBC-Neuro) falls short of what is required at the medical undergraduate level (Moxham et al., 2015). Moreover, the clinical interpretation of the basic neuroanatomical facts to aid in neurological localization has not been discussed. The novel interactive UCC e-resource for learning the spinal pathways has been designed to overcome the limitations of the existing resources.

Materials and Methods

A novel, self-learning neuroanatomy tool was created using Microsoft PowerPoint™ 2017 (Microsoft Corp., Redmond, WA). The corticospinal motor tract (CST) and the dorsal column medial lemniscal sensory pathway were selected as topics to design the online tool.

Screen Layout

The layout of the PowerPoint™ screen was divided into two sections; a Study Pad section (left half of the screen) and an Interactive Sketch Pad section (right half of the screen). Initially, the information regarding the topic is provided to the learner in the Study Pad while the Interactive Sketch Pad offers an opportunity to revise the same information by prompting the user to actively trace the course of the neuronal tracts. Both regions of the screen are simultaneously visible to the learner, at all times.

Insertion of Action Buttons

Various action buttons were inserted to systematically interlink the slides as part of the tool design (Figure 4.1).

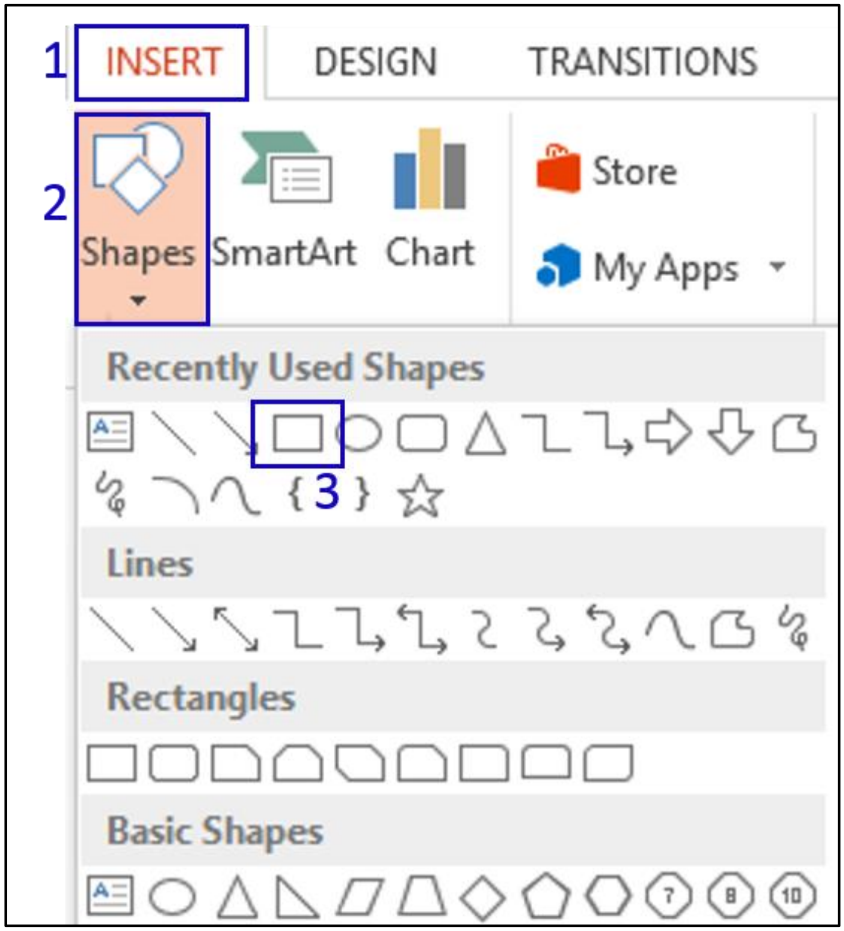

Figure 4.1: Steps undertaken to insert an action button. The Insert tab was selected (1), followed by clicking the. Shapes icon (2). A shape (e.g. rectangle) was picked (3) and inserted into the desired location in the PowerPoint™ screen. It was subsequently formatted for its shape, color, margins (beveled) and labels to impart a button-like appearance to it (using the 'Format tab' and 'Shape effects' options).

Each action button is programmed to carry out a specific function allowing users to navigate between the screens (or slides) in an interactive and structured fashion (Figure 4.2).

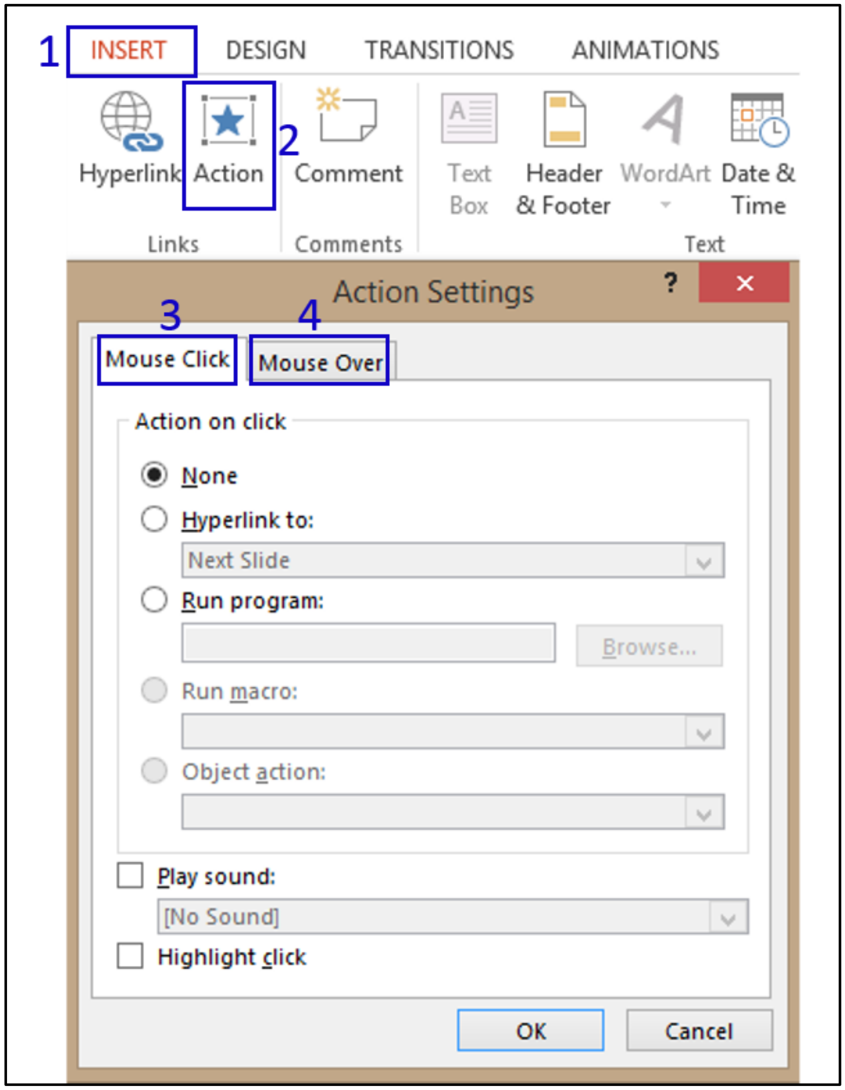

Figure 4.2: Step undertaken to program action settings for a button. The Insert tab was selected (1), followed by choosing the. Action button (2). The action settings were employed to program each action-button to carry out a specific function when clicked (3) or when the mouse is hovered over it (4). Hyperlinks were inserted into the button to program it to navigate to the appropriate location in the module when clicked. Appropriate sounds were also added to the action buttons.

The modules for the corticospinal and dorsal column pathways, each begin with a tutorial window, describing various sections of the screen layout and explaining the functions of the navigation buttons (Figure 4.3).

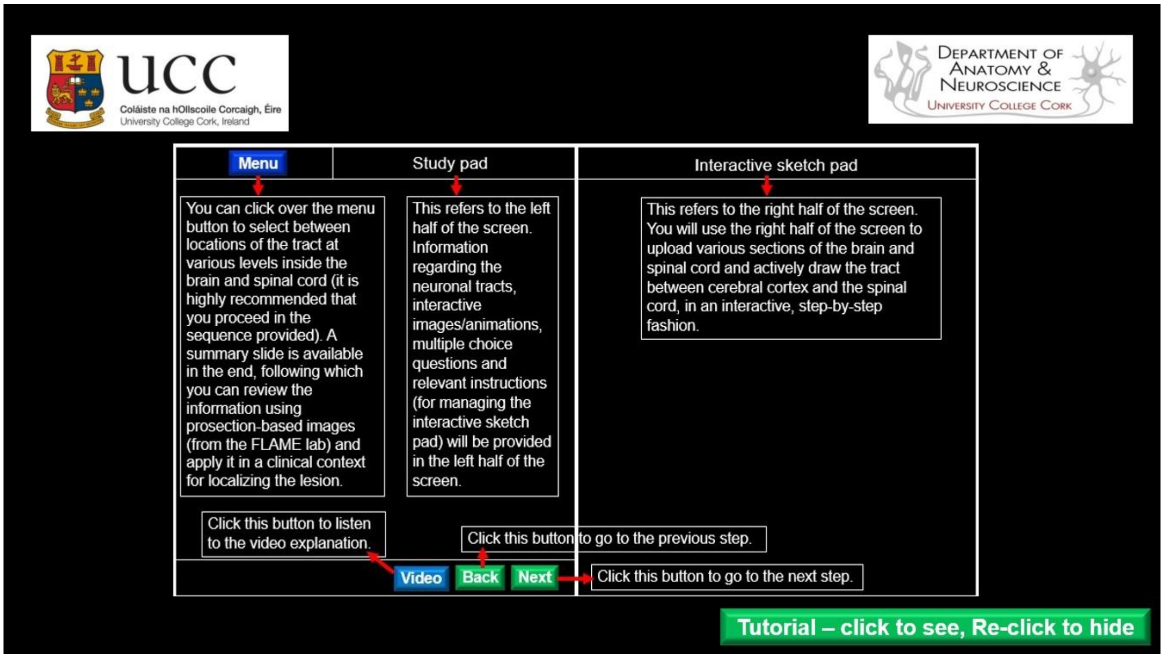

Figure 4.3: Tutorial window. A tutorial window emerges upon clicking the tutorial button available in the beginning of the interactive learning module (right lower corner). It explains functions of action buttons employed for navigation and the learning activity which can be exercised in the Study pad and the Interactive sketch pad regions of the PowerPoint™ screen.

A Menu button provides a drop-down list of the various learning stations of the CNS (Figure 4.4). Each learning station in the e-resource corresponds to a specific axial section of the brain or the spinal cord along the course of a spinal tract. The user learns the course of the entire neuronal pathway by actively studying its anatomy at each of these learning stations. The user has the freedom to jump between various stations to revisit the material using the menu-list, however, within each learning station, the screens are sequenced and interlinked in a way which makes it mandatory for the user to scroll through them in a structured pattern; originally configured by the author. Hence, imparting a combination of user control as well as some degree of structure to the instructional design of the learning module.

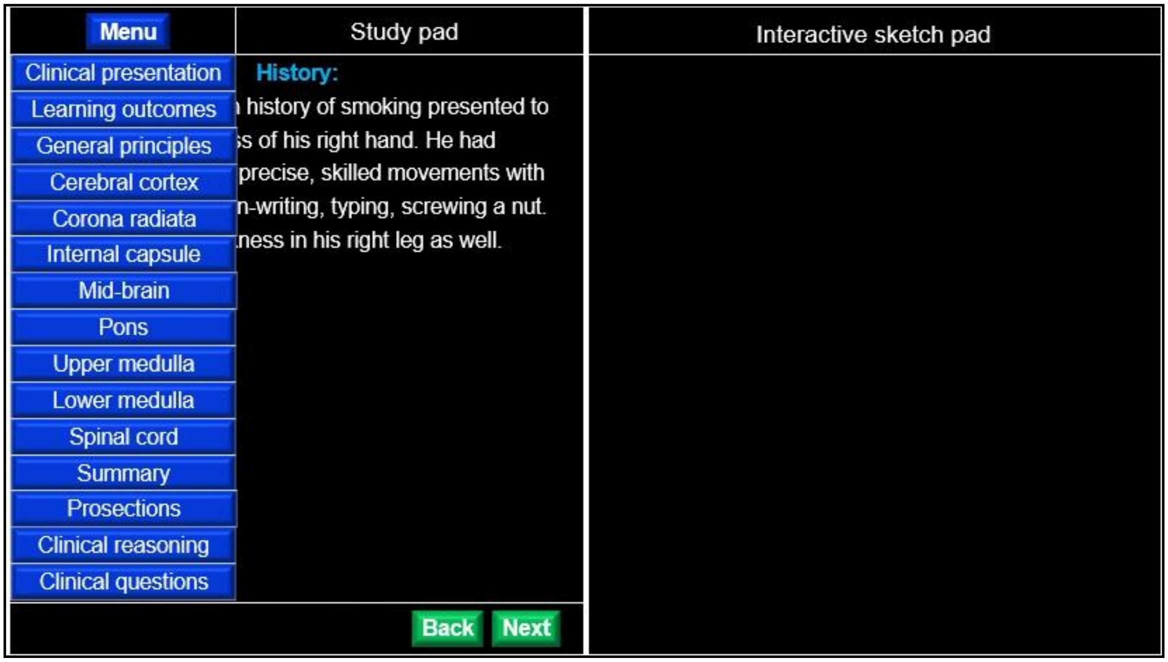

Figure 4.4: Action-buttons and the menu-list. Clicking over the ‘Back’ button enables the user to jump to the previous relevant interlinked screen. While clicking over the ‘Next’ button enables user to jump forward to the next relevant interlinked screen. Clicking over the ‘Menu’ button reveals a drop-down list of learning stations, representing various axial sections of the brain and spinal cord along the course of the spinal tract.

Sequence of Presentation of Screens

The sequence of presentation of screens within each learning level follows a specific and consistent pattern to render the user-interface and instructional design intuitive to use for the learner. In the case of the corticospinal motor tract, the first learning-station (the cerebral cortex) commences with a text-based description about the origin and location of the tract. (Figure 4.5).

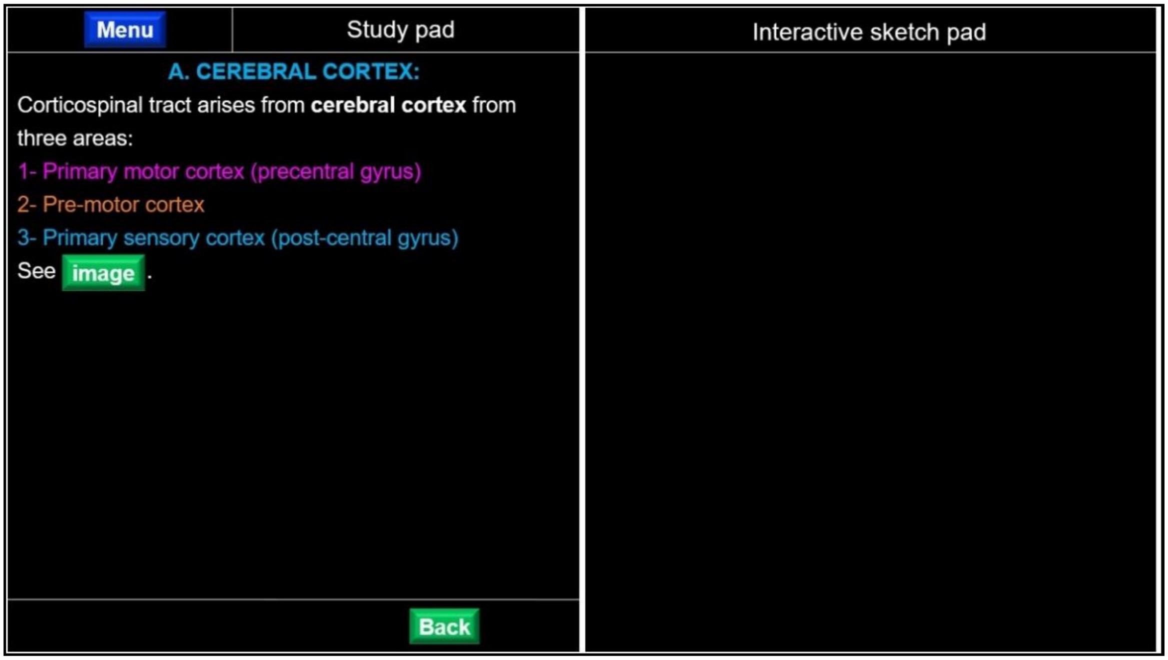

Figure 4.5: Text-based description of the cortical origin of the CST. Each learning station (in the drop-down menu list) commences with a PowerPoint™ screen containing a text-based description of the three areas of origin of the CST on the cerebral hemisphere. Clicking over the image button directs the user to the subsequent screen, containing an interactive image of the cerebral cortex.

The image button within the text, directs the user to a subsequent screen, containing an interactive image of the CNS for that level (Figure 4.6). Since, there is no other action button on the text screen, other than the image button, therefore, the learner does not have any other option except to click over it to proceed further. Such enforced direction of learning to the flow of screens adds structure to the instructional design.

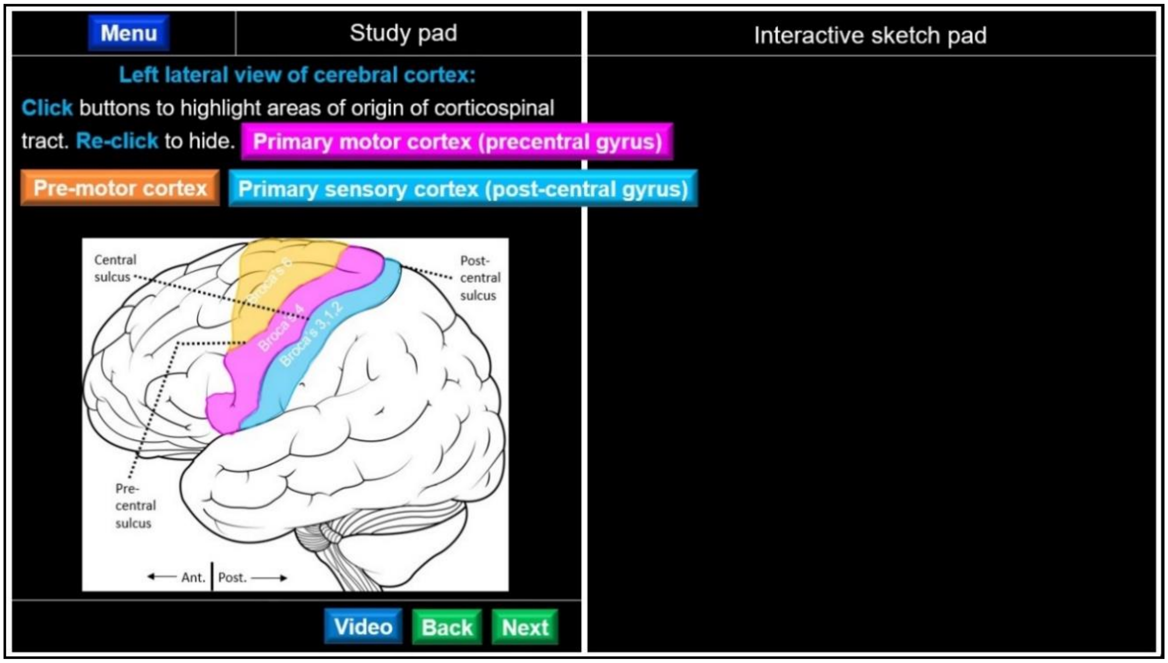

Figure 4.6: An interactive image for the cortical origin of the CST. The three interactive buttons regarding the origin of the corticospinal tract from the cerebral cortex were color-coded in pink for the primary motor cortex, in orange for the pre-motor cortex and in blue for the primary sensory cortex. Clicking over these buttons highlights the relevant areas of origin of the CST on the cerebral hemisphere image. The labelling interactivity provides immediate feedback to the user. A video button (in blue) provides a video based description of the content.

Image Creation and Imparting Interactive Features to Images

Line drawings of the structures were prepared using the image manipulation software GIMP™ (version 2.8.22, www.gimp.org). The GIMP™ image file (of the left lateral view of the cerebral hemisphere) was inserted into the image-screen of the PowerPoint™ presentation. Interactive features were added to the line drawings within the PowerPoint™ software. For instance, the three distinct regions representing the origins of the corticospinal tract, were highlighted and color coded on the image, in relation to their respective action-buttons (Figure 4.6). To achieve this goal, firstly, we selected the ‘Insert’ option from the menu. The Shapes option was subsequently selected and a rectangular shape was overlaid onto the image. The shapes were custom-outlined as per the underlying regions of the cortex, to mark areas of origins of the CST (Figure 4.7).

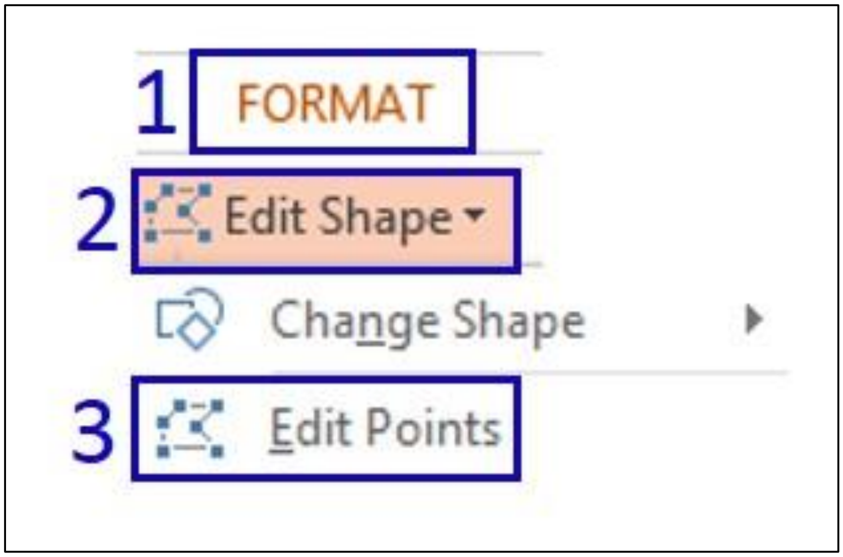

Figure 4.7: Steps undertaken for editing the inserted-shape. The followings were selected: 1. Format option from the menu bar, 2. Edit-Shape option, 3. Edit-points sub-option selected to mold the boundaries and edges of the previously inserted shape (the rectangle) as per the underlying region of the cerebral cortex, which marks the origin of the CST. The process was repeated separately the precentral gyrus, the premotor area and the postcentral gyrus.

Once the shapes were custom-outlined as per the relevant underlying regions of the cortex, animations were programmed into them and the shapes were interlinked with their respective action buttons (Figure 4.8).

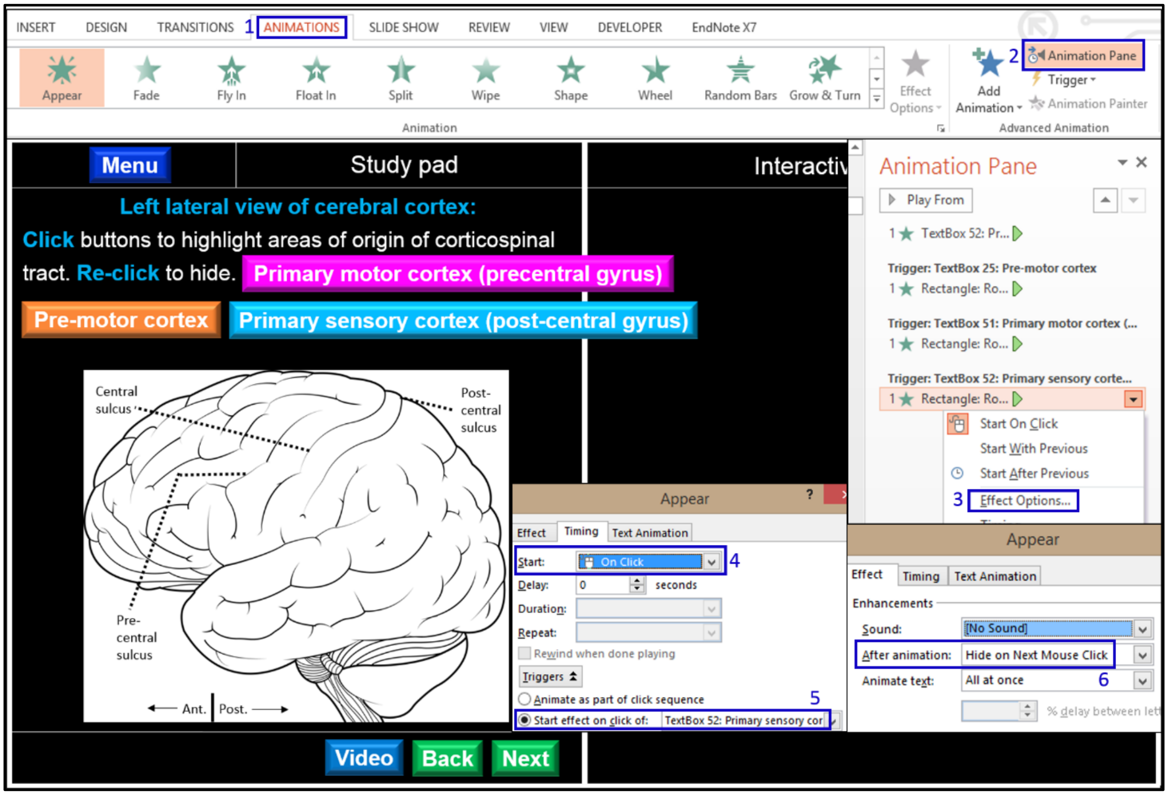

Figure 4.8: Insertion of animation into action buttons. Animation was programmed into each highlighted region on the image marking the cortical origin of the CST, imparting them with a labelling interactivity feature. This interactive animation was triggered by the action buttons (primary motor cortex in pink, pre-motor cortex in orange and primary sensory cortex in blue). To achieve this goal the Animations option was selected from the menu banner (1). Clicking over the Animation Pane (2) and by employing the Effect Options (3) offered a range of techniques to adjust the triggering (4, 5, 6) of animations (appearance / disappearance of highlighted regions) for each button.

Video Button

A video button underneath the interactive image provides a detailed video-based description of the information outlined earlier. The steps involved in the creation of the video file have been described in Figures 4.9 and 4.10:

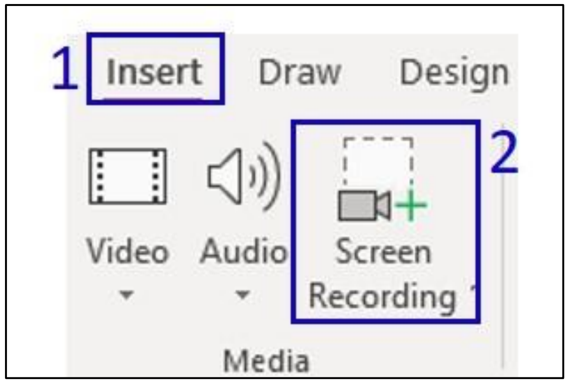

Figure 4.9: Steps undertaken for the video screen recording (part 1). Insert option was selected from the menu banner (1) followed by clicking over the screen recording option (2). This opened a window box containing several buttons related to video screen recording (Figure 4.10).

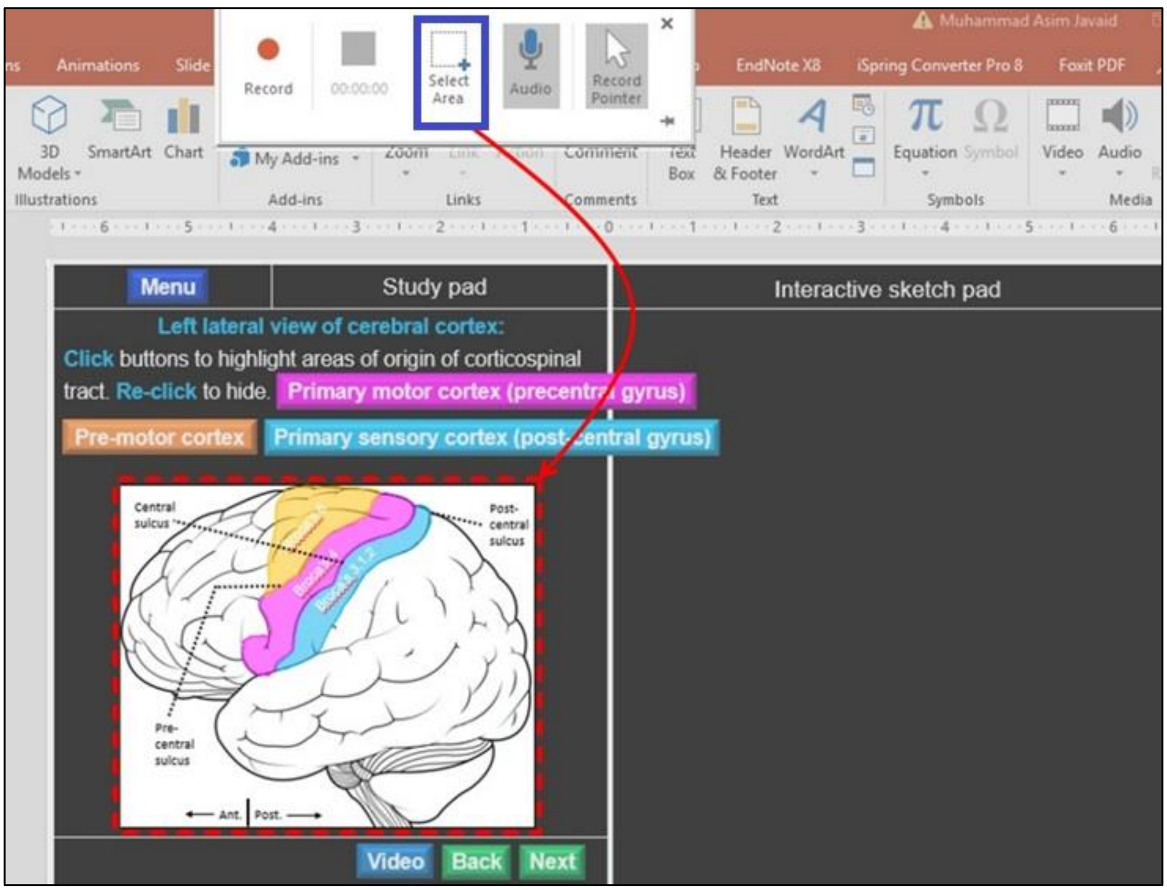

Figure 4.10: Steps undertaken for the video screen recording (part 2). Select Area button was used to delineate the screen area (the image) to be included in the video recording. A microphone was plugged into the laptop for voice recording. The video recording commenced by clicking the (round shaped) red record button. They (square shaped) grey stop button was used to stop the recording.

Clicking the Next button escorts the user to an image of a coronal section of cerebral cortex (Figure 4.11, left). The user can visualize and learn the representation of the human body parts on the primary motor cortical region by using the ‘see homunculus’ button (Figure 4.11, right).

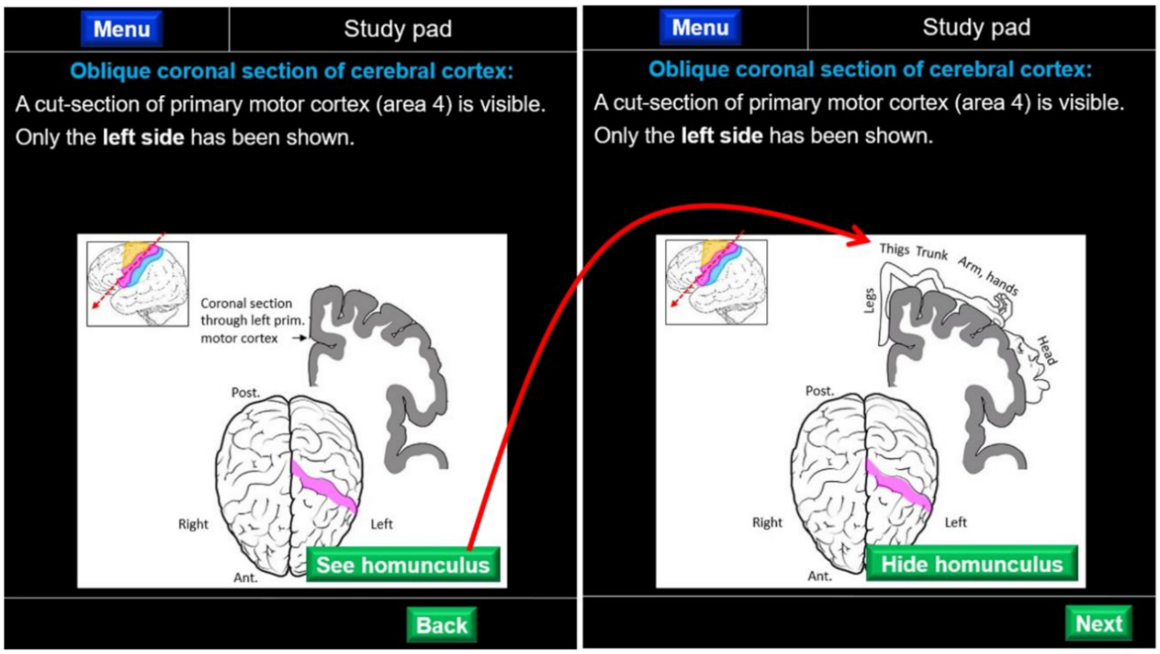

Figure 4.11: Images of coronal sections of the cerebral cortex. The two screens have been shown side-by-side. Clicking over the ‘see homunculus’ button (shown on left) directs the user to the next screen (shown on right) where the motor representation of body parts from head to toe can be visualized on the superolateral and medial surfaces of the cerebral cortex in the primary motor area.

The subsequent slide discusses the blood supply of the cerebral cortex and the difference in neurological presentation resulting from an obstruction of the anterior v. the middle cerebral artery. Clicking individual buttons for the anterior cerebral artery (ACA) and the middle cerebral artery (MCA) highlights the areas of blood supply for these vessels, while re-clicking removes the highlighting. Such on/off clicking provides immediate feedback to the learner (Figure 4.12, Table 4.1).

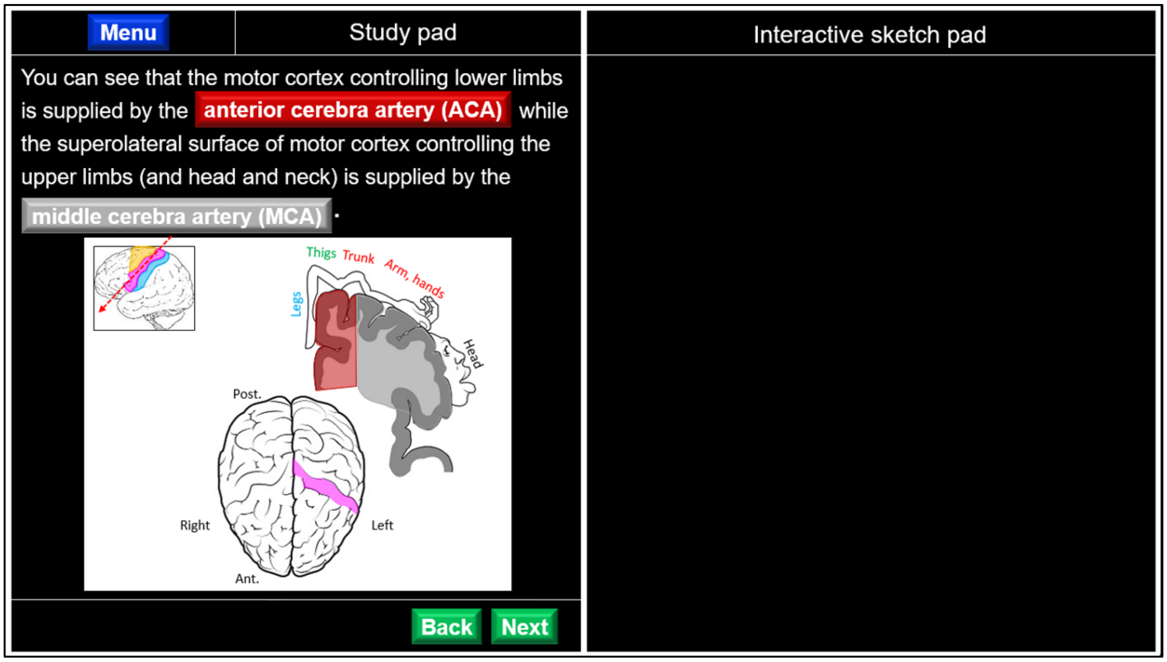

Figure 4.12: Cortical blood supply on a coronal section of cerebral cortex. The motor representation of body parts from head to toe on the superolateral and medial surfaces of the cerebral cortex in the primary motor area is called motor homunculus. The upper trunk, upper limb and head and neck regions are represented on the superolateral cortical surface, which is supplied by the middle cerebral artery MCA (color coded in grey). The lower limbs are represented on the medial cortical surface and a 1 cm wide cortical strip on the medial boundary of the superolateral surface. This region is supplied by the anterior cerebral artery ACA (color coded in red). Hence, a stroke involving each of the two arteries will lead to motor impairments in distinct parts of the body (upper limbs in an MCA stroke while lower limbs in an ACA stroke).

Table 4.1: Link between CF-ONLine, Students' perception and e-Tool design features

Elements of CF-ONLine and Students' perception (Aim 2)	Features of the online neuroanatomy learning web-resource
-Pre-training principle	-Tutorial window, -Key principles explained in the beginning
Reducing extraneous processing	
-Intuitive interface, -Students imparting high importance to the ease of accessibility and usage of content layout	-Action buttons (consistent location, intuitive button-like appearance), -Images (color-coded labels, important words / instructions highlighted)
-Spatial contiguity principle	-Two screens being simultaneously visible (Study pad and interactive sketch pad)
-Learning cycles	-Consistent sequence of presentation of screens within learning stations
-Menu button with a drop-down list of structures	-Site-map provided made navigation easier
Promoting active / deep learning	
-Interactive learning, feedback, reflection, -Students' preference for quizzes and feedback for self-testing	-Interactive on / off labelling -Interactive sketch pad (actively tracing the neuronal pathway) -Quizzes with feedback explanation
Managing essential processing for innately complex neuroanatomy	
-Guided self-learning, catering for individual learning differences, motivation for the learner, SDT (imparting autonomy)	-User control through Menu/site-map, navigation buttons), but also having a structure to the structure
-Needs assessment for motivation, enhancing interest, -Students' preference for concise clear instruction	-Clear articulation of intended learning outcomes / objectives
-Segmenting principle, sequential learning, -Students' preference for step-by-step learning	-Multiple linked-slides in the module offering incremental increase in knowledge
-Contextualization, Motivation, SDT (imparting relevance), -Students' perception of interest-enhancement with clinical correlation	-Module starts with clinical scenario, -Clinical reasoning offered at end for lesion-localization along spinal pathways and course of facial nerve
-Catering for individual learning styles	-Multimodal content presentation (text, videos, prosections), -Greater user-control
-Repetition and revision	-Opportunity to learn information via text-based screen, followed by video description and interactive quizzes and feedback, which proceeds further with active tracing of neuronal pathway and summarization at the end accompanied with revision opportunities through prosection-images
-Personalization principle	-Conversational language of the text and videos (to enhance user-interest and foster generative processing)

CF-ONLine = Conceptual framework for online neuroanatomy learning, SDT = Self-determination theory,

Quiz Section

A quiz section follows each learning phase / level (Figure 4.13). Each question commences with a brief clinical scenario before assessing the user on an important neuroanatomical fact taught during the same learning phase. The user is required to choose between two or three options. Selecting the correct answer provides immediate feedback along with a detailed description. While selecting the incorrect answer prompts the user to 'Try again' by being redirected to the original question.

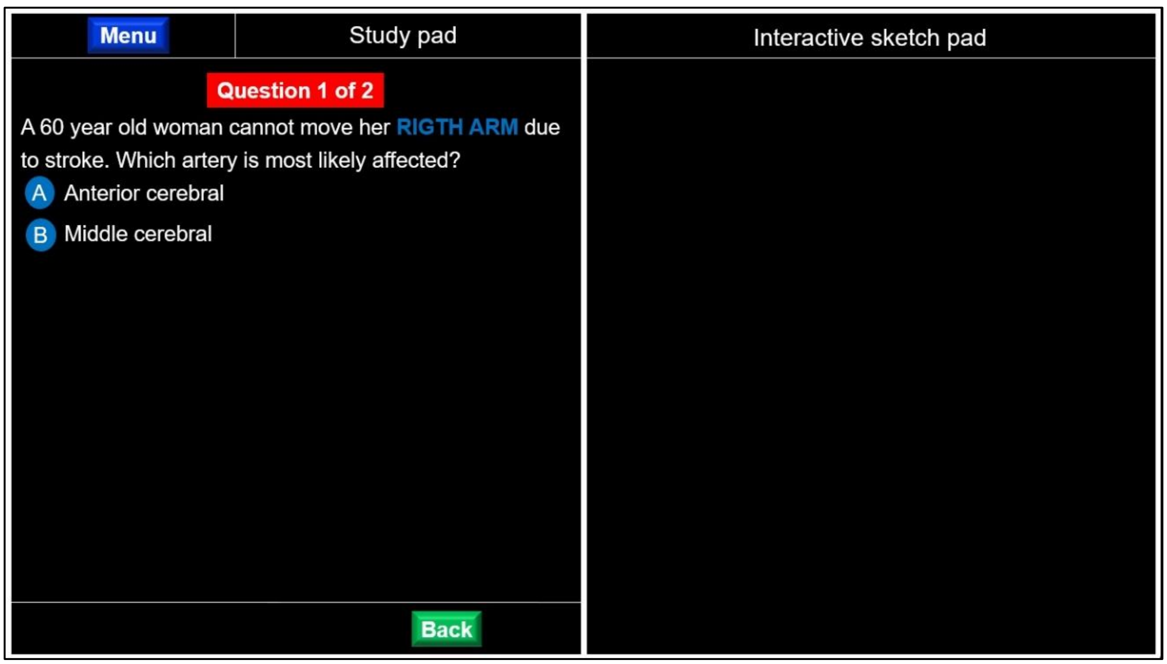

Figure 4.13: Quiz regarding cortical blood supply and motor homunculus. A quiz section follows each learning station. Selecting the correct answer (option B) provides immediate feedback regarding reasons behind the option B being correct and option C being incorrect. Selecting the incorrect answer (option A) prompts the user to 'Try again'.

Interactive Exercise

Each learning station ends with an interactive exercise which requires the learner to actively trace the pathway of the neuronal tract inside the Interactive Sketch Pad (Figures 4.14, 4.15).

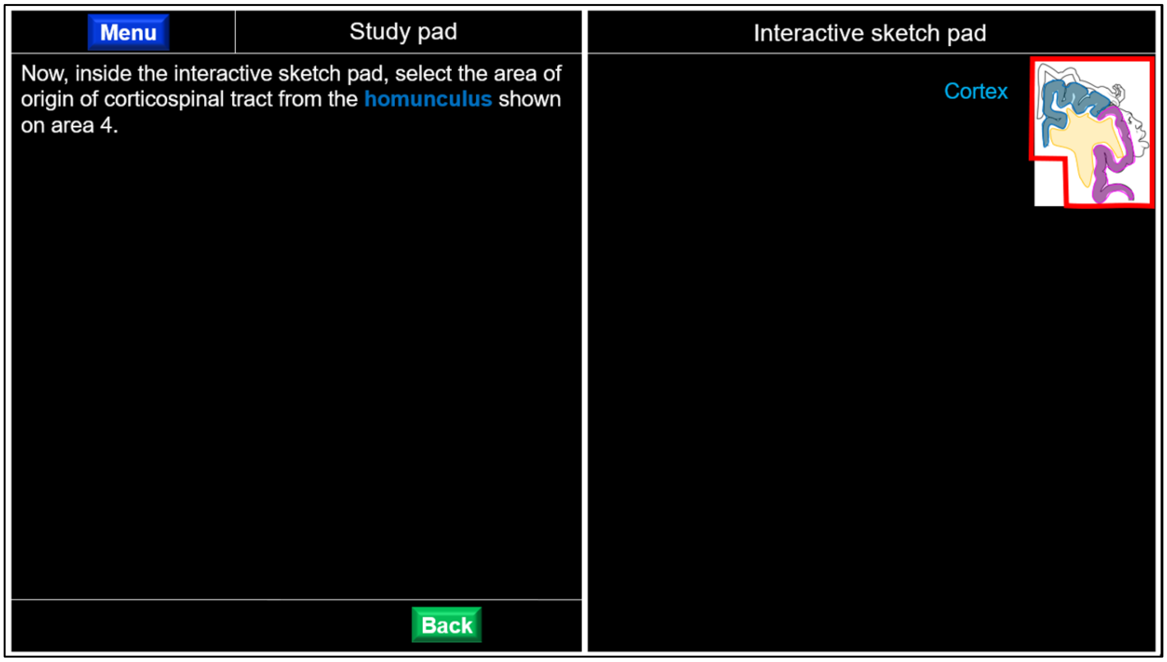

Figure 4.14: Interactive exercise component of cerebral cortex learning station. The learner is required to upload coronal cross-section of the cortex into the interactive sketch pad. The user is then asked to click over the area of origin of corticospinal tract within the uploaded image. A correct selection directs the user to the next learning level, that is, the corona radiata and internal capsule, while a wrong selection provides immediate negative feedback and prompts the user to try again.

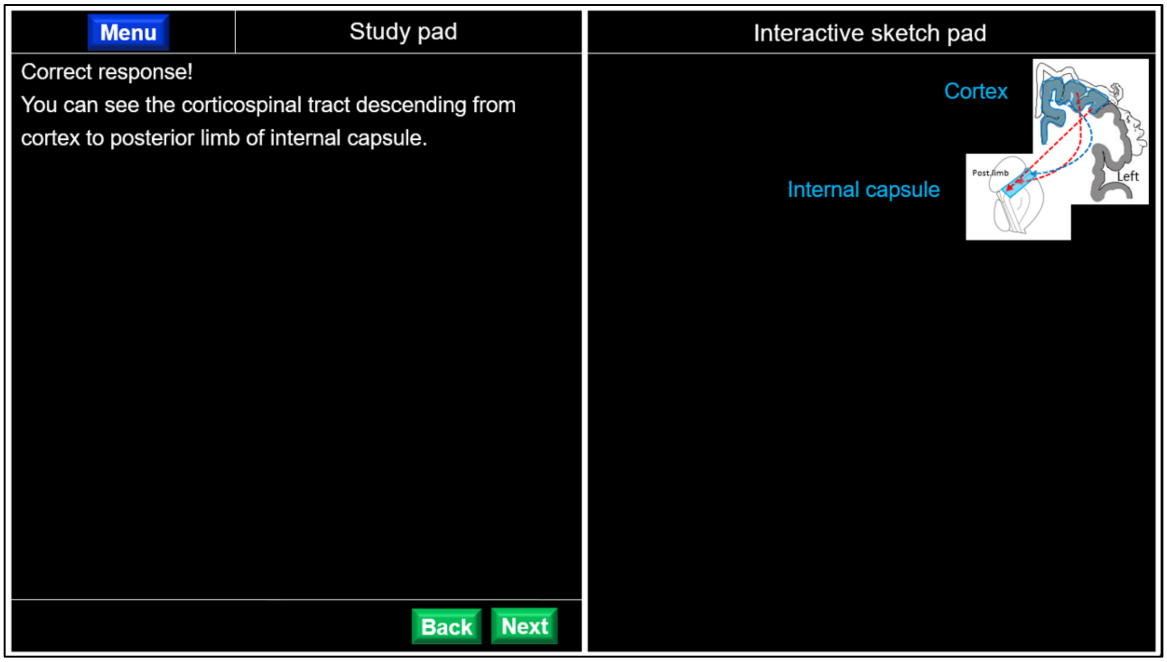

Figure 4.15: Interactive exercise component of the internal capsule learning station. The user is required to upload a horizontal section of the internal capsule and surrounding deep nuclei, inside the interactive sketch pad. The learner is then assessed by being asked to select the location of CST on the horizontal section. A correct selection automatically traces the pathway of the tract by connecting its preceding location (in the cortex) with its location in the horizontal section the internal capsule (posterior limb). The user is subsequently directed to the next learning-level, that is, the mid-brain. On the contrary, a wrong selection regarding location of the tract in the internal capsule provides immediate negative feedback and prompts the user to try again.

Additional learning levels which follow the cerebral cortex, include corona radiata, internal capsule, crus cerebrum (of midbrain), ventral pons, medulla oblongata and the spinal cord. The sequence of PowerPoint™ screens is consistent within each learning level to make learning intuitive and to reduce the extrinsic cognitive load (Table 4.1). Once all learning stations have been completed, the learner has actively traced the entire corticospinal tract inside the interactive sketch pad. It is then followed by a summary of the tract (Figure 4.16).

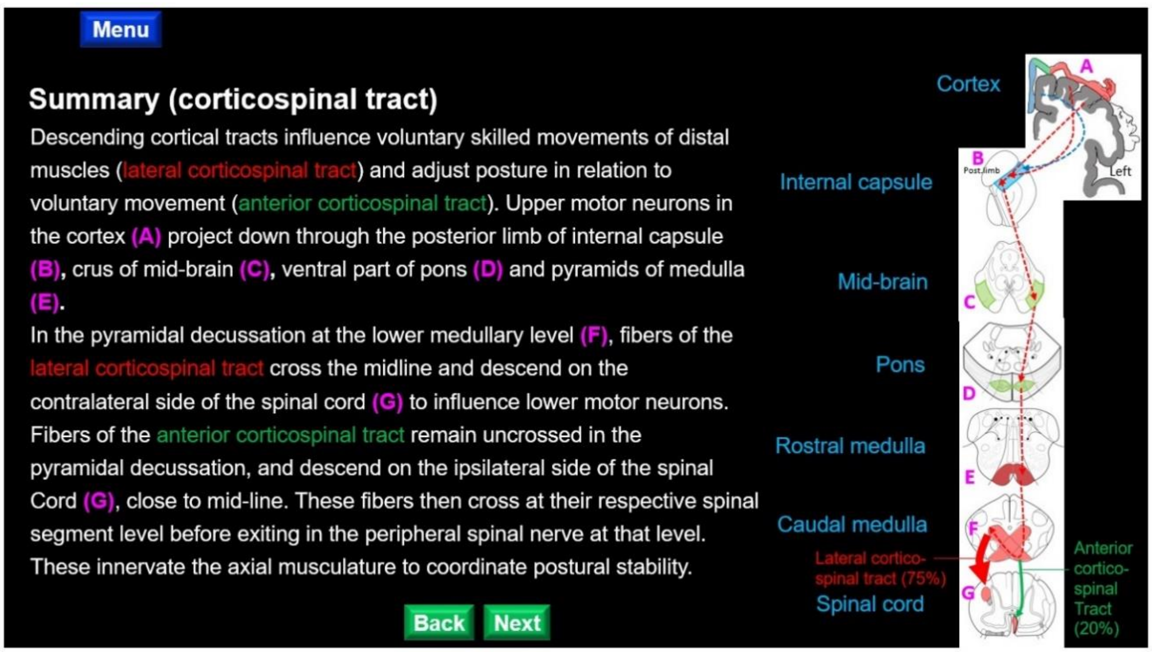

Figure 4.16: Summary of the corticospinal pathway.

Review of the Corticospinal Tract through Prosection Images

The locations of the CST at various levels of the CNS (from the cortex to the medulla oblongata) was reviewed by visualizing the location of the tract on illustrative images and prosection photographs, simultaneously. The images of prosections, had been acquired from the cadaver specimens in the anatomy laboratory at the institution. An example from the cerebral cortex has been given below (Figures 4.17).

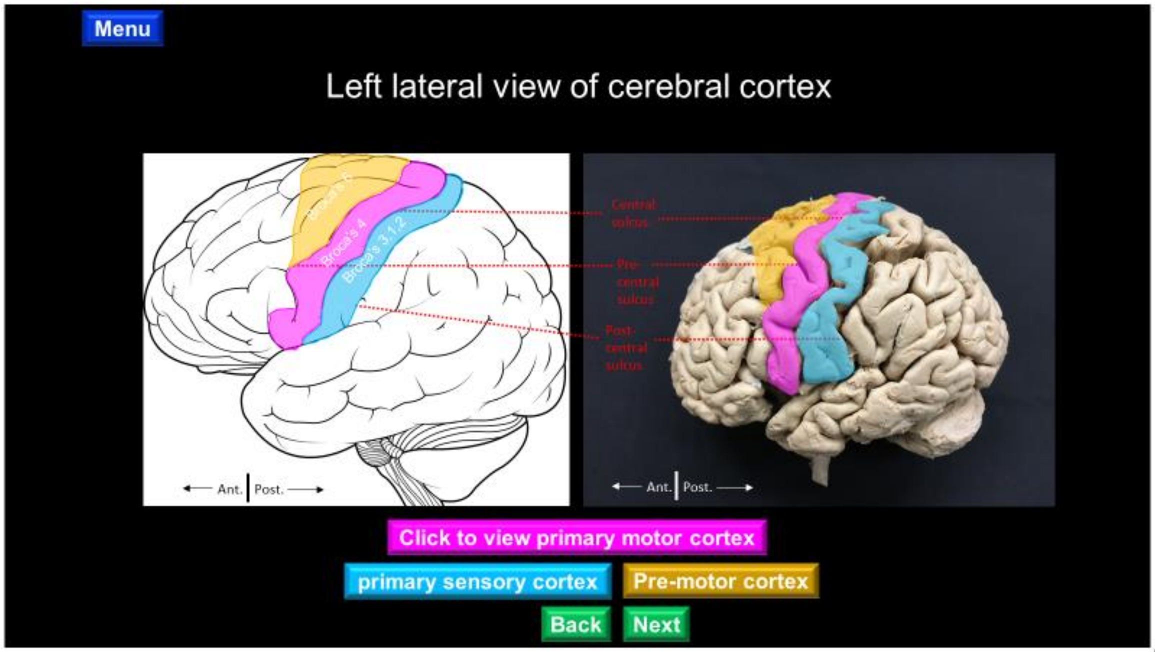

Figure 4.17: Left lateral view of cerebral cortex. The areas of origin of the CST has been shown on the illustration of the left lateral cerebral hemisphere (left) and on the cortical surface of a brain prosection (right). Clicking over the buttons (for primary motor cortex, primary sensory cortex and pre-motor cortex) simultaneously highlights these areas on the illustration and the prosection photograph, providing immediate feedback to the learner with on / off labelling. The buttons and cortical areas of origin of the CST have been color coded with pink (for primary motor cortex), blue (for primary sensory cortex) and yellow (for pre-motor cortex).

Clinical Correlates of Spinal Pathway

A clinical interpretation of the neuroanatomy of the entire pathway in the context of localization of neurological lesion is discussed at the end (Figures 4.18-4.20), followed by additional multiple-choice-items for practice.

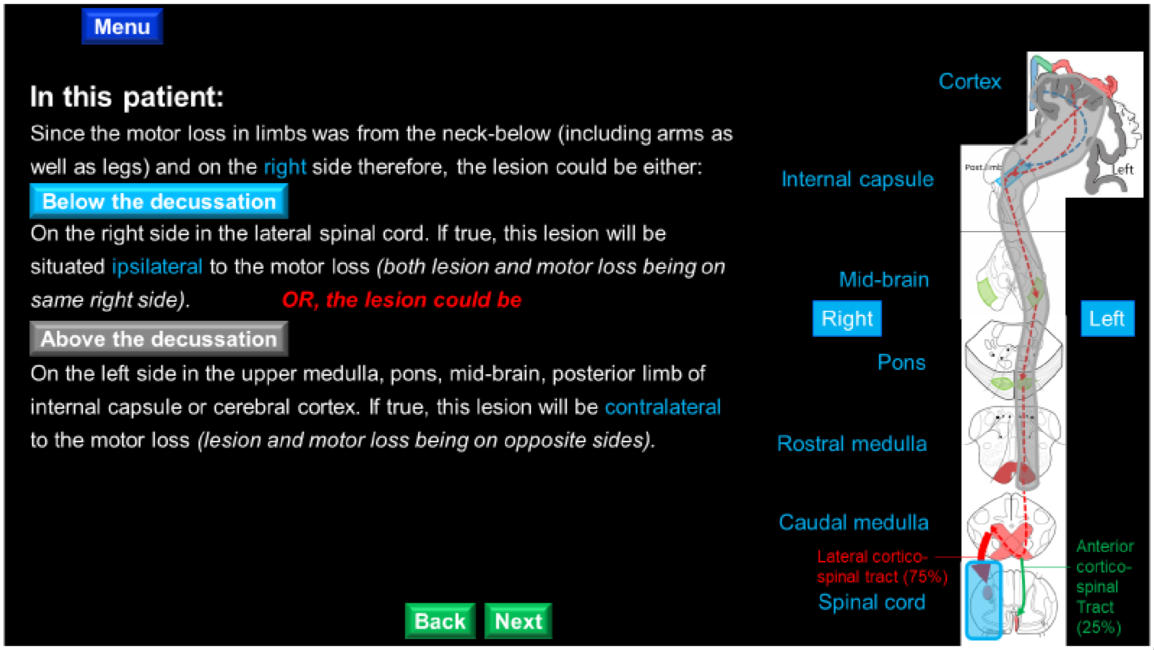

Figure 4.18: Clinical interpretation of neuroanatomy of CST for localization of lesion. The possible locations of a lesion were discussed in a patient with right-sided weakness in arms and legs. The CST decussates in the lower medulla. Therefore, the lesion could be either below the decussation of the tract in the right lateral spinal cord (highlighted in blue) or it could reside above the decussation of the tract in left upper medulla, pons, mid-brain, internal capsule or cerebral cortex (highlighted in grey).

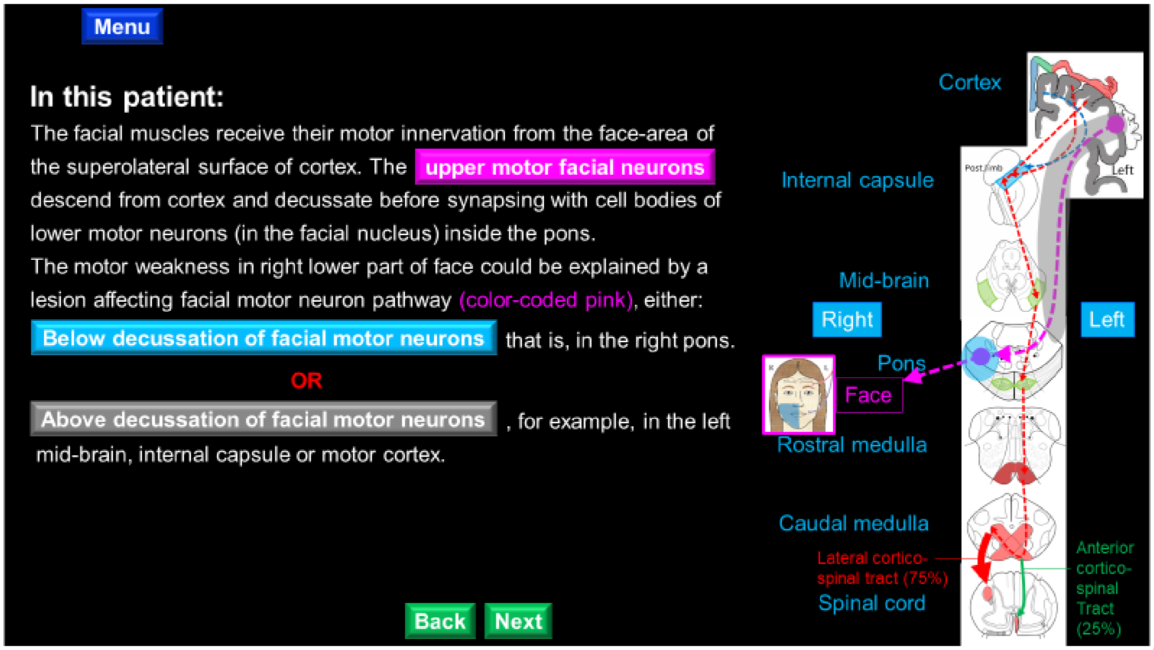

Figure 4.19: Clinical interpretation of neuroanatomy of facial nerve for localization of lesion. The possible locations of lesion were discussed in a patient with right-sided weakness in her lower face. The upper motor neurons of facial nerve decussate in the pons before synapsing with the cell bodies of the lower motor neurons in the pons. Therefore, the lesion could be either below the decussation of the facial upper motor neurons in the right pons (highlighted in blue) or it could be above the decussation of the facial upper motor neurons in the left mid-brain, internal capsule or cerebral cortex (highlighted in grey).

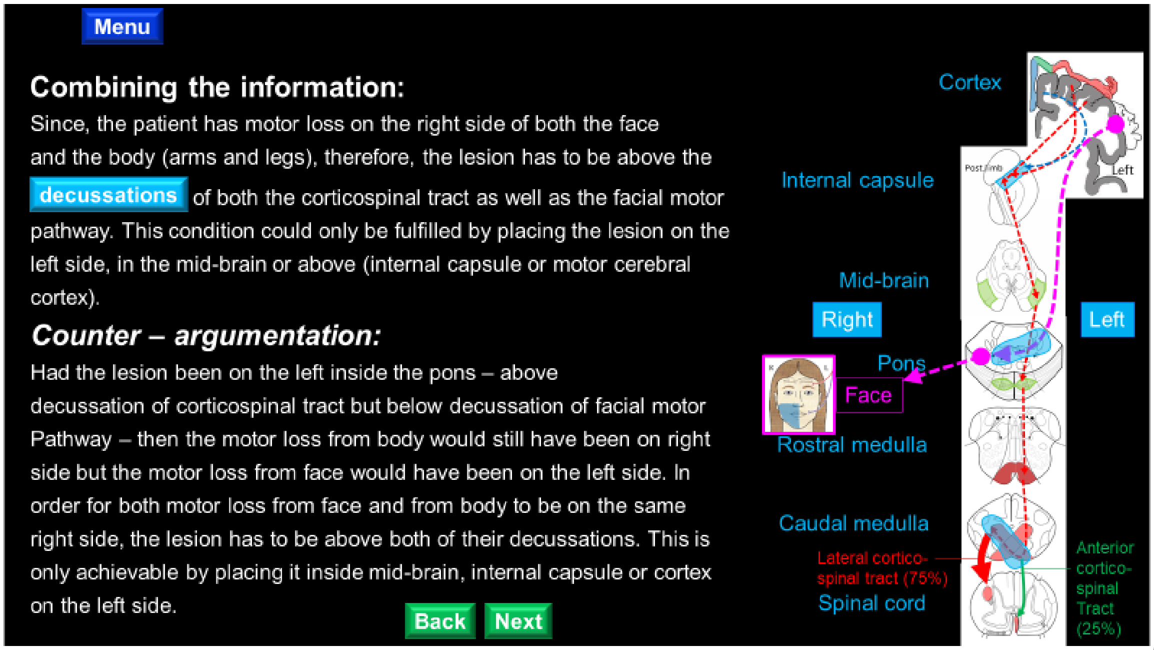

Figure 4.20: Clinical interpretation of neuroanatomy of corticospinal tract and facial nerve for localization of lesion. The possible locations of lesion were discussed in a patient with right-sided weakness in arms and legs and the right lower face. Since, the patient has motor loss both on the right side of face and right the body, therefore, the lesion must be above the decussations of both corticospinal tract as well as facial motor pathway (highlighted in blue). Such a clinical presentation could be explained if the patient has a neurological lesion on the left-side; in the mid brain or higher up (internal capsule or motor cerebral cortex).

Dorsal Column Pathway

The second prototype was created for a sensory neuronal tract called the dorsal column medial lemniscal pathway. The learning stations follow a similar pattern to that in the corticospinal tract, however, since dorsal column is a sensory neuronal pathway, therefore, it commences with the spinal cord and ends up at the cerebral cortex. The learning stations include the Spinal cord, Medulla oblongata, Pons, Mid-brain, Thalamus and the Cerebral cortex (Figure 4.21).

The sequence of dynamically interlinked screens within each learning station also mirror those inside the CST described above. These included a text based screen, followed by an interactive image screen, a quiz section and an interactive exercise for actively tracing the sensory neuronal pathway. The former three learning steps are conducted inside the Study Pad while the latter most step; the interactive exercise, is carried out inside the Interactive Sketch Pad (Figure 4.21).

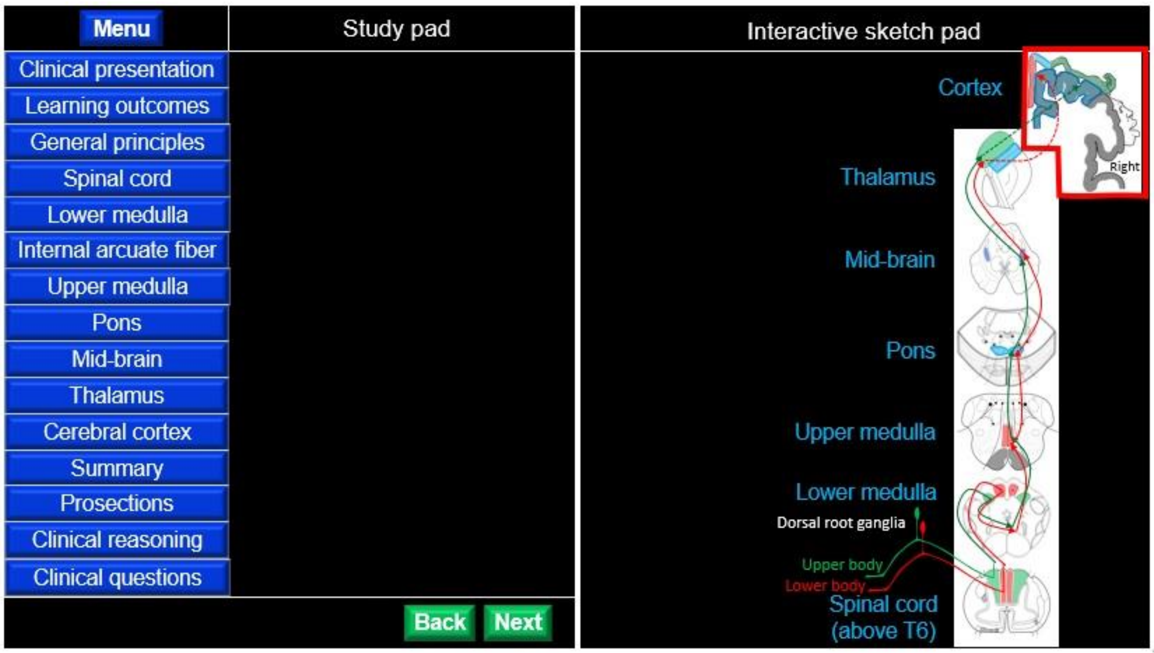

Figure 4.21: Dorsal column pathway traced inside the interactive sketch Pad. A drop-down menu list on the left side shows the sequence of learning stations. An interactive exercise appears at the end of each learning station requiring the user to upload an image of the respective cut-section of the central nervous system and select the correct location of the dorsal column tract within it. The software then actively traces the pathway from its location in the preceding section to the location in the recently uploaded one. Since, the exercise is repeated after each learning level, therefore, at the end of the last learning station (i.e. the cerebral cortex), the entire neuronal pathway has been actively traced in the interactive sketch pad (from spinal cord to the cerebral cortex). The dorsal column pathway has been separately color coded in red for the upper body (above T6) and in green for the lower body (below T6).

The learner is provided with a summary of the dorsal column pathway once all learning stations/levels have been finished (Figure 4.22).

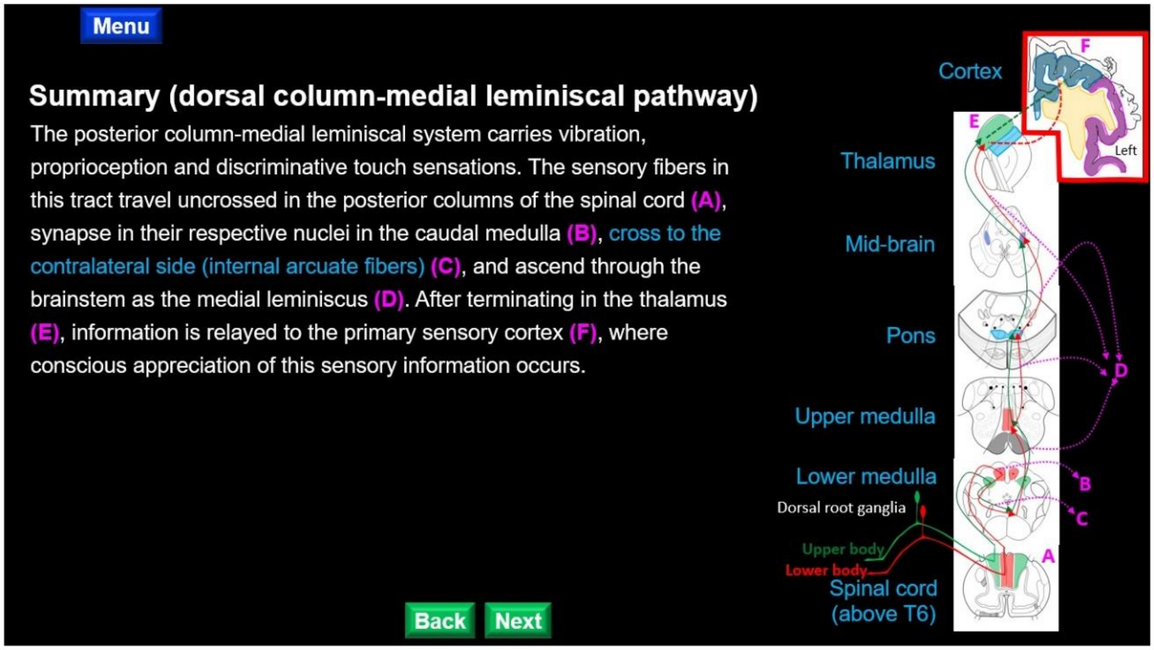

Figure 4.22: Summary of the dorsal column medial leminiscal pathway.

The location of the tract within different regions of the central nervous system could also be reviewed with the help of images of the prosections of the CNS available in the anatomy lab at the institution. An example of the cerebral cortex has been shown (Figure 4.23).

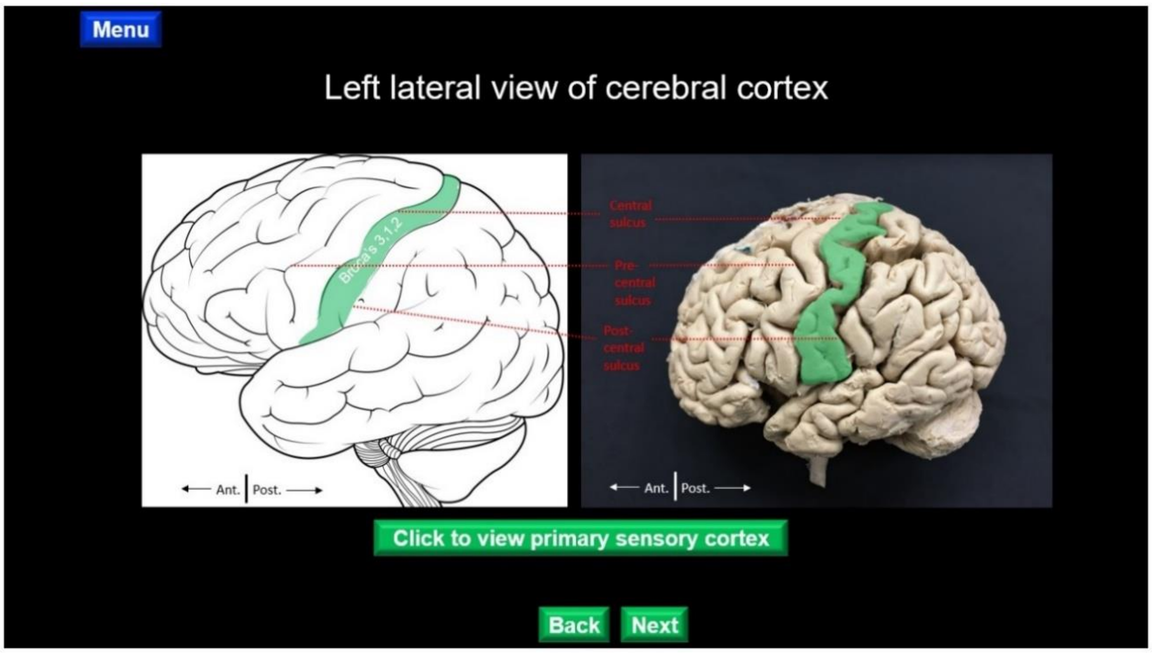

Figure 4.23: Left lateral view of the cerebral cortex. The area-of-destination of dorsal column medial leminiscal pathway can be reviewed simultaneously on the illustration (left) and on the image of the cortical surface of a brain-prosection (right). Clicking over the button for viewing the primary sensory cortex, simultaneously highlights the area on the illustration and the prosection and provides immediate feedback to the user through on / off labelling.

As done previously with the corticospinal tract, the clinical interpretation of the neuroanatomy of the dorsal column medial lemniscal pathway was also discussed in the end, in the context of localization of neurological lesion (Figures not shown), which was followed by additional multiple-choice quiz items.

The PowerPoint™ presentation (pptx.) file was converted into an interactive slide show (ppsx.) file. Prior to saving as a PowerPoint™ slide show file (.ppsx), the presentation was setup for the KIOSIK mode to disable the mouse wheel and keyboard controls (Figure 4.24).

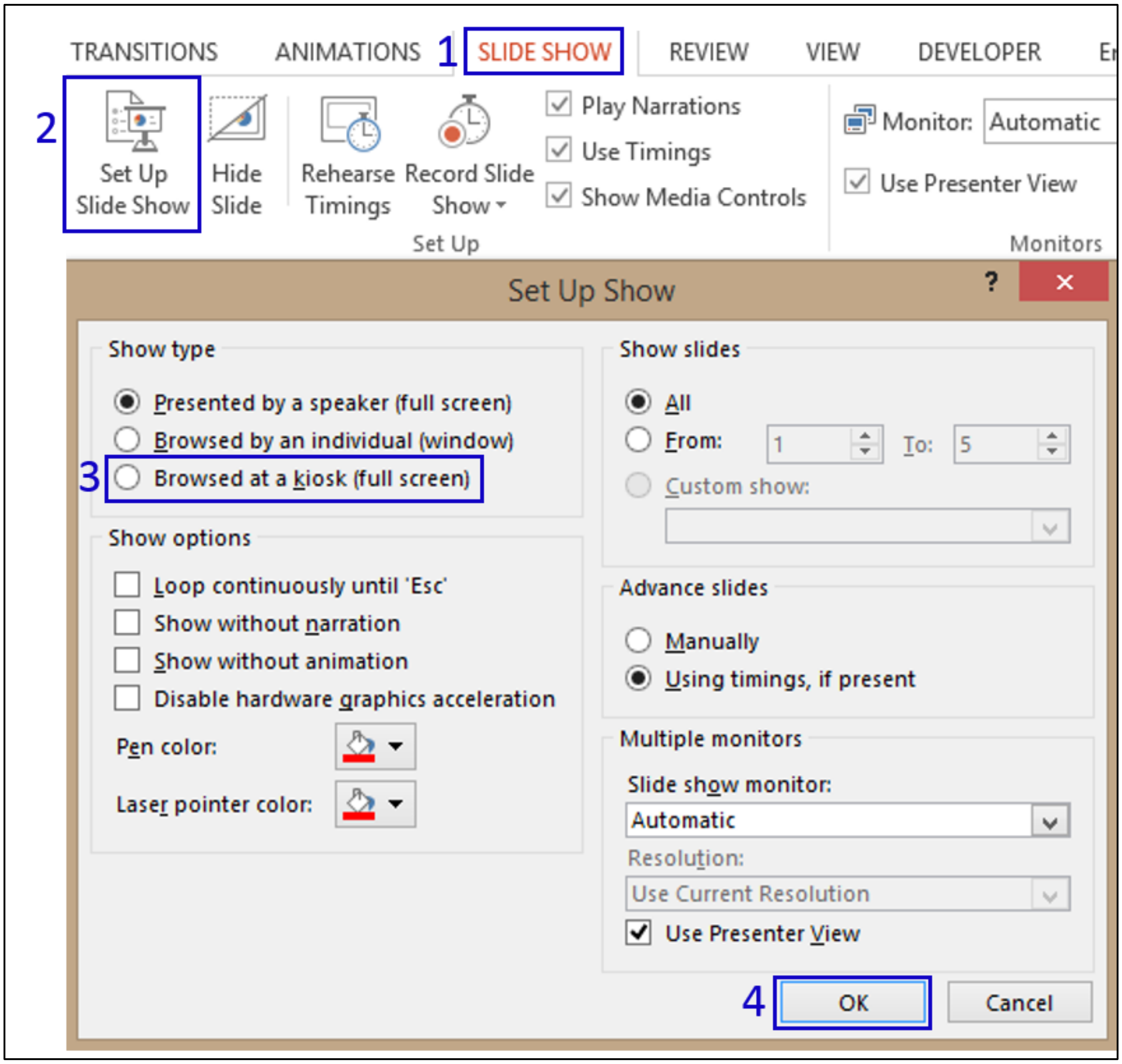

Figure 4.24: Steps undertaken to set up PowerPoint™ as an interactive KIOSIK presentation. The Setup Slide Show option was selected (2), from the slide show tab at the top (1). Once the Setup Slide Show dialogue box appeared, the option of Browsing at a KIOSIK (full screen) was chosen (3). Changes made to the slide show set up were accepted by clicking the OK button (4). Setting up the KIOSIK mode disabled the mouse wheel and keyboard controls which rendered the slide show screens non-responsive. Hence, the user is not able to change slides or to control the flow of presentation by right-clicking or using any keyboard button, except when clicking the action buttons provided.

The e-resource was uploaded to the Google drive™ folder of a dedicated Gmail™ account (spinalpathways@gmail.com) and could be downloaded using a link provided to users via email. The evaluation of this e-learning tool will be described in Chapter 5.

Discussion

The purpose of this article is to describe our group's experience with the development of a PowerPoint™ based, computer assisted learning resource for spinal pathway neuroanatomy. The use of PowerPoint™ to develop the module, offers an opportunity to every neuroanatomy educator to contribute to enhancement of educational content by creating customized neuroanatomy learning modules. As compared to the previously available resources (http://bit.ly/UniOfUtah and http://bit.ly/UBC-Neuro), our resource offers a greater level of interactivity through quizzes and interactive drawings of the spinal pathways. Moreover, it explains the basic neuroanatomical facts in a clinical context with the aim of successfully addressing the neurophobia in the future. The module is easily accessible and downloadable and does not demand any special rendering requirements. We intend to offer this e-tool as a supplementary resource for undergraduate medical, therapies, neuroscience and other health sciences students. The use of computer assisted learning resources as an adjunct to conventional teaching modalities, has already been favored by a wide cohort of medical and health science students (Javaid et al., 2018). The e-tool described in this article provides information on the spinal pathways through a dynamic, interactive, step-by-step incremental learning approach coupled with a discussion of the clinical interpretation of basic neuroanatomical fact to aid in neurological localization.

Previously identified neuroanatomy learning e-resources are overall limited in their description of spinal pathways. Online resource by the University of Utah (http://bit.ly/UniOfUtah) offers a brief visual enumeration of the spinal pathway neuroanatomy coupled with quizzes. The neuroanatomy resource by the University of British

Columbia (Krebs, 2016 - http://bit.ly/UBC-Neuro) contains comprehensive neuroanatomy modules, including those on spinal pathways. However, the detail offered falls short of what is required at the medical undergraduate level (Moxham et al., 2015). The students are not able to appreciate the spatial neuroanatomical relationships of the spinal pathways at various levels of the brain and the spinal cord. Moreover, the clinical interpretation of basic neuroanatomical facts to aid in neurological localization has not been discussed.

The effectiveness of any instructional tool is dependent on how well its design reflects human cognitive architecture (Mayer, 2003). In an intelligently designed online instructional resource the extraneous source of cognitive load, associated with the way information is presented, should be kept to a minimal. Doing so, the learner is provided with an opportunity to maximally divert his mental efforts towards the scheme construction associated with learning (Young et al., 2014).

Following are a few highlights of the instructional design of our e-learning tool:

Results from our previous work show that undergraduate medical and neuroscience students considered the step by step approach to explain the pathways, very useful (Javaid et al, 2019; Table 4.1). The cognitive load reduction section of the CF-ONLine also favors the application of segmenting principle in designing the pedagogical construct of an e-learning resource by presenting information in a step by step, sequential and incremental fashion, to reduce the load on the working memory capacity for schema construction (Table 1.2, Chapter 1). In this context, our online resource comprises of multiple slides, with each slide offering some new incremental information which is serially linked with the preceding one. This allows the learner to consolidate the schema before the next piece of information is added onto it. The approach is in accordance with the best learning practices proposed by the Mayer's Multimedia Theory of Learning (Mayer, 2003) and the Cognitive Load Theory (Paas et al., 2003). The latter argues that the extent to which relevant elements of an information interact is a critical determinant of the intrinsic cognitive load. The information varies on a continuum from low to high in element interactivity. The elements of high element interactivity cannot be understood until all of the elements and their interactions are processed simultaneously in the working memory (Paas et al., 2003). A step-by-step approach of incremental increase in knowledge makes the learning task simpler by not allowing the number of novel interactive elements to encroach beyond the confines of the working memory capacity of the learner at every learning stage. In support of this argument, the Mayer's Multimedia Theory of Learning offers a similar Segmenting principle as a potential solution to prevent cognitive overloading of the working memory with the processing demands (Table 4.1). The principle states that the presentation should be broken down into bite-size segments so that the learner has time to perform the additional processing associated with the organization and integration of selected pieces of information before the next segment of information is presented (Mayer and Moreno, 2002). On the contrary, many of the existing neuroanatomy resources have limited the efficacy of their instructional design by providing the entire informational jargon regarding each neuroanatomical topic, all at one go (http://bit.ly/UniOfUtah; Krebs, 2016 - http://bit.ly/UBC-Neuro). Additional measures for reducing extraneous processing include a menu button with a drop-down list of structures, which provides a site-map for making navigation easier for the user (Table 4.1), while consistency in the sequence of presentation of screens within each learning station make the user interface intuitive and easy to use. Moreover, the incorporation of a tutorial window and early explanation of key principles before the commencement of the module, helps to equip the learner with the baseline information and makes the future learning manageable (CF-ONLine; pre-training principle).

The PowerPoint™ screen has been divided into two sections, namely the Study Pad and the Interactive Sketch Pad. As the user acquires new information on spinal pathways in the Study Pad, he can simultaneously view the neuronal pathway being traced inside the Interactive Sketch Pad. Such an approach is in accordance with the contiguity principle of Mayer's Multimedia Theory of Learning and has been postulated as part of the CF-ONLine as well (Table 1.2, Chapter 1). The principle states that it is better to present corresponding words and pictures simultaneously rather than separately when giving a multimedia explanation (Mayer and Moreno, 2002; Table 4.1). Moreover, the interactive sketch pad provides a higher level of interactivity where students can learn the neuroanatomy by actively tracing the entire neuronal pathway in a step-by-step fashion (Table 4.1).

The results from our previous work show that undergraduate medical students imparted high importance to the accessibility and the ease of use of the layout of the instructional content (Javaid et al., 2019; Table 4.1). This is important as the way information is presented to the learner also helps to minimize the extraneous cognitive load. For instance, any instructional procedure that requires learners to engage in either a search for navigation buttons or to invest a lot of mental effort in comprehending the user-interface of the software, is likely to impose a heavy extraneous cognitive load because working memory resources must be used for activities that are irrelevant to schema acquisition and automation (Paas et al., 2003). Hence, to make learning as intuitive as possible, we have kept the instructional design as consistent as possible. For instance, the sequence of screens in the novel UCC tool has been kept the same within each learning-station, such that, each learning-station starts with a text-based screen, which is then followed by an interactive image, a quiz-section and then an interactive exercise. Moreover, the action-buttons are situated at similar locations inside all the slides making navigation as intuitive as possible. The images / illustrations have been color-coded for their labels and important words / instructions in the text have been highlighted to provide important cues to the learners for emphasizing high-yield facts. The cognitive component of the CF-ONLine, once again highlights the need to reduce extraneous processing (Table 1.2, Chapter 1).

The current resource offers flexibility to the learner to control their pace of instruction which helps to custom-titrate the intrinsic load to the working memory capacity of individual learner. ‘Repetition’ was identified as an important part of learning by the undergraduate students (Javaid et al., 2019). In the current resource, the user can jump back and forth between various learning stations using the menu-option to revise any previous information (Table 4.1). Moreover, the immediate feedback offered through the on/off option of revealing / hiding the tracts’ location inside the illustrated images, and the quizzes incorporated into the module, provide an opportunity to revise the previously learnt content in an interactive fashion (Table 4.1). The results from our previous study also reveal that undergraduate medical and health science students believe that the online quizzes with feedback provide the ability to test oneself. They especially liked the quizzes at the end of the video tutorials to assess if they understood the information supplied (Javaid et al., 2019). In context of the students’ favorable opinion regarding an interactive form of learning, an interactive sketch pad was incorporated into the e-tool design to provide a higher level of interactivity where students can learn the neuroanatomy by actively tracing the entire neuronal pathway in a step-by-step fashion (Table 4.1).

Lack of understanding of the clinical relevance of basic neuroanatomy has been identified as a major reason underlying the prevailing neurophobia (Javaid et al., 2018). In this context, the notion of contextualized learning suggests that learning is most effective when it is situated in the context in which it will be used (CF-ONLine, Javaid et al., 2019). The learning content should be framed around realistic situations in which it will be practically used in the future. Our resource commences by presenting a clinical scenario and in addition, discusses the clinical interpretation of the basic neuroanatomical facts at the end, in detail. This will motivate and enhance user-interest in learning the topic (Table 4.1). On the contrary, the clinical contextualization and interpretation of basic neuroanatomical facts has currently not been conducted by existing top-ranked neuroanatomy web-resources (http://bit.ly/UniOfUtah; Krebs, 2016 - http://bit.ly/UBC-Neuro).

In our resource, the user has been given a unique opportunity to trace the neuronal pathway inside the Interactive Sketch Pad by selecting the correct locations of the tract within the cross-sectional images of the brain and the spinal cord and interconnecting those loci to trace the spinal pathway. Doing so, provides a novel opportunity to the learner to revise the information acquired earlier in the Study Pad section. Moreover, the interactive nature of the interactive sketch pad while actively tracing the neuronal pathway, also enhances user-interest by promoting active learning (Table 4.1). This goes in accordance with the proposed connection between constructivism and adult learning theory in online learning environments (Huang, 2002). On the contrary, the level of interactivity of the existing neuroanatomy web-resources is limited and does not extend beyond on/off labelling of neuroanatomical images and multiple-choice quizzes (http://bit.ly/UniOfUtah; Krebs, 2016 - http://bit.ly/UBC-Neuro), while the interactive sketch pad offers a higher-level interactive learning opportunity.

The use of text-based description, interactive images (both illustrations and images of prosections) and videos provide a multimodal learning experience to cater for the varying learning styles of users with different learning preferences. Adult learning theory acknowledges that most adults have a strong preference for one sense over another with regards to taking in and processing information. Howard Gardner's multiple intelligences inventory assesses seven different types of intelligence which span the three domains; cognitive, physical and affective domains (Gardner and Hatch, 1989). In order for learning to be effective, all intelligences must be addressed in teaching. The educators should try, as much as possible, to plan the learning activities that address the three domains. Results from previous studies have shown that students from medical and neuroscience backgrounds favored using a diversity of learning tools suggesting an appreciation of a multi-modal approach to learning the anatomy of the spinal pathways and visualizing the neuroanatomical relationships (Javaid et al., 2019; Table 4.1).

Conclusion

In summary, a simple, interactive computer-assisted learning module/resource has been developed for learning the sensory and motor spinal pathways. This is the first known description of the development of such a pedagogical advancement in undergraduate medical education. As with all educational tools, this resource will undergo empirical evaluation to determine its role and its effectiveness as a supplemental resource for neuroanatomy education. A prospective study is currently underway, investigating objective outcomes of student knowledge as well as individual subjective feedback on the online resource, in the context of learning the spinal pathways. We hypothesize that the current tool which is in alignment with the users' feedback acquired in our previous work (Javaid et al., 2019; Table 4.1) will have a positive impact on the student learning outcomes when integrated with the conventional undergraduate neuroanatomy teaching methods.

CHAPTER 5

Neuroanatomy of the Spinal Pathways: Evaluation of an Interactive Multimedia E-Learning Resource

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Abstract

Health practitioners interlink difficulties in managing neurology patients with impaired understanding of neuroanatomy and associated clinical correlates. Owing to the limitation of traditional pedagogies, the targeted design of e-resources could be instrumental in helping students learn neuroanatomy. Previous work from our group identified important features in the design of neuroanatomy learning tools. This study describes the design and evaluation of a novel, interactive, neuroanatomy e-resource.

Following initial assessment of knowledge of the spinal pathways (quiz 1, Appendix 9), participants were randomized into experimental and control groups and provided access to the novel tool or a previously identified best-ranked e-resource. Following 2 weeks of access, the participants' knowledge was re-assessed (quiz 2, Appendix 10). Participants who did not use the allocated resource were placed in a no-use (NU) group. The usefulness of the tool used was gauged using Likert-scale questionnaires (Appendix 11).

Participants in the three groups showed a significant increase in their knowledge of neuroanatomy. When the increase in the novel tool group was compared against the NU group, the improvement in quiz 2 score was significantly higher than the control tool v. NU comparison. The Likert ratings revealed a significantly higher median rank-score for the novel tool compared to the control tool for learning clinical correlates. Lastly, the significantly stronger correlations between the students' perceptual opinion and their quiz 2 scores imply that students favored the instructional design of the UCC e-tool. The e-resource

shows promising results in bridging the gap between neuroanatomy knowledge and its clinical application, potentially contributing to a reduction in neurophobia.

Key words: Neuroanatomy, anatomy, medical education, computer assisted learning, neurophobia.

Introduction

Students and health care professionals have long complained of the cognitive challenges associated with learning intricate neuroanatomy concepts (Martin et al., 2014; McCarron et al., 2014; Javaid et al., 2018). Consequently, a poor conception of neuroanatomical knowledge leads to an apprehension of managing neurology patients, termed neurophobia (Jozefowicz, 1994). Non-conventional e-learning pedagogies could assist students in developing a better understanding of the complex, and often abstract, neural connections and pathways, as well as in learning the spatial inter-relationships within the neuroanatomical nexus. E-leaning offers several advantages, such as, a superior 3D visualization of complex neuroanatomical relationships, active learning opportunities through interactive teaching designs, user-friendly interfaces, cost effectiveness, ease of distribution and accessibility (Cook, 2007). In addition, custom-adaptive learning designs can offer greater control over the content, sequence, pace and time of learning, thus providing opportunity to the learners to tailor their experiences to meet their personal learning objectives and constraints (Ruiz et al., 2007). The significance of online applications increases many-folds in the context of the overall reduction in time devoted to anatomical education (Drake et al., 2009; Drake et al., 2014; Arantes and Ferreira, 2016), lack of qualified instructors (Turney, 2007; Arantes and Ferreira, 2016), various legal, financial and health concerns (De Craemer, 1994; Batra et al., 2010) and the limited visibility associated with the small size of the neuroanatomical structures.

A vast array of computer assisted learning resources are available as potential aids to supplement the study of neuroanatomy. Various 3D digital brain models (Nowinski et al., 2009; Chariker et al., 2011; Ruisoto et al., 2012; Drapkin et al., 2015; Allen et al., 2016), e-learning resources (Brinkley et al., 1997), brain atlases (Stewart et al., 2007; Li et al., 2014) and stereoscopic resources (de Faria et al., 2016; Cui et al., 2017), while providing enhanced visualization of neuroanatomical relationships, are however limited from a learning perspective. These tools simply test the location and naming of gross neuroanatomical structures and provide a limited feedback to the students in the form of correct or incorrect responses or percentage scores. Other 3D digital brain models have not been quantitatively assessed for their educational efficacy (Adams and Wilson, 2011; Palomera et al., 2014). A few interactive brain atlases have attempted to explain the clinical neurological correlates (Nowinski and Chua, 2013) and the art of neurological lesion-localization (Lewis et al., 2011), however, they fail to link the clinical presentations with the underlying basic neuroanatomical details. Lately, technologically advanced virtual (Richardson-Hatcher et al., 2014; Stepan et al., 2017) and augmented reality applications (Wang et al., 2016) have emerged on the arena, along with various commercially available applications (Frasca et al., 2000). However, despite the wealth of neuroanatomy resources available, to date, an interactive tool that offers an active opportunity to acquire an in-depth understanding of neuroanatomy of the spinal pathways and to prepare learners to exercise this information for localizing neurological lesions, is missing. The persistence of neurophobia, despite the abundance of online resources, highlights the need for the development and evaluation of a novel, interactive neuroanatomy learning online resource that could overcome the challenges confronted by the students while learning the intricate neuroanatomical concepts associated with the spinal pathways.

The purpose of this study was to examine the educational efficacy of a novel interactive neuroanatomy learning e-resource developed using PowerPoint™ software technology at University College Cork (UCC), Ireland. The design of the UCC learning resource was underpinned by the theories of cognitive load (Paas et al., 2003; Paas et al., 2004), adult learning (Cercone, 2008; Taylor and Hamdy, 2013) and Mayer's theory of multimedia learning (Mayer, 2003). In this context, the conceptual framework (CF-ONLine) outlined in chapter 1 (Table 1.2) provided important guidelines, while the information gathered in a previous survey and assessment of existing neuroanatomy e-resources also informed the instructional design (Javaid et al., 2019). In particular, educators and users had identified a number of features that were valuable in the delivery of neuroanatomical information and ranked three e-resources for their efficiency in contributing to teaching of the sensori-motor spinal pathways. The newly designed UCC neuroanatomy e-learning tool was evaluated in an educational setting among undergraduate medical and clinical therapies students.

A randomized controlled trial (RCT) was employed as part of the experimental design to assess the educational efficacy of the novel e-learning tool against the best available e-resource. Despite the challenges associated with assessing educational strategies through RCTs in real-life settings (Parks, 2009; see discussion), RCTs have still been advocated as an effective research tool to assess educational interventions (Cook, 2007; Calvert and Freementle, 2009). There are several benefits associated with a RCT in order to learn what works. For instance, the superiority of employing RCT in the design of an educational-interventional experiment and drawing causal inferences, is best justified based on the random assignment of participants to the two groups being contrasted. This allows for – provided the experiment is properly maintained over time – the final performance difference between control and experimental groups to be attributed to the intervention (by minimizing selection-bias) (Cook, 2007). Moreover, the research on design effects in education shows that individual experiments (RCTs) produce less biased answers than their design-alternatives, such as reviews and surveys. In addition, as studies of a topic accumulate, experiments provide more efficient answers, making experiments less expensive than their alternatives in the long run as fewer of them would be needed for achieving the same degree of confidence in drawing up a causal link (Cook, 2007).

The results from our study reveal that users of the novel UCC tool had a more significant improvement in their neuroanatomy knowledge assessment than their non-user classmates. Furthermore, the results show that the students perceived the instructional design of the UCC-tool to be more effective for learning and clinically applying the intricate concepts of spinal pathways' neuroanatomy as compared to the best available e-resource (Krebs, 2016; Javaid et al., 2019).

Materials and Methods

Design and Development of the UCC Neuroanatomy Learning Tool

A self-learning neuroanatomy resource for the anatomy of the spinal pathways (corticospinal tract and dorsal column medial lemniscal pathway) was created using Microsoft PowerPoint™ 2017 (Microsoft Corp., Redmond, WA).

The layout of the PowerPoint™ screen was divided into two sections; a Study Pad section (left side) and an Interactive Sketch Pad section (right side) (Figure 5.1). Initially, the information regarding the topic is provided to the learner in the Study Pad while the Interactive Sketch Pad offers an opportunity to revise the same information by prompting the user to actively trace the course of the neuronal tracts.

Various action buttons were inserted to systematically interlink the slides as part of the tool design. Each action button is programmed to carry out a specific function allowing users to navigate between the screens (or slides) in an interactive and structured fashion. Image and video buttons are available at various stages, offering an opportunity to learn the anatomy of the spinal pathways through interactive images, with on / off interactive labeling (Figure 5.1A) and short video-based descriptions, respectively.

The module begins with a tutorial window, describing various regions / sections of the screen layout and explaining the functions of navigation buttons. A Menu button provides a drop-down list of the various learning stations of the CNS (Figure 5.1B). Each learning station in the e-resource corresponds to a specific axial section of the brain or the spinal cord along the course of a spinal tract. The user learns the course of the entire neuronal pathway by actively studying its anatomy at each of these learning stations.

The sequence of presentation of PowerPoint™ slides / screens within each learning-station follows a consistent pattern. For instance, in the case of the corticospinal motor tract, the first learning-station (the cerebral cortex) commences with a text-based description about the origin and location of the tract. The image button within the text, directs the user to a subsequent screen, containing an interactive image of the CNS for that level (Figure 5.1A). Line drawings of the structures were prepared using the image manipulation software GIMP™ (version 2.8.22, www.gimp.org). Interactive features were added to the line drawings using the PowerPoint™ software. The interactive interface allows the user to switch labels and highlights on or off, acquiring immediate feedback (Figure 5.1A).

Following the image and video-based descriptions, the user is presented with a quiz section comprising multiple choice questions. An immediate feedback is provided to the learner for correct or incorrect responses accompanied by a detailed explanation. The user is prompted to try again if an incorrect response has been selected.

An interactive exercise follows the quiz section, in which the user uploads the relevant axial sections of the CNS into the Interactive Sketch Pad (right side) and is prompted to click over the location of the spinal tract in that uploaded image (Figure 5.1B). A correct selection automatically draws and connects the location of the spinal tract in the adjacent axial section.

Once all learning stations (from the cerebral cortex to the spinal cord) have been completed, the learner has interconnected the loci of the tract in all uploaded axial images in the Interactive Sketch Pad, in a step-by-step fashion, thus successfully drawing the entire neuronal pathway (Figure 5.1B).

At the end, the learning module offers an opportunity to revise the spinal tract neuroanatomy using cadaver- / prosection-based images (Figure 5.1C). The module ends with a clinical interpretation of the pathway information in the context of localization of neurological lesions.

Prior to saving as a PowerPoint™ slide show file (.ppsx), the presentation was setup for the KIOSIK mode to disable the mouse wheel and keyboard controls. The e-resource was uploaded to the Google drive™ folder of a dedicated Gmail™ account (spinalpathways@gmail.com) and could be downloaded using a link provided to users via email.

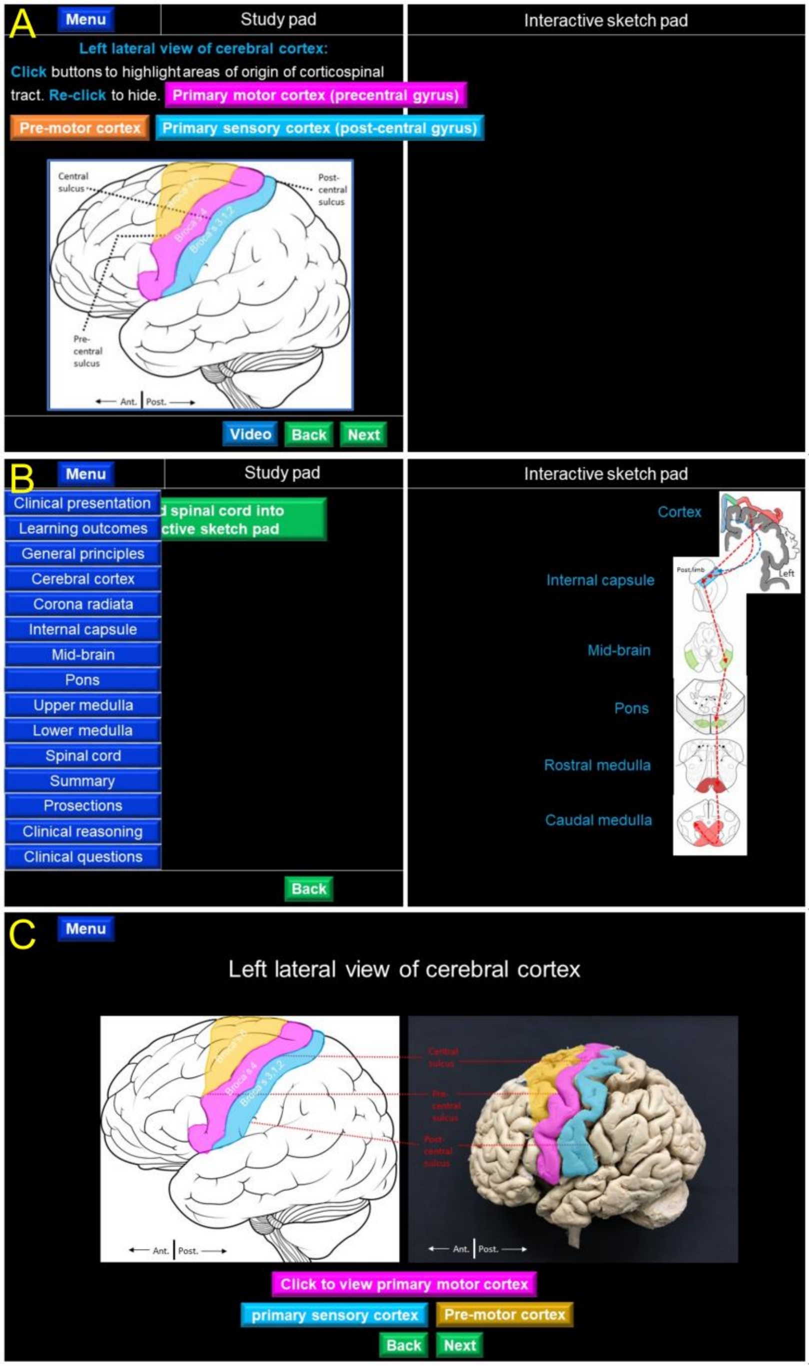

Figure 5.1. Design the novel UCC neuroanatomy learning tool. **A,** Interactive image of the left cerebral hemisphere displayed in the study pad of the UCC tool. The three areas of origin of corticospinal tract are color-coded and matched with interactive buttons above (pink for primary motor cortex, orange for pre-motor cortex, blue for primary sensory cortex). Clicking these buttons provides on and off labelling for the highlighted regions providing immediate feedback to the user. **B,** Menu list for various levels of the CNS. The interactive sketch pad displays sectional images from the selected levels and interconnect the loci of the spinal tract in each section to trace the entire neural pathway. **C,** Review of the studied material using prosection images. Illustrations (left) and photographs (right) of the same structures are displayed and highlighted side-by-side.

Study Design

A single-blinded experimental-control study was devised to determine, if the novel neuroanatomy teaching tool increases student performance relative to the previously identified best e-resource (Javaid et al., 2019). The study was conducted during teaching of the Human Neuroanatomy course at University College Cork in the autumn semester of 2017. The course has been described in detail in our previous work (Javaid et al., 2018). This study received approval from the institutional Social Research Ethics Committee (log no. 2017-101, Appendix 12 and 13).

The study design was explained to all participants prior to the teaching of the neural pathways. The students were provided information on the study and volunteers signed an informed consent form (Appendix 12). A baseline assessment of the participants' knowledge of neuroanatomy of the spinal pathways was conducted by requesting them to complete a quiz (Table 5.1, quiz 1, Appendix 9) comprising of 24 multiple-choice items (Figure 5.2). The quiz was distributed among the students on standardized sheets of paper inside the anatomy lab. It took approximately 25 minutes to complete and was collected for marking.

Following on from the delivery of lectures and laboratory sessions on the spinal pathways, the students were randomly assigned to control and experimental groups (Figure 5.2). They were blinded to whether they were assigned to the experimental or the control group. Students in the control group were emailed a hyperlink for the highest-ranked online neuroanatomy learning resource already available on the web (http://neuroanatomy.ca) (Krebs, 2016; Javaid et al., 2019) while the experimental group received a link for the UCC e-learning tool, developed as part of this study (Figure 5.2). Students in both groups were also provided with additional links for 1) a neuroanatomy e-textbook available in the institutional library e-resources, 2) instructions regarding how to access the respective learning resource and, 3) the learning outcomes. Students were allowed two weeks of continuous access to the learning tools, after which they, were re-assessed for their knowledge of neuroanatomy using another MCQ-based quiz (Table 5.1, quiz 2, Appendix 10). Finally, participants' perception of the e-resources was gauged using a Likert-scale questionnaire (Figure 5.2, Table 5.2). A number of participants declared not having used the allocated resource, from both control and experimental groups and were placed in a separate group called the 'no-use group (NU)'. Hence, the final analysis was conducted using three participant-groups; the no-use (NU), the control and the experimental groups. After completion of the study, both e-resources were made available to all students as course material.

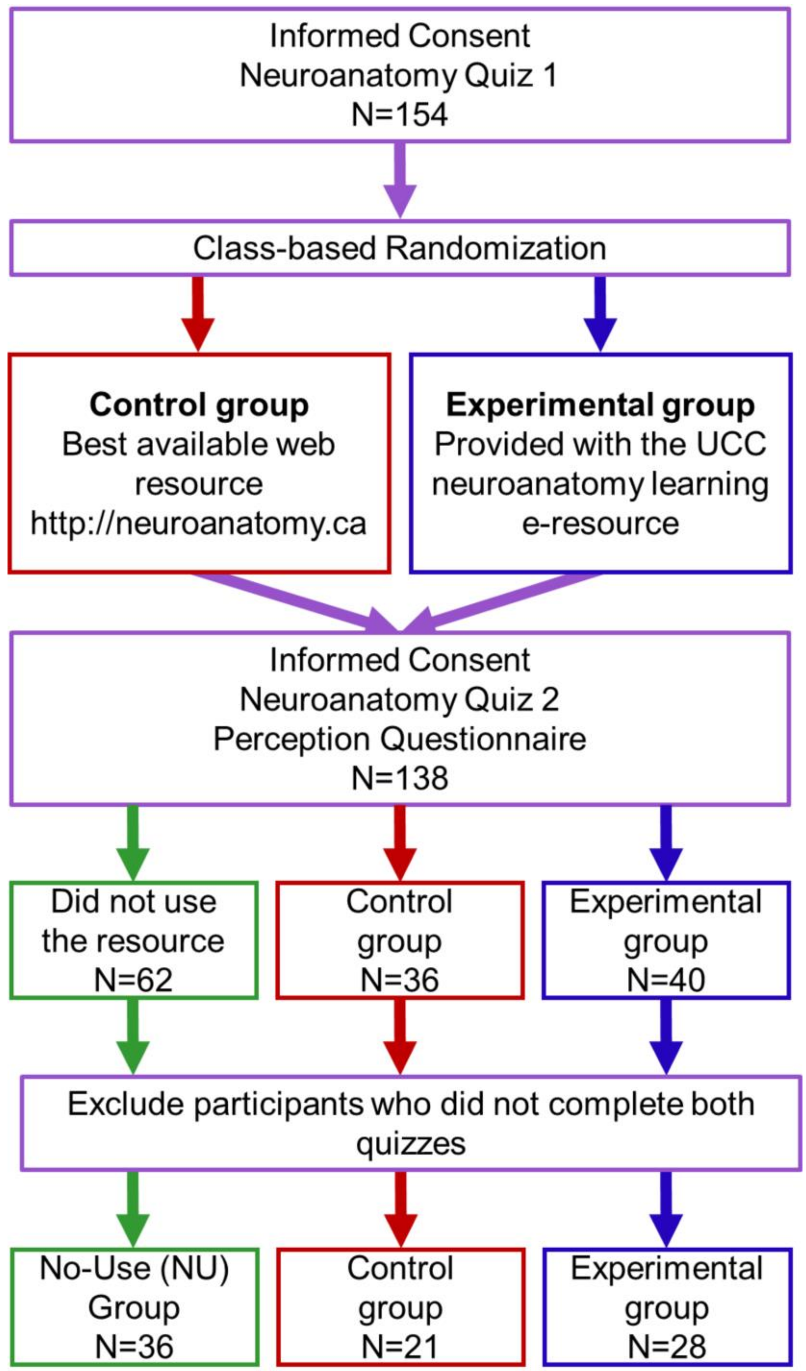

Figure 5.2. Experimental design. A randomized, case-control study was designed to gauge improvement in students' knowledge of neuroanatomy of spinal pathways after being provided access to e-learning tools for 2 weeks. All participants completed a baseline knowledge assessment (quiz 1) at the onset of the study and a second assessment at the end of the study (quiz 2). The control group (in red) was provided with the previously identified best-available online resource while the experimental group (in blue) was provided with the novel UCC tool. Participants who did not use the allocated resource were placed in the no-use (NU) group (in green). Participants in the control and experimental groups also filled a Likert-scale questionnaire to provide their opinion regarding the perceived usefulness of the accessed resource.

Table 5.1: Neuroanatomy quizzes (before and after exposure to e-learning resources)

Question topics for quiz 1		Question topics for quiz 2
Q1. Location of fasciculus cuneatus	E	Q1. Location of fasciculus gracilis
Q2. Functional impairment by lesion in fasciculus gracilis	E	Q2. Functional impairment by lesion in anterior CST
Q3. Identification of decussation-fibers	E	Q4. Level of decussation of CST
Q10. Location of nucleus gracilis	E	Q7. Location of DCMST
Q11. Function-loss by lesion in lateral CST	E	Q8. Functional impairment by lesion in spinocerebellar tract
Q15. Location of CST fibers	E	Q9. Crossing of 2nd order neurons
Q16. Location of CST fibers	E	Q11. Level of decussation of dorsal column
Q17. Function-loss by lesion in fasciculus cuneatus	E	Q16. Location of nucleus cuneatus
Q18. Decussation-level of anterior CST	E	Q17. Functional impairment by lesion in SPT
Q21. Structure identification (image)	E	Q21. Identification of crus-cerebrum(image)
Q22. Structure identification (image)	E	Q22. Identification of ventral pons (image)
Q23. Structure identification (image)	E	Q23. Identification of pre- and post-central gyri (image)
Q24. Location of VPL nucleus	E	Q3. Matching tracts with their functions
Q5. Matching tracts with their cells-of-termination	E	Q13. Ranking location of CST in descending order
Q7. Ranking location of Dorsal column in ascending order	E	Q18. Matching loci of CST
Q12. Matching tracts with cells-of-origin	E	
	D	Q6. Localization on labelled image
Q20. Localization: Function-loss by lesion in L-primary motor cortex	D	Q12. Function-loss by lesion in posterior limb of internal capsule
Q19. Infarct of cerebral cortical arteries	D	Q5. Infarct of R-anterior cerebral artery
Q4. Hemisection of spinal cord and dorsal column	D	Q10. Hemisection of spinal cord and dorsal column
Q6. Localization: lesion in the L-crus & medial leminiscus of mid-brain	D	Q14. Function-loss by lesion in R-internal capsule
Q8. Loss of function (infarct in L-thalamus)	D	Q15. Clinical scenario: Weakness of face and body on contralateral sides
Q9. Localization: L-occulomotor, R-facial, R-arm, L-leg weakness	D	Q19. Localization: lesion in the crus of mid-brain
Q13. Localization: Cerebral cortical artery stroke	D	Q20. Localization: lesion reported in the R-crus of mid-brain
Q14. Localization: Lesion in L-dorsal column	D	Q24. Hemisection of spinal cord and dorsal column

E=easy question=Bloom’s taxonomy level 1 / 2 (remembering / comprehension), D=difficult question= Bloom’s taxonomy level 3 (knowledge application), CST=corticospinal tract, VPL=ventral posterior lateral, DMST=dorsal column medial leminiscal tract, SPT=spinocerebellar tract, L=left, R=right

Design of Neuroanatomy Knowledge Quizzes

The content for both quizzes was sourced from standardized published neuroanatomy textbooks. Multiple choice questions were categorized into easy and difficult based on the revised Bloom's taxonomy (Anderson et al., 2001). Bloom's taxonomy of educational objectives was incorporated into the questions to gauge and precisely define students' understanding of the topic based on knowledge acquired through using the allocated e-learning resource. Although the taxonomy identifies three domains of learning (cognitive, affective and psychomotor), students' critical thinking skills were assessed in the cognitive domain, which is the primary focus of classroom education. While some have criticized the successive functionality of the proposed rigid hierarchical system of not being reflective of the integrative real-life learning (Soozandehfar et al., 2016), arguments by the proponents of Bloom's taxonomy have been widely cited in the literature (Van Hoejj et al., 2004; Da Miller et al. 1991). Kim et al. (2012) showed that during the feedback sessions of a pharmacotherapeutics course, majority of students perceived that adoption of Bloom's taxonomy helped them to identify the type of questions they had missed and understand the purpose behind each question (Kim et al., 2012).

Essay questions might have been an ideal way to evaluate higher hierarchical cognitive levels of Bloom's taxonomy, however, such assessments would have been time and labor intensive when administered to a large student cohort, thus resulting in a delayed feedback to students. Moreover, if multiple graders were involved, there would have been the potential for inter-rater variability (Kim et al., 2012).

In the context of Bloom's taxonomy, questions for which the user was required to recall and mentally process only a single item or information, were ranked as 'easy questions'. These questions assessed memory and comprehension of the participants and ranked at levels 1 or 2 in Bloom's taxonomy. The participants were assessed across various domains including the location and function of neuroanatomical structures, and the decussation of pathways. Difficult questions required the user to mentally process more than one item or information and apply the basic information to clinical patient-based descriptions. All clinical questions geared towards the localization of neurological lesions were included in this category and were ranked equivalent to Bloom's taxonomy level 3. A panel of three experienced anatomy educators independently rated the difficulty level of the questions and only questions that reached a consensus were included in the quizzes (Table 5.1).

Likert-Scale Questionnaire

Participants in both control and experimental groups were also requested to complete a Likert-scale based questionnaire to assess their attitudes and perceptions regarding the usefulness of various features of the resources provided, in the context of learning neuroanatomy of the spinal pathways, visualizing neuroanatomical structures in 3D and understanding the clinical implications of basic neuroanatomical facts (Table 5.2, Appendix 11). Participants were also inquired about the mental effort they invested to learn neuroanatomy while using the resources. Lastly, participants were asked usability questions to record user-analytics regarding their interaction with the tools (usage, frequency, time of use and venue).

Table 5.2: Perceptual Assessment of Resources

Likert-scale question	Control Median (IQR)[a]	Experimental Median (IQR)
Rate (1=very poor; 9=excellent) the online resource for:		
Clarity of explanation	8 (7.2-9)	8 (7-9)
Enhancing interest to learn spinal pathways	6 (5-9)	8 (6-9)
Rate (1=very poor, 9=excellent) the usefulness of following features of the online resource for learning spinal pathways:		
Explanation of key principles of pathway layout[b]	7 (6-9)	8 (7-9)
Step by step drawings of neural pathways	8 (7-9)	9 (7.5-9)
Cross-sectional images containing spinal tracts	8 (7-9)	9 (7-9)
Summarization of information and tables	8 (7-9)	8 (7-9)
Quizzes, feedback	7 (6-9)	8.5 (6-9)
CT, MRI images	6 (6-8.75)	8 (6.5-9)*
3D computer models	6.5 (6-9)	8 (6-9)
Rate (1=very poor; 9=excellent) the usefulness of online resource for learning:		
Clinical relevance of neuroanatomy of tracts	8 (6-9)	8 (7-9)*
Localization of neurological lesions	8 (6.25-9)	8 (7-9)
3D relationship of structures	7 (6.5-9)	8 (7-9)
Neuroanatomical structure identification on CT, MRI	7 (6-9)	8 (6.25-9)
Explaining objectives mentioned in learning outcome	9 (7-9)	8 (7-9)
Rate usefulness of the features of online resource in 3D visualization of spinal pathways (1=very poor; 9=excellent):		
Images of brain prosections	8 (7-9)	8 (7-9)
2D / 3D illustrations	7 (6-9)	8 (7-9)
3D brain models	7 (5-9)	7 (7-9)
Animations, video lectures	7 (6-9)	8 (7-9)
Images of cross-sections of brain prosections	8.5 (7-9)	8 (7-9)
CT / MRI sections	8 (6-9)	8 (7-9)
Rate your interest in learning neuroanatomy after using the resource (1=very poor; 9=excellent)	7 (5-8)	7 (6-7.75)
Rate difficulty level for learning neuroanatomy while using the resource (1=very easy; 9=very difficult)	5 (3.25-8)	5 (3-7)
While using the resource, rate (1=very low; 9=very high) the mental effort associated with:		
Finding information mentioned in learning outcomes	5 (3-6.5)	5 (2-6)
Learning relationships of neuroanatomical structures	6 (5-8)	5.5 (4-6)
Understanding cross-sections of brain prosections	7 (4-7.5)	5 (3-6)
Learning to identify structures on CT, MRI images	6 (5-8)	5 (3-6)*
Learning clinical relevance of spinal tracts[b]	7 (6-8)	5.5 (4-6)**
Learning to localize neurological lesions	7.5 (6-8)	6 (4-7)*
Additional comments:		

[a] Inter-quartile range (25^{th} to 75^{th} percentile). [b] [A] what are 1^{st}-2^{nd}-3^{rd} order neurons, [B] how to relate ipsilateral / contralateral deficits with lesions being below/above decussation?

$^{*}P < 0.05$, $^{**}P < 0.01$ for comparison between control and experimental groups.

Study Population

A total of 154 participants completed the baseline quiz 1 (Appendix 9) and were considered eligible to participate in the study and were randomly assigned to the control and experimental groups according to their program of study (Figure 5.2). Following 2 weeks of online access to the learning tools, 138 students (68 control, 70 experimental) consented to further participate in the study and completed phase 2 (quiz 2 and perception questionnaire). Sixty-two participants did not use the allocated online resources and were placed in the 'NU group'. Participants in each group were matched against the initial list of 154 participants for completion of quizzes 1 (Appendix 9) and 2 (Appendix 10). Those who had not completed both phases were excluded from further analysis leaving 36 students in the NU group (21 direct entry medicine, 15 graduate entry medicine students), 21 students in the control group (3 clinical therapy, 7 direct entry medicine, 11 graduate entry medicine students) while the experimental group contained 28 students (2 clinical therapy, 18 direct entry medicine, 8 graduate entry medicine students) (Figure 5.2).

Statistical Analysis

Study data were coded, anonymized and entered into Microsoft Excel™ 2016 spreadsheets (Microsoft Corp., Redmond, WA). The percentage correct response (PCR) for easy, difficult and total (easy and difficult combined) questions, was calculated for each participant-for both quizzes, and was used as the dependent variable to compare students' performances between groups.

The PCR data for all participants was exported to the Statistical Package for Social Sciences™ (SPSS), version 22 (IBM Corp., Armonk, NY). Sample data was tested for normality and homogeneity of variance separately for easy, difficult and total categories (using histogram, normal probability plots, Shapiro-Wilk test), for six possible groups; quiz 1 and quiz 2, for control, experimental and NU groups each. Descriptive statistics (median, interquartile range) are used to present the data for neuroanatomy quizzes and Likert scale questionnaires, for each group, across a skewed sample distribution.

Performance-improvement in total, easy and difficult categories was gauged both between groups (control v. experimental, experimental v. NU, control v. NU) for both quizzes as well as within each group (quiz 1 v. quiz 2). Non-parametric testing was conducted due to skewed sample distributions of PCR scores. Kruskal-Wallis test was used to compare PCR scores between the three independent groups (control v. experimental v. NU), followed by a post-hoc Mann-Whitney U test (control v. experimental, experimental v. NU, control v. NU) (Table 5.3). Wilcoxon’s signed-ranks test was employed for the within-group comparison, as the quiz 1 as well as the quiz 2 data within each group had been acquired from the same participants (Table 5.3). Pearson’s rank correlations revealed the relationships between PCR scores and the Likert-scale perceptual ratings of participants.

Results

Table 5.3: Participants' Performances on Neuroanatomy Quizzes

	Quiz question	PCR[a]			Quiz comparison[b]			Group comparison[c]			
		Ctr	UCC	NU	Ctr	UCC	NU	Ctr v. UCC v. NU	Ctr v. UCC	UCC v. NU	Ctr v. NU
Q1	Total	20.8 (16.7 - 25.0)	16.7 (9.4 - 29.2)	16.7 (9.4 - 25.0)	***	***	***	0.474	0.279	0.832	0.277
	Easy	18.8 (12.5 - 25.0)	12.5 (6.3 - 23.4)	12.5 (6.3 - 25.0)	***	***	***	0.556	0.288	0.880	0.384
	Difficult	25.0 (12.5 - 37.5)	25.0 (12.5 - 37.5)	12.5 (12.5 - 25.0)	**	***	***	0.359	0.343	0.731	0.142
Q2	Total	66.7 (56.2 - 87.5)	81.3 (52.1 - 91.7)	62.5 (46.9 - 74.0)				0.134	0.356	0.062	0.236
	Easy	73.3 (60.0 - 90.0)	83.3 (66.7 - 93.3)	73.3 (53.3 - 86.7)				0.274	0.266	0.118	0.823
	Difficult	66.7 (38.9 - 77.8)	66.7 (33.3 - 100)	44.4 (33.3 - 63.9)				0.251	0.495	0.237	0.102

[a]Percentage correct response (median and interquartile range) on total, easy and difficult questions. [b]Comparison of PCR scores between Q2 and Q1 for total, easy and difficult questions (Wilcoxon's signed-ranks test, $**P < 0.01$, $***P < 0.001$). [c]Comparison of PCR scores between groups (Kruskall-Wallis test for comparison of 3 groups, followed by post-hoc Mann-Whitney U test, *P* values shown).
Ctr = control tool group (N = 21), NU = no use group (N = 36), PCR = percentage correct response, Q1 = quiz 1, Q2 = quiz 2, UCC = UCC tool group (N = 28).

Following the completion of both quizzes, the percentage of correct response (PCR) was calculated for each group (control, experimental, NU), for total, difficult and easy questions (Table 5.3). The PCR scores were tested for normality and homogeneity of variance. The Shapiro-Wilk test reported a significant deviation from normality for the control, experimental and NU groups, for the total, easy and difficult questions in the baseline quiz 1

($P < 0.05$). A similar significant deviation from normality was also found for the quiz 2 PCR scores, except for the NU-total-quiz 2 (P = 0.44) and control-difficult-quiz 2 scores (P = 0.38). Outliers were identified in the easy category, however, these were not excluded from the analysis as their removal did not affect the normality results (data not shown).

Baseline Performance on Neuroanatomy Quiz 1

A comparison of baseline knowledge, before exposure to the online tools provided, shows that participants in the NU, control and experimental groups possessed a similar level of comprehension of spinal pathways' neuroanatomy. There was no statistically significant difference between the PCR scores of participants in the three groups (Table 5.3, Kruskal-Wallis test) for the total (χ^2 = 1.493, P = 0.474), easy (χ^2 = 1.176, P = 0.556) and difficult questions (χ^2 = 2.048, P = 0.359). Post-hoc Mann-Whitney U test (Table 5.3) revealed no significant difference between the PCR scores of control and experimental groups for the total (U = -1.083, P = 0.279), easy (U = -1.062, P = 0.288) and difficult questions (U = -0.948, P = 0.343). Similar results were obtained when experimental group was compared against the NU group (Table 5.3, Mann-Whitney U test, total; U = -0.212, P = 0.832, easy; U = -0.151, P = 0.880 and difficult questions; U = -0.344, P = 0.731) and the control group was compared against the NU group (Table 5.3, Mann-Whitney U test, total; U = -1.088, P = 0.277, easy; U = -0.871, P = 0.384 and difficult questions; U = -1.470, P = 0.142).

Comparison of Performance Between Quiz 1 and Quiz 2

The results reveal that participants' knowledge of neuroanatomy of spinal pathways enhanced after being provided online access to the learning tools for two weeks. Wilcoxon's signed-ranks test showed a statistically significant difference between the PCR scores, before and after exposure to the online tool (quiz 1 v. quiz 2), in the control group (easy questions; $Z = -3.982$, $P < 0.001$, difficult questions; $Z = -3.374$, $P < 0.01$, total questions, $Z = -3.877$, $P < 0.001$, Table 5.3). A similar significant enhancement of performance (quiz 1 v. quiz 2) was shown within the experimental group (Wilcoxon's signed-ranks test, easy questions; $Z = -4.624$, $P < 0.001$, difficult questions; $Z = -4.260$, $P < 0.001$, total questions, $Z = -4.604$, $P < 0.001$, Table 5.3). It was noted that the participants in the no-use group who did not access the online tools provided, also showed a similar enhancement in their PCR scores after the two week time period (Wilcoxon's signed-ranks test, easy questions; $Z = -5.233$, $P < 0.001$, difficult questions; $Z = -4.678$, $P < 0.001$, total questions, $Z = -5.233$, $P < 0.001$, Table 5.3).

Comparison of Performance in Quiz 2 Between Groups

An analysis of the participants' performances in the second neuroanatomy quiz was conducted to compare between the control, experimental and NU groups. Students in all three groups were found to have a similar level of knowledge of spinal pathways' neuroanatomy. For the easy-questions, Kruskal-Wallis test showed no statistically significant difference between PCR scores of three groups ($\chi^2 = 2.588$, $P = 0.274$). The results were further supported by a post-hoc Mann-Whitney analysis which also revealed no difference for individual comparisons between pairs of groups (Table 5.3, control v. experimental; $Z = -1.113$, $P = 0.266$, experimental v. NU; $Z = -1.564$, $P = 0.118$, control v. NU; $Z = -0.224$, $P = 0.823$). Similar results were obtained for the difficult questions (Table 5.3, $\chi^2 = 2.768$, $P = 0.251$, Kruskal-Wallis test) with no significant difference seen between control and experimental groups (Table 5.3, Mann Whitney U test, $U = -0.683$, $P = 0.495$), experimental and NU groups (Table 5.3, Mann Whitney U test, $U = -1.183$, $P = 0.237$) and control and NU groups (Table 5.3, Mann Whitney U test, $U = -1.636$, $P = 0.102$).

For the three-group comparison for the total questions, no significant difference was observed between the groups (Table 5.3, $\chi^2 = 4.022$, $P = 0.134$, Kruskal-Wallis test). However, the PCR scores of the experimental group (Mdn = 81.3, IQR = 52.1-91.7) were found to be higher than those of the NU group (Mdn = 62.5, IQR = 46.9-74.0), with a Mann-Whitney U test revealing a borderline statistically significant difference between them (Table 5.3, $U = -1.865$, $P = 0.062$). The remaining group comparisons did not reach significance (Table 5.3, Mann Whitney U test, control v. experimental; $U = -0.923$, $P = 0.356$, control v. NU; $U = -1.185$, $P = 0.236$).

To further analyze the learning gain following the 2 week-time period, the changes in the PCR scores, i.e. the difference in PCR between quiz 2 and quiz 1, was calculated (quiz 2 PCR - quiz 1 PCR = ΔPCR). The ΔPCR values for the experimental and NU group were found to be significantly different from each other while the control v. NU comparison did not reach statistical significance.

A Kruskal-Wallis test showed no significant difference between the ΔPCR values of the control, experimental and NU groups for the easy ($\chi^2 = 0.002$, $P = 0.960$), difficult ($\chi^2 = 0.406$, $P = 0.524$) and total questions ($\chi^2 = 0.171$, $P = 0.679$). Post-hoc analysis of ΔPCR scores for the total category revealed that the experimental group showed a higher median score (Mdn = 58.3, IQR = 42.72-69.77) compared to the control (Mdn = 45.8, IQR = 31.3-64.6) and the NU groups (Mdn = 45.8, IQR = 33.34-54.17), with a statistically significant difference found for the experimental v. NU comparison (Mann Whitney U test, $U = -2.133$, $P = 0.033$). The difference did not reach a statistically significance level for the experimental v. control ($U = -1.265$, $P = 0.206$) and control v. NU comparisons ($U = -0.414$, $P = 0.679$). A

Mann Whitney post-hoc analysis for comparison of ΔPCR values for the three groups (control, experimental, NU) was also conducted separately for the easy and the difficult questions, but no significant difference was revealed for the experimental v. control (easy; $U = -1.031$, $P = 0.302$, difficult; $U = -0.849$, $P = 0.396$), control v. NU (easy; $U = -0.050$, $P = 0.960$, difficult; $U = -0.638$, $P = 0.524$) and experimental v. NU comparisons (easy; $U = -1.577$, $P = 0.115$, difficult; $U = -1.510$, $P = 0.131$).

The ΔPCR represents the absolute learning gain from the Quiz 2 and Quiz 1 PCR scores, between two different time points before and after the intervention. However, since the maximum test score of the questionnaire cannot rise beyond 100%, therefore, a higher Quiz 1 (pre-intervention) score could be inversely correlated with the Quiz 2 (post-intervention) score, thus giving a false perception of a lower learning gain. In order to reduce the confounding influence of the baseline knowledge of neuroanatomy (Quiz 1 score) of the participants on performance enhancement, the normalized learning gain is calculated by dividing the absolute learning (Quiz 2 – Quiz 1 PCR score) by the maximum possible learning gain (100 – Quiz 1 PCR score) (Pickering, 2016). This allows for the actual learning gain to be recorded independent of Quiz 1 scores (or baseline neuroanatomy knowledge) and permitting a better comparison between groups. When conducting the analysis, Kruskal-Wallis test showed no significant difference between the learning gains of the control, experimental and NU groups for the easy ($P = 0.238$), difficult ($P = 0.122$) and total questions ($P = 0.109$). However, like the ΔPCR results mentioned above, post-hoc analysis of the normalized learning gain values for the total category revealed that the experimental group performed significantly better than the NU group (Mann Whitney U test, $U = -2.112$, $P =$

0.035). The difference did not reach a statistically significance level for the experimental v. control (U = -1.162, P =0.245) and control v. NU comparisons (U = -0.645, P = 0.519).

Like the ΔPCR analysis highlighted above, Mann Whitney post-hoc analysis for comparison of normalized learning gain values for the three groups (control, experimental, NU) was also conducted separately for the easy and the difficult questions. Once again, no significant difference was revealed for the experimental v. control (easy; U = -1.133, P = 0.257, difficult; U = -0.963, P = 0.335), control v. NU (easy; U = -0.058, P = 0.954, difficult; U = -1.278, P = 0.201) and experimental v. NU comparisons (easy; U = -1.693, P = 0.090, difficult; U = -1.875, P = 0.061).

Comparison of Performance between Easy and Difficult Questions

Further analysis showed that the participants' increase in knowledge of neuroanatomy measured in quiz 2 was higher for the easy questions compared to the difficult questions. Within the control group, students showed a significantly enhanced knowledge of neuroanatomy of spinal pathways when answering the easy questions (Mdn = 60.8, IQR = 24.9–71.0) as compared to the difficult questions (Mdn = 38.9, IQR = 7.65–59.0) (Z = -2.56, P < 0.05, Wilcoxon's signed-ranks test). Similarly, within the experimental group, a significantly enhanced performance was observed when participants answered the easy questions (Mdn = 67.1, IQR = 41.2–74.9) as compared to the difficult questions (Mdn = 35.4, IQR = 19.7–75.0) (Z = -2.82, P < 0.01, Wilcoxon's signed-ranks test). Similar enhancement in performance for easy v. difficult questions (easy; Mdn = 73.3, IQR = 53.3–86.67, difficult; Mdn = 44.44, IQR = 33.33–63.89) was also shown for the NU group (Z = -4.36, P < 0.001, Wilcoxon's signed-ranks test).

Likert-Scale Questionnaire Results

Participants who had accessed the online resources, were asked a series of questions to acquire insight into user-analytics (Appendix 11). For instance, most participants accessed the online tool ‘only once’, except, for 4 participants in the control group (accessed twice) and 9 in the experimental group who accessed the tool ≥ 2 times. The experimental devoted an average of 42.5 minutes, while the control group dedicated an average of 31 minutes while learning from the online tool. The duration of usage of the online tool was not correlated with quiz 2 performance (the PCR score), for the experimental group participants (easy questions; r = 0.07, difficult questions; r = 0.02), while only a weak correlation was observed in control group (easy questions; r = 0.2, difficult questions; r = 0.39). The usage of online tool was homogenous across the time of the day and the venue where the tool was accessed.

When Likert-scale questions were used to inquire about the participants’ perceived usefulness of various components of the learning tools (Appendix 11), overall the median (and interquartile range) scores for the experimental group were found to be higher compared to the control group. However, the difference reached statistical significance only for the questions of clinical relevance. CT and MRI images; when employed by the UCC online tool (experimental group) were perceived to be more useful for learning the neuroanatomy of the spinal pathways as compared to the control resource (Table 5.2, U = -2.187, P < 0.05, Mann-Whitney U test). The UCC tool was also perceived to be more useful for learning the clinical correlates of the spinal pathways (Table 5.2, U = -1.652, P < 0.05, Mann-Whitney U test). Lastly, results showed that less mental effort was required for learning to identify neuroanatomical structures on radiological images (Table 5.2, U = -2.007, P < 0.05, Mann-

Whitney U test), learning the clinical correlates of the spinal tracts (Table 5.2, $U = -2.633$, $P < 0.01$, Mann-Whitney U test) and the localization of neurological lesions (Table 5.2, $U = -2.308$, $P < 0.05$, Mann-Whitney U test), when using the UCC online tool as compared to the control tool.

Further correlational analysis was conducted between the Likert-perceptual ratings of the participants and their PCR scores in the quiz 2; separately for the easy and the difficult categories of questions. Overall, stronger correlations were found in the experimental group as compared to the control group (Figure 5.3). For the control group, a significant correlation was demonstrated between the quiz 2 PCR scores of the participants and the perceived usefulness of the cross-sectional images (with labelled spinal tracts) contained within the online resource (Figure 5.3, $P < 0.05$ for difficult questions). All remaining correlations were weak and non-significant ($P > 0.05$).

On the contrary, significant correlations were identified in various domains for the experimental group, ($P < 0.05$), across both easy and difficult questions, including the clarity of explanations, enhancement of student interest, the usefulness of step by step drawing of the neural pathways, the use of cross-sectional images, quizzes with feedback, the use of CT and MRI images, and the use of 3D digital models in the resource. Finally, a significant correlation was revealed only for the easy questions with regards to the summarization of information in the novel UCC resource (Figure 5.3, $P < 0.01$).

The perceived Likert-ratings of participants in the experimental group were also strongly correlated with their quiz 2 results in the context of learning clinical correlates and the localization of neurological lesions, 3D relationship of neuroanatomical structures, structure identification on neuroradiological images (CT, MRI) and the explanation of objectives mentioned in the learning outcomes (Figure 5.3, $P < 0.01$). None of these domains revealed a significant correlation in case of the control group (Figure 5.3, $P > 0.05$).The questionnaire inquired if the images of brain prosections, 2D / 3D illustrations, 3D digital brain models, animations and video lectures, cross-sectional brain images, and CT / MRI sections, when present within the allocated resources, were useful for 3D visualization of the spinal pathways. A Cronbach's alpha analysis showed a significant internal consistency between the Likert ratings of these items (control group $\alpha = 0.893$, experimental group $\alpha = 0.964$). The individual item Likert results revealed that participants' opinion in the experimental group was significantly correlated with the quiz 2 scores for cross-sectional images of brain prosections in both easy and difficult categories of questions (Figure 5.3, $P < 0.01$). Significant correlations were also observed for the images of gross brain prosection sand 3D digital brain models across the easy category of questions (Figure 5.3A, $P < 0.05$). When specifically inquired about the usefulness of neuroimaging (CT, MRI sections) in aiding 3D visualization of spinal pathways, significant correlations were obtained between the Likert ratings and the quiz 2 scores for the difficult questions (Figure 5.3B, $P < 0.01$).

Results from the experimental group also reveal that while using the UCC resource, a significant inverse correlation existed between the mental effort required for finding the information mentioned in the learning outcomes and PCR score on quiz 2 (easy questions $r = -0.43$, difficult questions $r = -0.39$, $P < 0.05$). A significant inverse correlation was also observed for the difficult questions between learning to identify structures on CT and MRI and quiz 2 score ($r = -0.41$, $P < 0.05$). On the contrary, in the control group, none of the inverse correlations between the mental effort invested and quiz 2 score were significant ($P > 0.05$, data not shown).

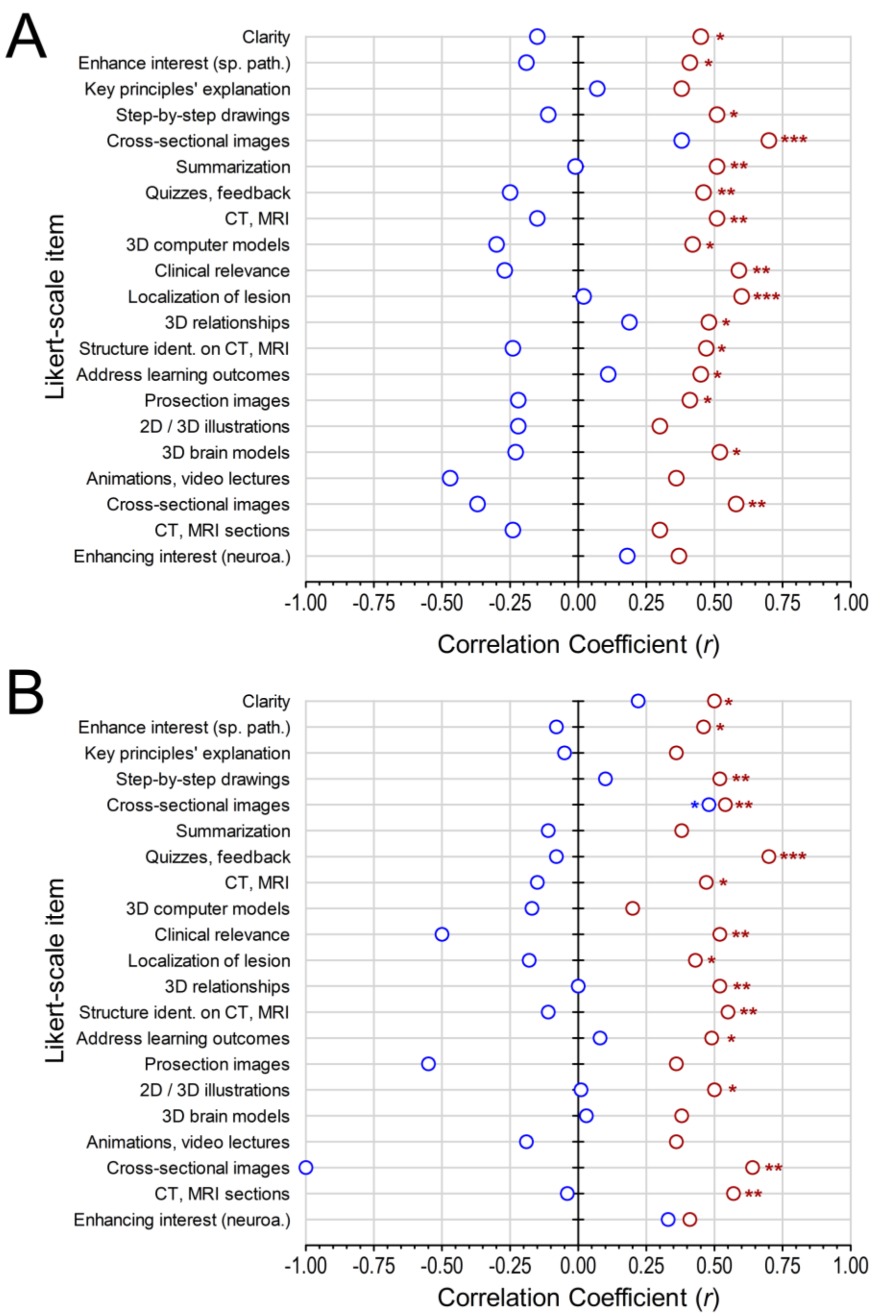

Figure 5.3. Relationship between quiz 2 performance scores and participants' Likert-scale ratings. **A,** Graphical representation of the Pearson's rank correlation coefficients for the linear relationship between the participants' quiz 2 PCR scores and their Likert-scale perceptual ratings for the easy questions. **B,** Graphical representation of the Pearson's rank correlation coefficients for the linear relationship between the participants' quiz 2 PCR scores and their Likert-scale perceptual ratings for the difficult questions. Blue dots: UCC tool, Red dots: Control tool. Pearson's rank correlation (r), *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.

Discussion

The novel application developed and evaluated as part of the current research study is the first resource whose instructional design has been based on the suggestions and limitations previously identified in existing neuroanatomy learning resources by a group of experienced anatomy educators and undergraduate students (Javaid et al., 2019).

The control neuroanatomy web-resource by the University of British Columbia had been ranked as the best-available free online resource for learning spinal pathways' neuroanatomy in a previous research study conducted by our group (Krebs, 2016; Javaid et al., 2019). However, the resource has limitations in terms of the level-of-detail offered when examined in light of the core neuroanatomy syllabus outlined by Moxham et al. for early stages of medical education (Moxham et al., 2015). Moreover, it did not elaborate upon the clinical correlates of neuroanatomical concepts and linking basic neuroanatomy with its clinical neurological correlates to address neurophobia. Nowinski and Chua, on the other hand, created a neurological localization software, which was geared towards clinical neurology but lacked in explaining the underlying basic neuroanatomical details (Nowinski and Chua, 2013). To date a resource which could explain the spinal pathways' neuroanatomy in adequate detail and in an interactive fashion and at the same time, streamline the thinking process of novice learners towards practical application of this knowledge for localization of neurological lesions, is missing. Such a link between basic neuroanatomy and its clinical application in any pedagogical approach is paramount for its success in effectively addressing the grueling problem of prevailing neurophobia.

In this study, a randomized controlled trial (RCT) was employed as part of the experimental design to assess the educational efficacy of a novel e-learning tool against the best available e-resource. Later, a third group was generated comprising of students who did not use any allocated e-resource. The results suggest that the three groups performed similarly on the baseline quiz 1 and all improved significantly on quiz 2 (Table 5.1). Although, RCTs have been advocated as effective research tool to assess educational strategies (Calvert and Freementle, 2009). However, when looking at the results one must be mindful of the fact that educational research is hard to control. While RCTs help to avoid selection-bias, there are challenges associated with assessing educational strategies through RCTs in real-life settings (Parks, 2009). For instance, at what stage during their studies might students be randomized? The similar improvement in quiz 2 performance across the three groups may be linked with the time when randomization was conducted during the neuroanatomy course. The e-resources were allocated to the students in the control and experimental groups, around the midpoint of the course at which time a significant proportion of the students might have begun their study towards examination. This may account for a significant portion of the improvement noted across all groups. While comparison of quiz 2 performances across the three groups revealed no significant difference, a marginal difference was observed between the experimental group and the non-user group. Moreover, analysis of the ΔPCR scores (quiz 2 PCR – quiz 1 PCR) showed that students using the novel UCC tool improved their performance to a significantly greater extent than the non-user group. When a similar comparison was performed between the control tool and the non-user group, the statistical analysis revealed no difference in performance improvement. In the context of performance improvement discussed above, it could be argued that the novel UCC tool is a more reliable resource in improving student's performance.

An additional challenge linked with an RCT is the difficulty associated with blinding the teacher and the student. Thus, any RCT is vulnerable not only to performance bias (the behavior of the teacher applying novel techniques might be very different from their colleague giving a didactic lecture) but also placebo effects (the students might pay more attention and be more willing to turn up for novel teaching methods). Paradoxically, students might also be resistant to change and reluctant to participate in classes where new and unfamiliar teaching methods are tried further confounding the results. To overcome such potential confounds in our study, the students were not made aware of their allocation into the control or the experimental groups. However, once the quiz 2 evaluation had been conducted, it was ensured that both novel and control e-tools were accessible to every student in the class, thus abiding by the approved institutional ethical guidelines and not depriving students of valuable e-learning content.

When the comparison of quiz 2 to quiz 1 results were broken down into easy and difficult questions, the results for both tools showed that the improvement in participants' performance in the easy category was significantly greater as compared to their performance enhancement in the difficult category. Since, all questions pertaining to the clinical localization of neurological lesions were included in the difficult category, the lack of improvement implies that neither tool (control or experimental) is effective in enhancing the capability of the undergraduate students in applying the basic neuroanatomical knowledge onto clinical situations. Both tools have a limited capability in effectively breaking the problematic nexus between the neuro-anatomy-phobia and the consequent neuro-phobia.

Furthermore, a comparison between the Likert-scale ratings revealed that the students using the novel UCC tool had a higher appreciation of the tool than their counterparts using the control tool with regards to performance enhancement across various clinical domains. However, comparison of quiz 2 performance in the difficult category (questions with clinical application) between the two groups showed no statistically significant difference. The apparent contradiction between the perceptual opinion of the students and the quantitative quiz 2 results implies that although the novel UCC tool successfully enhanced students' interest in learning neuroanatomy and its clinical correlates, its instructional design still did not have sufficient impact to translate the participants' positive perceptual opinion into hardcore factual improvement in their quantitative performance scores.

The correlation analysis between the participants' perceptual opinion (Likert ratings) of the usefulness of various features of the resources and their knowledge assessment (quiz 2 PCR scores), provides further evidence in support of the implication above. As both groups performed similarly in quiz 2, the higher strength of the correlations observed for users of the UCC tool suggest that students who performed well on the assessment had a higher opinion of the tool they used while high performers in the control group did not share this level of appreciation for their tool. The link between the perceptual opinion of the participants regarding the efficacy of the novel UCC tool and the resultant quantitative outcome is in contradiction with results for the best available resource offered to the control group. While students in the control group rated their instrument lower than the experimental group, their results showed that they performed equally well on quantitative assessment (quiz 2).

Despite the fact that there were no differences in quiz performance between the experimental and control groups, it must be noted that users of the UCC tool displayed a higher performance improvement on quiz 2 than their non-user counterparts while the control group showed no difference with the non-users. Similarly, the overall Likert ratings showed that user of the UCC tools had a higher appreciation of the features of the novel tool in relation to their learning of the neuroanatomical spinal pathways. It appears that while it only partly achieved its educational goal, the instructional design of the UCC tool based on previous queries of similar cohorts was more appealing to the participants and better met their learning needs than the control tool. The tool was designed to meet the learning objectives for the spinal pathways of the published core syllabus of the International Federation of Associations of Anatomists (IFAA) and of the European Federation for Experimental Morphology (EFEM) (Moxham et al., 2015) with the aim of bridging the disconnect between the acquisition of neuroanatomical knowledge and its clinical application. As discussed above, users of the tool did not display more significant improvement in answering clinically oriented questions than their counterparts in the other groups, suggesting that the tool did not reach its clinical correlation objective. Neuroanatomy is considered primarily a basic science and is usually taught in the preclinical years of medical and clinical sciences curricula. The lack of clinical exposure and its associated information processing may have impeded the capacity of students to perform equally well on clinically oriented questions (application of knowledge) compared to fact-based questions. As it raises the possibility that neuroanatomy teaching may occur too early in the curriculum, leading to the well described disconnect between knowledge and its application accepted as the source neurophobia, it would be of interest to revisit curriculum design and re-assess the tool with later cohorts of students.

Features of a good multiple-choice-question (MCQ) test and ways to improve the test-design in the future

A good multiple-choice-questions' test should be able to accurately gauge students' mastery of the topic with a linear relationship between the test-scores acquired and students' knowledge of the topic. In order to minimize guessing in an MCQ-based evaluation, several guidelines could be taken into consideration pertaining to the stem of the question, the design of options (keyed response and distractors), and the formulation of the evaluative scoring scheme.

1) In order to improve the validity of the test, MCQs could be asked across different categorizations of Bloom's taxonomy, such as, remembering and understanding, applying and analyzing, evaluating and creating. Both quizzes (1 and 2; Table 5.1) contained questions falling along different categories along the Bloom's hierarchy and thus were labeled as 'easy' or 'difficult' (described in the results). However, 'easy' or 'difficult might be a very broad categorization of questions. A more detailed categorization could implemented in the future by having questions representative of all stages of Blooms' taxonomy.

2) The stem of the MCQ item / question should always be phrased like a question (not a partial sentence). A question stem is preferable because it allows the student to focus on answering the question rather than holding the partial sentence in working memory and sequentially completing it with each alternative, thus unnecessarily increasing the cognitive load. The stem should be meaningful, focus on one problem and avoid unnecessary information (for instance, Quiz 1–Q4 contains unnecessary information not relevant to assess to learning outcome, i.e., the right / left-sided functional impairment in relevance to the

lesion. The question-stem should be positively phrased, unless specific learning outcomes require a negative phrasing. Lastly, trick questions should be avoided, as they do not assess content-mastery. In context of the stem of the question providing an answer to the student, perhaps the option of matching the questions (Quiz 1–Q5, Quiz 2–Q3) and arranging them in a chronological sequence (Quiz 2–Q13), could have been avoided. In addition, to reduce extraneous processing the question-stem and images provided should be placed in close proximity to the options. The spatial contiguity principle was not strictly observed in Quiz 1–Q21.

3) Test-wiseness is a skill that permits a test-taker to utilize the characteristics and forms of tests and/ or test-taking situation to receive a high score. A test will be considered as a good test, if the options and distractors are designed in a way which minimizes students' ability to apply the test-wiseness strategies or intelligent-guess work and get a higher score which is irrelevant or independent of the learning outcome they are supposed to master. Not being able to accomplish this, comprises the validity of the test.

In context of test-wiseness (and intelligent guess work) and task-irrelevancy, followings considerations could be undertaken while designing effective options and alternatives (distractors). a) Implausible distractors should not be designed. Common student errors provide the best source of distractors, with the number of alternatives usually limited to four. The number of alternatives in some quiz questions in the study dropped down to 3 and in others went up to 8 (for example, Quiz 1–Q17). b) Alternatives should be stated clearly and concisely. Items that are excessively wordy assess students' reading ability rather than their attainment of the learning objectives. Moreover, they should be the same length as the keyed response. c) Ideally, the alternatives should be mutually exclusive with no overlapping content as these may be considered ‘trick’ items by test-takers. In this context, some overlapping alternative-statements in our quizzes should have been avoided (Quiz 1–Q4; option D overlapping over C, Q13; overlapping of A and F on other options, Q19; options E and F are overlapping the other options). However, at the same time they should be homogenous in content, as alternatives which are heterogenous in content can also provide cues to student about the correct answer. d) Inadvertent clues could be used by sophisticated test-takers to guess the correct answer. This could be minimized by using alternatives with similar length, wording them in a similar way to make each option believable for those students who have not covered the topic well, ensuring that the grammar and syntax of both the stem and the options agree and varying the placement of the correct answer to avoid creating a pattern. For the latter, the alternatives could be presented in a logical order (e.g. alphabetical or numerical) to avoid a bias towards certain positions. e) Using “all of the above” and “none of the above” reduce the accuracy of the test in assessing the content and hence discouraged. Thirdly, absolutes such as “always” and “never” should be avoided as they could throw off the students having them think that there is one-exception. Moreover, negative words such as “except” or “not” (for instance, in Quiz 1–Q15 and Quiz 2–Q7). create confusion and not to be used, because students cannot know the answer without reading the options and hence are not only being tested on the content but also for their ability to work through the negatives to answer the question.

Negative marking has been employed as an approach to prevent guess work. However, I am of the opinion that it renders the risk of obtaining test results which are an incorrect representation of students’ knowledge of the topic. Instead, students should be provided the liberty to select a sub-set (> 1) of options and then scored based on the number of distractors identified. Unsure students might be able to identify a group of options by eliminating a few distractors only; not all of them. These students should also be given some mark but not the same as the students who correctly identified the single best answer (or in other words, ruled out all distractors successfully). Doing so, qualifies the test-score as a very good indicator of students' knowledge of the topic.

In-depth interviews and / or focus groups vs. free-text surveys

The questionnaires were preferred over in-depth interviews and focus groups in all studies because once the surveys had been designed, they could be distributed to a large number of students with very little effort (Fricker and Schonlau, 2002; Smith et al., 2018). This was logistically feasible, as the second-year medical students in our institution are available during the first semester only. Failure to acquire, analyse and interpret the data during this limited time, could have introduced a potential danger of diminished students' accessibility and consequent reduced participants' response rate (Cook et al., 2000; Truell et al., 2002). Moreover, the preference for employing free-text surveys was also dictated by the research study-design. As part of the aim 3 (Chapter 5), students could be assessed for their knowledge of spinal pathways (Quiz 2; Table 5.1, Appendix 10), once they had been taught the sensory and motor spinal pathways as part of their scheduled lectures in the module. Following their last lecture on spinal pathways, there remained a very short time-window available to acquire the data (Quiz 2, Table 5.1, Appendix 10) prior to the commencement of the end-of-module summative assessment.

In the above-mentioned context, the surveys were a safer choice versus in-depth interviews. Interviews would have been conducted on a one-to-one basis. These would have required a large amount of the investigator's time during the interviews and also for transcribing and coding the data. Focus groups, on the other hand consist of one investigator and a number of participants in any one session (Adams and Cox, 2008). Although the views of any one participant cannot be probed to same degree as in an in-depth interview, the discussions that are facilitated within the groups often result in useful data in a relatively shorter space of time than that required by one-to-one interviews (Adams and Cox, 2008).

I would, however, would like to highlight that the surveys used in the studies also contained some open-ended questions, allowing students to provide additional detailed opinions, if they deemed it necessary. The thematic analysis of such responses provided additional insight into their perceived usefulness of various features of neuroanatomy learning e-resources, apart from that acquired from the surveys (Joffe and Yardley, 2004). However, the study-design for the future studies could still be improved by employing all above-mentioned research methodologies (i.e., interviews, focus groups and questionnaires) for acquiring participants' data. Such a triangulation of data-acquisition techniques enables them to complement each other's weaknesses (De Leeuw, 2005; Adams and Cox, 2008).

Limitations

The following limitations to this study are worthy of discussion.

Baseline Normalization of Participants Across Control, Experimental and Non-User Groups.

Although the quiz 1 performance results did not show statistically significant differences between groups, additional normalization measures could have been exercised, including measures of spatial orientation and cognitive performance.

Limitations of RCTs and Designing Repeat RCTs in Stringent Controlled Settings.

Since, the issue of neurophobia, in the context of neurology patient management, has been widely associated with impaired understanding of neuroanatomy and its prevalence is recognized despite widely available e-pedagogies (Flanagan et al., 2007; Youseff, 2009; Giles, 2010; Sanya et al., 2010; Zinchuk et al, 2010; Matthias et al., 2013, McCarron et al., 2014; Pakpoor et al., 2014), therefore, the educational efficacy of any future educational intervention needs to be compared against the existing pedagogies, prior to its incorporation into the mainstream curriculum design. RCTs would be useful choice from an experimental design perspective. Of course, the possibility exist that the intervention's effects could vary by circumstance. Hence, it may be wise to design the experiment not just to assess the intervention's main effect but also to elaborate some of the conditions under which this effect size varies.

In the same vein, we could argue that since the tools used in this study were not the primary teaching method in the course, the small amount of time spent using the resources may partly explain the lack of difference between the PCR scores of the experimental and the control groups. A future experiment in stringent controlled settings, where participants use the e-resources provided for a similar amount of time and are incentivized to devote a similar attention-level, might reveal a significant difference in performance between the two groups.

Institution-Bias and Single-Use Intervention Bias.

The study was conducted in a single institution (UCC) and therefore the results might not offer a representation of the students' opinions and performances at the national and international levels. Furthermore, as the novel UCC tool was based on prior probing of students from the same institution (Javaid et al., 2018, 2019), it may present an instructional design bias towards the learning style of these cohorts of students. The results, while exciting, need to be challenged by collaborating with and conducting similar experiments in other institutions. Doing so, will also address the potential single-use intervention bias associated with the results.

Conclusion

The novel UCC tool assessed as part of this study was based on an instructional design derived from our previous work. We had probed various aspects of existing neuroanatomy web-resources to identify strengths and weaknesses. In addition, open-ended queries had identified features that students found useful in studying the neuroanatomy of the spinal pathways. In that perspective, the novel UCC neuroanatomy learning tool is more representative of the students' perception. The results from the present study imply that students had a significantly greater belief in the instructional design of the novel online tool as compared to the University of British Columbia neuroanatomy resource (Krebs, 2016) on spinal pathways and that this higher appreciation partly translates into increased assessment performance. With further improvement to its instructional design, this novel tool stands a significantly higher chance to effectively break the prevailing perceived nexus between the neuro (-anatomy-) phobia and the neurophobia, compared to available neuroanatomy web-resources.

CHAPTER 6

General Discussion

6.1 Overview

Technology has infiltrated every aspect of our lives with education being no exception. Computer assisted, and e-learning resources have a significant role to offer to help students learn from the comfort of their homes and in a custom-designed fashion which suits the learning needs and style of each individual learner (Cook, 2007). In this thesis, we have emphasized upon the role of technological e-resources as supplementary teaching tools to address the limitations of existing traditional pedagogies, in the context of learning complex neuroanatomical concepts and structural inter-relationships. This notion becomes even more important while on-campus university teaching hours are being drastically cut down (Drake et al., 2002; Heylings, 2002; Plaisant et al., 2004; Azer and Eizenberg, 2007; Drake et al., 2009) and young medical doctors are consistently associating their impaired understanding of neuroanatomy with a fear of managing neurological patients.

The most important element to be taken into consideration while developing any educational product, is its instructional design. The prevailing problem of neurophobia could be addressed by enhancing student-interest with the help of intelligently designed interactive user-interface and clinical correlation of basic neuroanatomical facts. Hence, an exhaustive review of the literature was conducted which identified gaps in the existing neuroanatomy e-resources and eventually led to the development of the work presented in this thesis (Chapter 1). The novel neuroanatomy e-learning tool developed as part of this Ph.D., has attempted to bridge such gaps by addressing the limitations of the existing neuroanatomy e-learning resources.

Next, we sought to provide direct evidence of the students' perception regarding specific difficulties associated with learning neuroanatomy and we identified the measures required to address those issues (Chapter 2; Javaid et al., 2018). Results have shown that neuroanatomy is perceived as a more difficult subject compared to other anatomy topics, with spinal pathways being the most challenging to learn. The difficulty in understanding the neuroanatomical concepts was found to be linked with intrinsic factors such as the inherent complex nature of the topic rather than outside influences (e.g. lecture duration). Participants reporting high levels of interest in the subject also reported higher levels of knowledge, suggesting that developing teaching tools aimed at increasing interest, such as via case-based scenarios, would facilitate acquisition of knowledge. Participants believed that newer pedagogies, such as, purpose-designed Computer Assisted Learning (CAL) and online resources could enhance neuroanatomy understanding and decrease the neurophobia (Javaid et al., 2018).

Despite the abundance of adjunct teaching neuroanatomy web-resources, students and early career physicians continue to report difficulties in learning and clinically applying neuroanatomy. In this context, we identified the features of neuroanatomy web-resources that were valued by both educators and students with regards to their pedagogical construct (Chapter 3; Javaid et al., 2019). One resource was ranked highest by end-users and educators in terms of clarity of explanation, step-wise teaching design, summarization of information, control of instructional-pace, integration with neurophysiology, neuroradiology and clinical correlates, deployment of pedagogical tools and factors for visualizing neuroanatomical inter-relationships. These results provided a novel user perspective on the influence of specific elements of neuroanatomy web-resources to improve instructional design and enhance learner performance.

The fourth chapter has described the development of a novel, interactive, neuroanatomy learning e-resource developed at University College Cork (UCC), whose instructional design or pedagogical construct has been informed by students' and educators' opinions acquired earlier (Javaid et al., 2019). The e-resource provided information on spinal pathways through a dynamic, interactive, step-by-step incremental learning approach coupled with a discussion of the clinical interpretation of basic neuroanatomical facts to aid in neurological localization, with the aim of successfully addressing the neurophobia in the future.

Next, we sought to evaluate the above-mentioned novel UCC e-resource against the previously identified best-ranked neuroanatomy e-resources. Participants included medical, clinical-therapies and neuroscience students. The knowledge of neuroanatomy of spinal pathways was assessed using neuroanatomy quizzes (quiz 1 and 2); before and after the two-week period of usage of the allocated neuroanatomy e-resources. Participants who did not use the allocated resource were placed in the no-use (NU) group. Participants' opinion regarding usefulness of various components of the tools was gauged using a Likert scale-questionnaire. When quiz 2 percentage correct response scores of the experimental group were compared against the NU group. The increase in knowledge of spinal pathways was found to be significantly higher than the control v. NU comparison. Moreover, the Likert scale ratings revealed a significantly higher median rank-scores for the experimental tool (v. the control tool) for learning the clinical neurological correlates. In addition, the stronger and significant correlations between the students' perceptual opinion and their quiz 2 scores imply that it enhanced students' interest in neuroanatomy.

The data collectively suggests that the novel e-resource has shown promising results in context of breaking the perceived nexus between the neuroanatomy-phobia and the neurophobia.

6.2 Developing the UCC Neuroanatomy E-learning Tool: Pedagogical Constructs

To maximize efficacy, the instructional design of an e-learning tool should be informed by user opinion, including students as well as educators. Such a user opinion for the neuroanatomy e-resources had been previously missing in the literature. The instructional design of the UCC tool has been informed from the principles of cognitive load (Paas, 2003) and Mayer's multimedia theory of learning (Mayer, 2003), and from the adult learning theory principles (Huang, 2002). Most importantly, the novelty of the tool lies in the fact that the tool design has taken into consideration the opinion of the users, namely the medical and health sciences students, regarding factors which they considered most useful for learning neuroanatomy (Javaid et al., 2019).

In the above-mentioned context, the thematic analysis results from Chapter 3 suggested that students prefer easy, simple explanation of facts while avoiding unnecessary detail. The UCC e-learning tool has been designed to provide simple explanations for neuroanatomical facts which are brief, compact and to-the-point, unlike the lengthy, text-based explanations used by many existing e-resources.

The results from Chapter 3 also revealed that students favor an instructional design in which the information is conveyed in a step-by-step manner facilitating a gradual and incremental increase in their knowledge. This allows the overall mental load to remain within the confines of the working memory capacity of the learner at every learning stage. The UCC e-learning resource has incorporated multiple slides into its neuroanatomy learning modules. Each new slide offering incremental information, which has been serially linked with the preceding one, thus giving students the opportunity to assimilate the learnt-content in a gradual, systematic manner. On the other hand, many of the existing e-resources, have the entire neuroanatomy content condensed into one text document, making learning less accessible.

Repetition was also one of the themes identified from the qualitative analysis. The quiz section and the interactive exercise has offered an opportunity to the learner to revise the information learnt earlier, in an interactive fashion. Thus, offering the learner added familiarity with the material and reducing the perceived complexity of the topic.

6.2.1 Interactivity of the Pedagogical Construct of the Existing Neuroanatomy E-resources

Most neuroanatomy web-resources have offered only a limited basic-level interactivity to actively engage the users. This included interactive buttons for text-based description, rollover image labelling with immediate feedback and rotation and panning of 3D models. O' Byrne and colleagues imparted a fade-through image function with the help of a sliding bar that could be used to serially move across sectional representations of the brain (O'Byrne et al., 2008). Interactive questions including MCQs, fill in the blanks, picking correct answers from a list of structures, had been provided by Choudhary et al. (Choudhury et al., 2010). Mobile-based 3D applications, such as, 3D4Medical (http://bit.ly/3D4Medic) and Visible

Body (http://bit.ly/visBod) permitted virtual dissection by allowing students to select and manipulate complex anatomical structures for better visualization (Lewis et al., 2014). e-Anatomy (http://bit.ly/eAnatom) and other similar apps (Brain MRI and Brain MRI Atlas) allowed users to scroll through multiplanar MRI sections and to selectively label specific neuronal structures. The above-mentioned examples show that much work is still left to be done both in developing and evaluating new instructional systems which could impart a greater level of interactivity.

The novel UCC tool has enhanced upon the interactivity of the e-instructional design by offering opportunity to the users to actively trace and draw the entire neuronal pathway. An interactive exercise follows each learning station in which the user is required to upload a specific cross-sectional image of the CNS along the course of the spinal pathway. The user is then required to select the correct location of the spinal pathway within the uploaded cross-sectional image. Incorrect response prompts the user to try again, while a correct response highlights the location of the spinal pathway and traces the pathway of the neuronal tract from its location in the preceding uploaded cross-section. At the end of the learning module the user has actively traced the entire course of the spinal pathway.

The self-learning interactive nature of the UCC e-learning resource, allows the learner to control the pace of his own learning and to choose the level of detail in the instructional resource. Doing so, enables the learner to custom-titrate the intrinsic cognitive load imparted by learning, to his working memory capacity.

We believe that this interactive design feature could be further enhanced with the help of augmented and virtual reality technology which could offer a deeper immersive learning experience to the users as they trace the course of the spinal pathway through different regions of the central nervous system. In this context, Küçük and colleagues (2016) devised an augmented reality application to enhance the learning experience from a neuroanatomy review book (Küçük, 2016). More advanced AR applications could be designed along similar lines, where the students could draw and trace the entire spinal pathway in an immersive learning environment. The augmentation of reality could be achieved through AR mobile-based applications or provision of headsets. Richardson- Hatcher and colleagues provided an immersive learning experience for the students to learn the anatomy of the trigeminal nerve using VR headsets (Richardson- Hatcher, 2014). Similar, fully immersive virtual reality interactive learning experiences could be devised for learning the spinal pathways as well.

6.2.2. Clinical Neurological Correlates in Neuroanatomy E-resources

The fear of applying basic neuroanatomical concepts onto clinical situations can be better addressed by teaching the basic science facts in a clinical and practical context. Unfortunately, only a very few 3D models / atlases had focused on teaching the clinical correlates of neuroanatomy to the students, including the localization of neurological lesions. For instance, Nowinski and Chua have developed a 3D interactive atlas of neurological disorders with various lesions synthesized over the 3D brain model (Nowinski and Chua, 2013). The 3D atlas describes the resulting disorders and clinical presentations associated with the lesions, however, it is limited in terms of describing the underlying neuroanatomy and neuroanatomical deficits associated with these lesions. In addition, a nerve lesion localizer was developed by Lewis and colleagues, but their software only described the facial nerve lesions (Lewis et al., 2011).

Previous findings by our research group have shown that medical and other health care disciplines students perceived that case-based teaching increased their interest in neuroanatomy (Javaid et al., 2018). As more and more horizontally and vertically integrated curricula are implemented in health sciences education programs, supporting e-resources with focus on describing and linking basic neuroanatomy with its clinical correlates, will provide added benefit to the users.

The UCC e-learning tool was designed to deliver the neuroanatomical details in a clinical context. The module commenced with a brief description of a clinical scenario. In addition, the clinical interpretation of the patient-presentation was discussed at the end of the module to help users revise the information in the context of learning the art of localization of neurological lesions. Doing so, challenges the learners to exercise a higher-level understanding and application of neuroanatomical facts, further consolidating the usage of acquired knowledge.

6.3 Assessment and Evaluation of the Existing Neuroanatomy E-resources

Innovative teaching aids are constantly being developed for learning neuroanatomy and visualizing neuroanatomical spatial relationships, however, many of the 3D neuroanatomical tools have not been evaluated in educational settings (Nowinski et al., 2009a; Nowinski et al., 2009b; Nowinski and Chua, 2013; Adams and Wilson, 2011). Out of those which have been evaluated, some lack objective or quantitative evidence as most of the evidence revolves around subjective student / learner perception and satisfaction (Palomera et al., 2012; Palomera et al., 2014; Gould et al., 2008; Petersson et al., 2009), which alone is insufficient to inform us about the impact of the incorporation of technology resources into anatomy education (Clunie et al., 2017). On the contrary, DeFaria et al. (de Faria et al., 2016), Stewart et al. (Stewart et al., 2007) and Werkmeister et al. (Werkmeister, 2015) did employ a quantitative assessment by gauging students' performance scores but they were deficient in acquiring students' perceptual opinion/s. Lastly, some 3D models, such as that of the cranial nerves, described by Yeung and colleagues did not increase student knowledge of neuroanatomy as compared to the traditional text and image-based materials, despite students' preference for using the 3D models (Yeung et al., 2012).

6.3.1 Quantitative and Qualitative Assessment of the UCC E-learning tool

The novel UCC e-learning tool developed as part of this PhD research project, has been evaluated by undergraduate medical and neuroscience students. The e-resource was evaluated quantitatively using neuroanatomy quizzes before and after offering access to the students for using the tool. This was also accompanied by acquisition of their perceptual opinion about the usefulness of various features of the tool using Likert-scale questionnaire. The results showed an increase in students' knowledge of neuroanatomy (quantitative results) and provided a stimulating learning experience (qualitative feedback) to the students. The use of innovative teaching aids along with traditional teaching methods will provide greater self-directed learning opportunities to the students and hence will offer the students an increased opportunity to better interact and engage with the staff during the limited on-campus teaching hours.

Quantitative results demonstrated an increase in students' knowledge of neuroanatomy of spinal pathways as compared to those who did not use any allocated e-resource. As compared to the participants in the latter category, the increase in knowledge was significantly higher for participants who used the UCC online tool versus those who used the previously highest ranked resource devised by the University of British Columbia. The stronger and significant correlations between the students' perceptual opinion and their quiz 2 scores imply that the novel tool enhanced students' interest in neuroanatomy and participants intuitively favored the pedagogical construct of the UCC e-tool. The UCC e-resource shows promising results with respect to breaking the perceived nexus between the neuroanatomy-phobia and the neurophobia.

6.4 Rank-order Listing of Neuroanatomy E-resources

Limited attempts to publish ranked-order lists of anatomy and neuroanatomy resources have been made in the past, however, these were not specific to neuroanatomy (Kim et al., 2003) or were non-comprehensive (Sharrow, 2015). As part of this PhD research project, a comprehensive list of neuroanatomy web-resources has been formulated, based on a criterion rooted in the principles of cognitive and adult learning theories and web-user interface features, providing a referential framework for ranking and selecting online content for incorporation into neuroanatomy curriculum.

6.5 The Role of Technology and the Future of Neuroanatomy Learning

In an era where the current cohort of students are referred to as the 'Net Generation' with most students using smartphones and laptops for educational purposes (Khatoon et al., 2014), the use of innovative technological teaching methods has demonstrated an increase in student satisfaction and interest in the taught course (Mitov et al., 2010; Vuchkova et al., 2012), improved confidence for clinical sessions (Hanson et al., 2016) and improved examination scores (Obrez et al., 2011). In the future, we will see an increased incorporation of innovative educational tools to supplement the traditional neuroanatomy teaching methods.

6.5.1 Computer simulations

There is increasing evidence that simulation provides high-quality, time-effective training. Since learning is correlated with the level of involvement (Bergman et al., 2008), interactive and problem-orientated learning adds interest and aids in long-term retention of knowledge (Turney, 2007). With improvements in computational power and advancement in visual and haptic display technologies, virtual surgical environments can offer benefits for surgical training, planning, and rehearsal in a safe, simulated setting. Such-simulations can also be effective for university students to learn anatomy by visualizing and interacting with internal organs.

Several different simulators are available at the neurosurgeon's disposal for simulating procedures, such as, endoscopic third ventriculostomy (Weinstock et al., 2017), ventriculostomy catheter placement (Lemole Jr et al., 2007; Kirkman et al., 2014), percutaneous spinal needle placement (Kirkman et al., 2014), cranial neurosurgery (Choudhury et al., 2013), cerebral angiography (Kirkman et al., 2014) and various trauma-related clinical skills including incision planning, burr hole placement, craniotomy, ventriculostomy and catheter placement (Lobel et al., 2013; Schirmer et al., 2013). Unfortunately, the major limitation linked with simulation softwares is that they are too expensive for use by medical students in neuroanatomy learning. Moreover, the technical challenges also limit the application of virtual surgical environments. In addition, 93.5% of the commercially available simulators have not been tested for validity to ensure adequate, safe, and affordable medical psychomotor skills training (Stunt et al., 2014). Despite the above-highlighted limitations, we predict that, as the cost comes down in the future with a widespread availability of technology and the technical challenges have been overcome, an increased employment of simulation-softwares will be seen in medical education and medical skills training that require physical actions. We propose that if the above-mentioned limitations have been catered for, then many of these digitally created 3D models could be 3D printed and used as simulation devices for training and education.

6.6 Changing Concepts of Neuroanatomy Teaching in Medical Education

Despite the abundance of neuroanatomy e-resources, the phobia of managing of neurology patients and the associated neuro (-anatomy-) phobia, still prevails. The results from our research project reveal that the increase in knowledge of neuroanatomy was significantly greater for students who used the UCC e-learning tool v. the NU-group as compared to the control v. NU-group comparison. Although the UCC e-resource was positively perceived by the students and they enjoyed learning neuroanatomy from it, however, the increase in the knowledge was not significantly greater than those who accessed the available best-ranked e-resource. These results highlight, on one hand, the importance of designing better e-learning resources whose pedagogical construct is rooted into the principles of human cognitive architecture, but on the other hand, also underscores the significance of assessing e-learning resources in the broader context of various other factors pertaining to the neuroanatomy syllabus and its curriculum design.

6.6.1 When in the Curriculum Should We Teach Neuroanatomy?

Neuroanatomy is being taught in a myriad of ways in universities across the globe and the manner in which neuroanatomy should be taught to undergraduate medical students, should be assessed as well. Previously, most medical school curricula emphasized upon teaching the essential basic science neuroanatomy in a traditional, lecture-based fashion following Essentialist principles. Over the passage of time, there has been increased adoption of a flexible, student-centered, experiential curricula which are more Progressivist (Hazelton, 2011). It appears that students and practitioners currently experience challenges incorporating their early neuroanatomy teaching into patient care. In the context of the shift from an Essentialist to a Progressivist approach, the best time for teaching neuroanatomy needs to be revisited. Should neuroanatomy be formally taught by academic anatomists, with most of the instruction taking place in the preclinical years? Or should the subject be taught sometime later, perhaps as part of a vertically integrated curriculum with clinical neurology or even as part of a spiral curriculum where the material is revisited multiple times with increasing complexity to reinforce learning.

6.6.2 What Neuroanatomy Should be Taught?

In the recent years, the number of neuroanatomy teaching hours have dropped and there is an increased pressure on teachers of neuroanatomy to justify its place in the curriculum (Drake, 2002; Hazelton, 2011). In this context, the entire neuroanatomy curriculum should be revisited; regarding what needs / need not be taught during undergraduate medical education. We evaluated participants' knowledge of the spinal pathways, however, intelligently designed e-resources should also be designed for other areas of interest in neuroanatomy. Most educators would agree that the amount of neuroanatomy that students learn should in some way be determined by what they will need in order to practice medicine and neurology. Afterall, the main goal of the neurological exam is to geographically situate the affected structure with the CNS, or 'locate the lesion'. Various core curricula could provide a guideline regarding what is expected for a recently qualified medical graduate to know in order to carry out many clinical procedures safely and effectively (Moxham, 2015). The call for increased integration between neuroanatomy and clinical neurology, demands that the educational efficacy of the e-learning resources should be assessed over a long time to evaluate their impact on improving students' knowledge of clinically relevant neuroanatomy topics and neurophobia-alleviation.

6.6.3 How Should We Teach Neuroanatomy?

A question which reasonably arises is that how neuroanatomy teaching should change to best meet the needs of this generation of students. Three commonly used pedagogies in neuroanatomy, namely hands-on dissection, problem-based learning, and CAL, each have their own advantages and disadvantages. Dissection / inspection allows students to learn neuroanatomy in detail, including normal anatomical variations, and takes advantage of fully exposed structures. Problem-based learning, as its name suggests, focuses on solving realistic clinical cases rather than rote memorization. CAL, meanwhile, provides wealth of teaching material to students to work through at their own pace: 3D brain scans, photographs of dissected specimens, high-resolution histological images, and explanatory videos. In my opinion, all of these pedagogical methods should be employed in various settings and at various times in teaching neuroanatomy, because they are complimentary and reinforce each other.

6.6.4 Students' Learning Preferences

It is important to recognize that medical student populations are more heterogenous and learning preferences more diverse than they used to be. In my opinion, we must use a variety of different teaching methods; some of the tried-and-true experiences such as cadaveric and specimen dissection, but also more flexible exercises that involve problem-based learning and digitally available materials (Chang and Molnar, 2015).

As technology advances and philosophical underpinnings of medical education continue to shift, it becomes ever more important to examine our assumptions and practices. Although it is still not entirely clear where these changes will take us, those involved in neuroanatomy education will need to respond to the evolving environment in a way that leads to improved student learning outcomes, and ultimately improved patient care.

The data presented in this thesis collectively shows that the current generation of students express a positive appreciation for the computer assisted and e-learning resources. Hence, if such e-resources are intelligently designed in the context of the guidelines proposed by the cognitive and adult learning theories, they can serve as powerful adjunct learning tools to supplement the traditional pedagogies in an attempt to address neurophobia and improve neurology patient care in the future. We have shown in this thesis that the UCC e-learning tool enhanced students' interest in learning neuroanatomy and significantly improved their knowledge of neuroanatomy compared to those who did not use the allocated e-resources. However, the robustness of this tool needs to be challenged and further studies should be conducted in various other institutions across the world and over a longer prospective time-period. Nonetheless, this is an exciting time for neuroanatomy teaching and integrating technology with traditional dissection / prosections and lecture-based pedagogies could lead to better clinical trainees in the future.

APPENDICES

Appendix 1

Neuroanatomy Education Questionnaire

UCC

Coláiste na hOllscoile Corcaigh, Éire
University College Cork, Ireland

Neuroanatomy Education Questionnaire

Please read the following instructions before proceeding with the questions.

The survey is being conducted by the Department of Anatomy and Neuroscience at University College Cork (UCC), Ireland.

The survey is part of a research project to identify the areas of difficulty in neuroanatomy education. The data acquired from this survey will help us in creating an online, freely accessible, neuroanatomy web resource.

Please note that your participation in this survey is voluntary and anonymous. Your participation (or not), will not in any way influence your grades or performance evaluations. You may skip any question for any reason.

For comments or questions please contact Dr. Muhammad Asim Javaid, Department of Anatomy and Neuroscience, UCC at muhammad.ajavaid@ucc.ie. Your feedback is very important for us.

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UCC

Coláiste na hOllscoile Corcaigh, Éire
University College Cork, Ireland

Neuroanatomy Education Questionnaire

1. Please state your gender.

- Male
- Female

2. Which programme are you currently enrolled in?

- Direct entry medicine
- Graduate entry to medicine
- Speech and language therapy
- Occupational therapy
- Dentistry

3. What is your current year of study in your programme?

- 1st year
- 2nd year
- 3rd year
- 4th year
- 5th year

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4. What is your highest previous qualification?

- Leaving cert. / A levels
- MSc (biological sciences)
- MSc (non-biological sciences)
- BSc (biological sciences)
- BSc (non-biological sciences)
- Biomedical sciences degree
- Medical degree
- Dental degree
- Other (please specify)

5. In which year did you attend/complete your neuroanatomy module in UCC?

- 2015
- 2014
- 2013
- 2012
- 2011
- Prior to 2011

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Coláiste na hOllscoile Corcaigh, Éire
University College Cork, Ireland

Neuroanatomy Education Questionnaire

For questions no. 6 to 11, please select the N/A option for any particular area of anatomy which you have not studied as part of your gross anatomy curriculum.

6. How would you rate the following areas of systemic anatomy in terms of their degree of difficulty?

	Very difficult	Difficult	Moderate	Easy	Very easy	N/A
Cardiovascular anatomy	◯	◯	◯	◯	◯	◯
Gastrointestinal anatomy	◯	◯	◯	◯	◯	◯
Genitourinary anatomy	◯	◯	◯	◯	◯	◯
Musculoskeletal anatomy	◯	◯	◯	◯	◯	◯
Neuroanatomy	◯	◯	◯	◯	◯	◯
Pelvic and reproductive anatomy	◯	◯	◯	◯	◯	◯
Respiratory system anatomy	◯	◯	◯	◯	◯	◯

7. How would you describe your current knowledge in the following areas of systemic anatomy?

	Very limited	Limited	Moderate	Good	Very good	N/A
Cardiovascular anatomy	◯	◯	◯	◯	◯	◯
Gastrointestinal anatomy	◯	◯	◯	◯	◯	◯
Genitourinary anatomy	◯	◯	◯	◯	◯	◯
Musculoskeletal anatomy	◯	◯	◯	◯	◯	◯
Neuroanatomy	◯	◯	◯	◯	◯	◯
Pelvic and reproductive anatomy	◯	◯	◯	◯	◯	◯
Respiratory system anatomy	◯	◯	◯	◯	◯	◯

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8. On a scale of 1 (very low) to 5 (very high), how would you rate your level of interest in the following areas of systemic anatomy?

	1	2	3	4	5	N/A
Cardiovascular anatomy	○	○	○	○	○	○
Gastrointestinal anatomy	○	○	○	○	○	○
Genitourinary anatomy	○	○	○	○	○	○
Musculoskeletal anatomy	○	○	○	○	○	○
Neuroanatomy	○	○	○	○	○	○
Pelvic and reproductive anatomy	○	○	○	○	○	○
Respiratory system anatomy	○	○	○	○	○	○

9. How would you rate the following areas of regional anatomy in terms of their degree of difficulty?

	Very difficult	Difficult	Moderate	Easy	Very easy	N/A
Abdominal anatomy	○	○	○	○	○	○
Head and neck regional anatomy (excluding Neuroanatomy)	○	○	○	○	○	○
Lower limb anatomy	○	○	○	○	○	○
Neuroanatomy	○	○	○	○	○	○
Pelvic anatomy	○	○	○	○	○	○
Thoracic anatomy	○	○	○	○	○	○
Upper limb anatomy	○	○	○	○	○	○

10. How would you describe your current knowledge in the following areas of regional anatomy?

	Very limited	Limited	Moderate	Good	Very good	N/A
Abdominal anatomy	○	○	○	○	○	○
Head and neck regional anatomy (excluding Neuroanatomy)	○	○	○	○	○	○
Lower limb anatomy	○	○	○	○	○	○
Neuroanatomy	○	○	○	○	○	○
Pelvic anatomy	○	○	○	○	○	○
Thoracic anatomy	○	○	○	○	○	○
Upper limb anatomy	○	○	○	○	○	○

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11. On a scale of 1 (very low) to 5 (very high), how would you rate your level of interest in the following areas of regional anatomy?

	1	2	3	4	5	N/A
Abdominal anatomy	◯	◯	◯	◯	◯	◯
Head and neck regional anatomy (excluding Neuroanatomy)	◯	◯	◯	◯	◯	◯
Lower limb anatomy	◯	◯	◯	◯	◯	◯
Neuroanatomy	◯	◯	◯	◯	◯	◯
Pelvic anatomy	◯	◯	◯	◯	◯	◯
Thoracic anatomy	◯	◯	◯	◯	◯	◯
Upper limb anatomy	◯	◯	◯	◯	◯	◯

12. How confident would you be in assessing and diagnosing patients with problems related to each of the following medical specialties? (Please answer this question only if you are a final year medical student in your program).

	Very uncertain	Uncertain	Moderately confident	Confident	Very confident	N/A
Cardiology	◯	◯	◯	◯	◯	◯
Endocrinology	◯	◯	◯	◯	◯	◯
Gastroenterology	◯	◯	◯	◯	◯	◯
Geriatrics	◯	◯	◯	◯	◯	◯
Nephrology	◯	◯	◯	◯	◯	◯
Neurology	◯	◯	◯	◯	◯	◯
Respiratory (Pulmonology)	◯	◯	◯	◯	◯	◯
Rheumatology	◯	◯	◯	◯	◯	◯

13. How easy or difficult is neuroanatomy compared to other topics of anatomy?

- ◯ Very easy
- ◯ Easy
- ◯ Neither easy nor difficult
- ◯ Difficult
- ◯ Very difficult

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University College Cork, Ireland

Neuroanatomy Education Questionnaire

14. On a scale of 1 (a minor cause) to 5 (a major cause), how would you rate the following factors in making neuroanatomy challenging to learn?

	1	2	3	4	5	N/A
Access to neuroanatomy information online	○	○	○	○	○	○
Access to neuroanatomy textbooks	○	○	○	○	○	○
Appreciating the 3D relationships of structures of the central nervous system	○	○	○	○	○	○
Complexity of the topic	○	○	○	○	○	○
Lecture duration	○	○	○	○	○	○
Memorizing neuroanatomical terminology (nomenclature)	○	○	○	○	○	○
Total time spent in FLAME lab/dissection room	○	○	○	○	○	○
Understanding the clinical aspects of neuroanatomy such as localization of nerve lesions	○	○	○	○	○	○
Visualization of structures on prosections of the central nervous system	○	○	○	○	○	○

Please explain any other reasons which you think might contribute to making neuroanatomy difficult?

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15. On a scale of 1 (least difficult) to 5 (most difficult), how difficult it is to understand the following topics in neuroanatomy?

	1	2	3	4	5	N/A
Arterial and venous drainage of the central nervous system						
Auditory system						
Autonomic nervous system (sympathetic and parasympathetic)						
Basal nuclei						
Brainstem structure						
Cerebellum and its connections						
Cerebral cortex						
Cranial nerve nuclei (sensory and motor, somatic and visceral, general and special)						
Cranial nerves						
Internal and external structure of the spinal cord						
Limbic system						
Meninges, ventricular system and the cerebrospinal fluid						
Motor pathways such as corticospinal tract						
Neurohistology						
Sensory pathway lesions						
Sensory pathways such as spinothalamic, dorsal column and spinocerebellar pathways						
Trigeminal sensory and motor system						
Vascular lesions of the medulla oblongata, pons and mid-brain						
Vestibular system						

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	1	2	3	4	5	N/A
Visual pathways and lesions, visual reflexes	◯	◯	◯	◯	◯	◯

In addition to those mentioned above, is there any specific topic which is difficult to understand?

16. On a scale of 1 (not useful) to 5 (very useful), please rate the usefulness of the following methods in improving your understanding of neuroanatomy?

	1	2	3	4	5	N/A
Anatomical models	◯	◯	◯	◯	◯	◯
Bedside clinical tutorials	◯	◯	◯	◯	◯	◯
Computer aided learning (CAL)	◯	◯	◯	◯	◯	◯
Dissection	◯	◯	◯	◯	◯	◯
FLAME lab practical sessions	◯	◯	◯	◯	◯	◯
Formative spot exams	◯	◯	◯	◯	◯	◯
Learning from peers	◯	◯	◯	◯	◯	◯
Lecture power point slides	◯	◯	◯	◯	◯	◯
Letures	◯	◯	◯	◯	◯	◯
Online web-resources	◯	◯	◯	◯	◯	◯
Prosections	◯	◯	◯	◯	◯	◯
Radiology	◯	◯	◯	◯	◯	◯
Textbooks (including online text books)	◯	◯	◯	◯	◯	◯
Tutorials	◯	◯	◯	◯	◯	◯
White board drawings	◯	◯	◯	◯	◯	◯

Other (please specify)

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17. On a scale of 1 (not useful) to 5 (very useful), how would you rate the efficacy of neuroanatomy computer aided learning resources in enhancing the following?

	1	2	3	4	5	N/A
Comfort level in the subject	○	○	○	○	○	○
Confidence in managing/dealing with patients with neurological problems	○	○	○	○	○	○
Knowledge of the topic	○	○	○	○	○	○

18. If applicable, and on a scale of 1 (very low) to 5 (very high), please rate the importance of case-based learning (clinical scenarios) during pre-clinical neuroanatomy teaching.

1	2	3	4	5
○	○	○	○	○

19. If applicable, and on a scale of 1 (not helpful) to 5 (very helpful), how helpful was your basic science neuroanatomy knowledge when applied to clinical years?

1	2	3	4	5	N/A
○	○	○	○	○	○

20. How would you rate the effect of clinical case-based teaching on your level of interest in neuroanatomy?

Increased it a lot	Increased it minimally	Neither increased it nor dereased it	Decreased it minimally	Decreased it a lot
○	○	○	○	○

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Neuroanatomy Education Questionnaire

We intend to develop an online neuroanatomy learning web-resource in the future, in light of the feedback which we obtain from you. We refer to it, in questions no. 21 to 24 as a "PURPOSE-DESIGNED COMPUTER AIDED NEUROANATOMY LEARNING RESOURCE".

21. The "PURPOSE-DESIGNED COMPUTER AIDED NEUROANATOMY LEARNING RESOURCE" can help in addressing some of the problems with neuroanatomy learning.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

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22. On a scale of 1 (very low) to 5 (very high), to what extent do you think the following components of the 'PURPOSE-DESIGNED COMPUTER AIDED NEUROANATOMY LEARNING RESOURCE" could improve the learning/teaching of neuroanatomy?

	1	2	3	4	5	N/A
Blog posts	○	○	○	○	○	○
Computer animations	○	○	○	○	○	○
Games, quizzes	○	○	○	○	○	○
Illustrated images from various anatomy atlases	○	○	○	○	○	○
Neurology examination clips	○	○	○	○	○	○
Neurosurgical and invasive neurological procedures' videos	○	○	○	○	○	○
Online dissection forums	○	○	○	○	○	○
PDF lecture notes	○	○	○	○	○	○
Podcasts	○	○	○	○	○	○
Power point slides	○	○	○	○	○	○
Radiology; 2D images and 3D reconstruction videos	○	○	○	○	○	○
Snapshots of brains prosections used in FLAME lab/dissection room teaching	○	○	○	○	○	○
Snapshots of brain sections (coronal and horizontal) used in FLAME lab/dissection room teaching	○	○	○	○	○	○
Snapshots of models (plastic and plastinated) present in the FLAME lab/dissection room	○	○	○	○	○	○
Video lectures (including animated videos)	○	○	○	○	○	○

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23. The "PURPOSE-DESIGNED COMPUTER AIDED NEUROANATOMY LEARNING RESOURCE" would:

Help in understanding the clinical aspects of neuroanatomy, such as, localization of nerve lesions	○	○	○	○	○
Help in further understanding of the topics which were outlined during the lecture time	○	○	○	○	○
Help in further understanding of the topics which were outlined during the FLAME lab/dissection room practical sessions	○	○	○	○	○
Elaborate upon the features of the central nervous system	○	○	○	○	○
Help in better visualization of structures in the prosections of the central nervous system	○	○	○	○	○
Help in memorizing the neuroanatomical terminology (nomenclature)	○	○	○	○	○
Help in appreciating the 3D relationships of the structures of the central nervous system	○	○	○	○	○

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24. Would you like to suggest a specific/unique way in which each component (mentioned in question no. 22), can be used in the future, within this "PURPOSE-DESIGNED COMPUTER AIDED NEUROANATOMY LEARNING RESOURCE" to improve the learning/teaching of neuroanatomy? (please specify)

Blog posts	
Computer animations	
Games, quizzes	
Illustrated images from various anatomy atlases	
Neurology examination clips	
Neurosurgical and invasive neurological procedures' videos	
Online discussion forums	
PDF lectures notes	
Podcasts	
Power point slides	
Radiology; 2D and 3D reconstruction videos	
Snapshots of brain prosections used in the FLAME lab/dissection room teaching	
Snapshots of brain sections (coronal and horizontal) used in FLAME lab/dissection room teaching	
Snapshots of models (plastic and plastinated) present in the FLAME lab/dissection room	
Video lectures (including animated videos)	

25. Please feel free to write your additional comments below.

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Appendix 2

Consent Form for Neuroanatomy Education Questionnaire

Department of Anatomy and Neuroscience, UCC

DEPARTMENT OF ANATOMY & NEUROSCIENCE UNIVERSITY COLLEGE CORK

<u>Project information for research participants</u>

Design of an Online Translational Neuroanatomy Teaching Web-Resource at UCC

Investigators: Dr. André Toulouse, Dr Harriet Schellekens, Prof. John Cryan, Dr. Muhammad Asim Javaid

Study Location: Department of Anatomy and Neuroscience, University College Cork, Cork, Ireland

Purpose of the Study. This study is concerned with identifying and reviewing areas of difficulty in neuroanatomy teaching to medical (graduate and direct entry), dentistry, occupational, speech and language therapy students, at University College Cork (UCC) with the aim of designing an online teaching resource to complement classroom delivery.

What will the study involve? Before the start of the study, you will be asked to sign the attached informed consent form. You can retain this information section. You will be handed a questionnaire at the end of a lecture session. There will be 22 questions which take approximately 10 – 15 minutes to answer. You will be asked to complete the questionnaire and return it to us before leaving the lecture room.

You have been asked to take part in this study because the overall aim of the research project is to create a novel, online, neuroanatomy learning web resource to complement neuroanatomy teaching to the students at UCC. The web resource will be created based on the feedback we obtain from your answers.

Your participation is entirely voluntary and we greatly value your input. Whether you participate or not, will not in any way influence your grades or performance evaluations. The survey is anonymous. Please do not add your name or student ID on this form.

The data will be kept confidential for the duration of the study. On completion of the thesis, they will be retained for a further six months and then destroyed. The results will be presented in an MD thesis and may be published in a research journal.

Any questions/queries will be addressed by contacting the researcher, Dr Muhammad Asim Javaid (Muhammad.ajavaid@ucc.ie).

This study has been reviewed and approved by the Social Research Ethics Committee at University College Cork.

If you agree to take part in the study, please sign the consent form overleaf.

We would like to sincerely than you for your participation in this study.

DEPARTMENT OF ANATOMY & NEUROSCIENCE
UNIVERSITY COLLEGE CORK

<u>Consent Form</u>

Design of an Online Translational Neuroanatomy Teaching Web-Resource at UCC

1. I……………………………………… (BLOCK PRINT) agree to participate in this research study.
2. The purpose and nature of the study has been explained to me in writing.
3. I am participating voluntarily.
4. I give permission for my data to be used for further analysis and research
5. I understand that my participation will not affect in anyway my grades/exam performance.
6. I understand that anonymity will be ensured in the research process.

Signed……………………………………. Date……………….

RS Ver 6 2/11/07

Appendix 3

Ethics Approval from SREC for the Neuroanatomy Education Questionnaire (Approval Granted 03/07/2015)

UCC Social Research Ethics Committee (SREC)

ETHICS APPROVAL FORM

Name of applicant	Dr. André Toulouse	**Date:**	June 6th, 2015
Contact Details	**Phone:** (021) 4205477	**Email:**	A.Toulouse@ucc.ie
Department/Unit	Department of Anatomy and Neuroscience		
Title of project	Design of an Online Translational Neuroanatomy Teaching Web-Resource at UCC		

		YES	NO
1	Do you consider that this project has significant ethical implications?		x
2	Will you describe the main research procedures to participants in advance, so that they are informed about what to expect?	x	
3	Will participation be voluntary?	x	
4	Will you obtain informed consent in writing from participants?	x	
5	Will you tell participants that they may withdraw from the research at any time and for any reason, and (where relevant) omit questionnaire items to which they do not wish to respond?	x	
6	Will data be treated with full confidentiality / anonymity (as appropriate)?	x	
7	If results are published, will anonymity be maintained, and participants not identified?	x	
8	Will you debrief participants at the end of their participation (i.e. give them a brief explanation of the study)?	x	
9	Will your project involve deliberately misleading participants in any way?		x
10	Will your participants include schoolchildren (under 18 years of age)?		x
11	Will your participants include people with learning or communication difficulties?		x
12	Will your participants include patients?		x
13	Will your participants include people in custody?		x
14	Will your participants include people engaged in illegal activities (e.g. drug taking; illegal Internet behaviour)?		x
15	Is there a realistic risk of participants experiencing either physical or psychological distress?		x
16	If yes to 15, has a proposed procedure, including the name of a contact person, been given? (see no 23)		

DESCRIPTION OF THE PROJECT

17. Aims of the project:
To identify and review the areas of difficulty in neuroanatomy teaching to medical (graduate and direct entry) dentistry, occupational, speech and language therapy students, at University College Cork (UCC) and create an online, translational, blended, interactive neuroanatomy learning web resource to complement teaching in the areas identified.

18. Brief description and justification of methods and measures to be used
Once the information about the study has been provided and consent obtained, a self-administered neuroanatomy questionnaire will be distributed among the above-mentioned student cohorts (see question 17) inside the UCC lecture rooms. The questions will pertain to (1) difficulties in neuroanatomy vs. other topics (2) possible reasons and (3) ways to address those difficulties/limitations by creating a novel online neuroanatomy web resource. The survey will comprise of open and closed-ended questions, Likert scale based and rating (scale of 1 to 5) questions (Please find a copy of the questionnaire attached with the application). This survey-based study is very important as the feedback obtained from the students will guide us in designing the online neuroanatomy learning web resource.

19. Participants: recruitment methods, number, age, gender, exclusion/inclusion criteria
Medical (graduate and direct entry) dentistry, occupational, speech and language therapy students, at University College Cork (UCC) will act as the potential participants. Students from all years of their programs; except the first year students who would not have studied sufficient neuroanatomy, will be invited to fill in the questionnaire. The questionnaires will be distributed inside the lecture rooms after the lecture time. Students will be requested to fill it and return it to us before leaving the lecture room. We aim to recruit approximately 120 participants from the various cohorts across the five programmes. Participation will be voluntary, we therefore expect that the gender, race or age balance will be reflective of the student cohorts selected. Prior informed consent will be obtained and queries will be addressed.

20. Concise statement of ethical issues raised by the project and how you intend to deal with them
We don’t envisage any ethical issues raised by the project. The forms will be anonymous and will be secured in a locked filing cabinet inside the principal investigator’s office with limited access only to the named investigators. The data will be entered online and secured in a password protected computer. Complete anonymity will be ensured throughout the processes of data analysis and publication. Participation will have no bearing on classroom assessment and performance.

21. Arrangements for informing participants about the nature of the study
An information session will be held in each class and written information regarding the study will be provided to the participants as part of the consent process (see attached consent form). Participation will be entirely voluntary. Any questions/queries will be addressed verbally, if any arise.

22. How you will obtain Informed Consent
Written informed consent form will be obtained before the commencement of the study. (Please find the informed consent form attached with the application)

23. Outline of debriefing process (cf. Question 8). If you answered YES to Question 15, give details here. State what you will advise participants to do if they should experience problems (e.g. who to contact for help).
We don’t envision any problem or discomfort arising among the participants after filling in the questionnaire. However, any questions/queries will be addressed; before as well as after the study. For additional questions/comments later on, participants would have the option of contacting the researcher at the following email address: Muhammad.ajavaid@ucc.ie

24. Estimated start date and duration of project.
September 2015 to August 2017 (duration = two years)

Signed ______________________________ Date _________________________
Applicant

Appendix 4

Author Evaluation Form for Assessment of Neuroanatomy Web-Resources

Categories	Questions
is the information in the website credible?	Has the authorship been disclosed? (author's name/contact information/credentials/institutional affiliation)
	Is the information referenced or bibliographied?
	Is the neuroanatomy information accurate (content-wise)?
	Are there any typos or grammar mistakes?
up-to-date	Have the website' pages been dated?
	Has the target audience been mentioned?
	Is an instructor available to guide or address queries? (for home institution/outside users)
Learning outcome	Have the learning outcome(s) LO been mentioned for the users?
	If yes, then:
	1)Has the content topic (to-be-learned) been mentioned in the LO?
	2)Has the required level of knowledge has been stated in the LO?
	3)Has the LO been articulated as per Bloom's taxonomy?
	4)Has the context in which learning will take place been mentioned?
Does the web-resource promote online interaction/communication?	Are the followings present?
	1)Comments-sections underneath the web-pages
	2)Discussion forum
	3)Bulletin board
	4)Chat room
	5)User-groups
	6)Listserv for subscribers
	7)Learners having the provision of emailing the instructor or web-master
	8)Learners having the provision of emailing other learners.
	Are students able to comment regarding the site/the course/the instructor?
Have the students been motivated to learn the topic?	Does the web-resource list advantages of using the package, such as:
	1)Better exam performance
	2)Clinical relevance
	3)Relevance to understanding research in the field
	4)Others
	Have some motivation quotes, peer-advice or success stories (from alumni) been included in the web-resource to motivate the learners?

Layout of the content	Are instructions (or tutorial) available to explain how to use the web-material?
	Has the information been organized into headings and sub-headings?
	Is there a sequential or logical link between the headings and sub-headings?
	Has a table-of-content or a flow-sheet of topics been provided?
	Is the formatting consistent? (usage of similar colours, image styles and fonts throughout all pages of the website)
	Have the learning outcomes been disclosed up-front?
	Has bold text been used to highlight important concepts?
	Have links been embedded within the text to interconnect relevant web-segments?
	Is a glossary of neuroanatomical terminologies available? OR have the key terms within the text being linked to the glossary?
	Have the key points been summarized at the end of each topic?
Is there any bias in the opinions stated on the	Does the web-resource state more facts than opinions?
	Have various viewpoints or theories been acknowledged by the author?
	Are advertisements present?
	Does the website have a sponsor or is selling a product?
	Is the information provided comprehensive?
	Have resources/links/materials been provided for future further self-directed learning?
	Has feedback been acquired FROM the students at the end of each topic taught?
	Has formative assessment and feedback been provided TO the students
	Are the personal choice helpers (such as frequently asked questions-section, search box, online help section) present?
	Is some advice included? (Guidance, tips and tricks, do's and don'ts, etc.) *(Hint: For instance, regarding how to effectively read the material and learn neuroanatomy, or regarding managing patients or preparing for licensure exams*
Is the website-interface and navigation user-friendly?	Are the basic navigation features present (forward or next page/backward or previous page/main menu/save/exit buttons/zoom in & out, etc.)?
	Does the page title provide an accurate description of the page-content?
	Is it possible to find necessary information easily from the homepage?
	Does each page offer a direct way to return to the homepage (separate icon, link)?
	Is the formatting consistent throughout all pages of the website (following the same colours, image styles and fonts)
	Is the website navigation highly intuitive?
	Is the website-interface mobile-adaptable?
	Do the links and hyper-links inter-connect different sections of the website (and perhaps relevant external web-pages)?
Is the web-resource easily accessible?	Is the website accessible via all main search engines and browsers; Google, Safari (for Mac), internet explorer?
	Are special 'plug-ins' required?
	Is registration or password required?
	Is web-material readily downloadable?
Does the web-resource encourage students to reflect on their learning experiences?	Are the students being encouraged to ask questions, such as? *What do you think they learned from this experience? OR (In an assessment setting) what did they not do, which they should have done before? OR What would they like to do next time to perform better?*

Is the web-material adaptable to the individual users?	Are the followings present?
	a.Individualized learning database
	b.Individualized instruction
	c.Individualized test/quiz
Does the web-resource focus on the clinical significance of basic	a.Has the clinical significance of basic science facts been explained?
	b.Have the basic science facts been taught in a case-based fashion OR have clinical scenarios or some form of PBL learning been included?
Have images/pictures been included?	Are the followings present?
	1)Diagrams, illustrations, schematics
	2)Atlas pictures
	3)Pictures of models (plastic, plastinated)
	4)Snapshots of prosections
	5)Radiological images (XRay, CT, MRI)
Have videos been included?	Are videos of the followings present?
	1)Clinical procedures (medical, interventional, surgical)
	2)Clinical neurological examination
	3)Dissection
	4)Animations
	5)Lectures
	6)Podcasts
	7)Radiology
Have notes been included?	Are the followings present?
	1)General text description on web-pages
	2)Lecture notes
	3)Transcripts (for videos/lectures included)
	4)Figure legends
Audio content	Is audio content included?
Is the web-resource aesthetically appealing?	Is the choice of colours appropriate for page-background, headers, navigation-posts and links?
	Is the choice of contrast between colours (in the images) appropriate?
	Are the web-pages over-cluttered with information?
	Are the images clear and non-blurry or non-pixilated?
	Is the text easily readable (font style, font size, colour scheme)?
	Have graphics (diagrams, illustrations, photographs/images) been included?
	Is the language style conversational (or audience-appropriate)?
	Are students able to control the sequence of the learning segments and offered an alternative to skip segments (in an assessment setting)?
	Is some element of fun incorporated into the learning process? (Jokes, games, quizzes, etc.)
	Has the information on current research in neuroscience or neuroanatomy education been included in the website?
	Is there a disclosure of copyright and intellectual property issues or a general disclosure?
	Is there any additional factor which is specifically likable or dislikeable in this web-resource for learning neuroanatomy? Please explain below; for instance, why do you think that way? (Give reason), how do you know that? (Give example), can you explain more?

Appendix 5

Educators' Evaluation Form for the Assessment of Neuroanatomy Web-Resources

The questionnaire is designed to compare the following 13 neuroanatomy web-resources with regards to their information of spinal pathways; sensory and motor. Please click over the hyperlinks below and evaluate by answering the following questions: (please read the comments inserted with the web-resources, as well).

	Questions for educators	Neuroanatomy web-resources												
		Duke Uni.	Digital anatomist	Columbia Uni.	MIT OpenCourses	Texas Uni.	Global anatomy	Hyperbrain	Atlas of functional NeuroAn.	Uni. of British Columbia	Uni. of New South Wales	Uni. of Bristol	Teach me anatomy	Neuroanatomy lab online
		1	2	3	4	5	6	7	8	9	10	11	12	13
A	Are the following items (if present ''in their current form'', in each of the 13 web-resources) useful/not-useful for learning the sensory and motor spinal pathways? Please evaluate from an educator's perspective.	Useful=1, Not useful=0, Not present in web-resouce=N/A												
1	Authorship disclosure (author's name/contact information/credentials/institutional affiliation)													
2	References or bibliographies													
3	Instructor availability													
4	Learning outcomes													
5	Instructions (or tutorial) to explain how to use the web-material													
6	Resources/links for further self-directed learning													
7	Feedback acquisition FROM the students													
8	Formative assessment and feedback provision TO the students													
9	Personal choice helpers, such as FAQ, search box, online help, etc.													
10	Advice for students (guidance, tips and tricks, do’s and don’ts, etc.)													
11	Downlodadle web-content													
12	Student reflection													
13	Individualized learning database													
14	Individualized instruction													
15	Individualized test/quiz													
16	Student control in managing the sequencing of learning segments													
17	Element of fun incorporated into the learning process													
18	Inclusion of information on current research in neuroscience or neuroanatomy education													
B	For each of the 13 web-resources:	Yes=1, No=0												
1	is the web-content up-to-date?													
2	Is there any bias in the content/information?													
3	Is the web-resource user-friendly?													

C	Would the following features (if present ''in their current form'' in each web-resource) motivate the students to learn the topic?	Yes=1, No=0												
1	Relevance to exam performance													
2	Clinical relevance													
3	Relevance to understanding research in the field													
4	Motivation quotes, peer-advice or success stories (from alumni)													
D	Would the following features (if present ''in their curent form'' in each web-resource) make the layout of the content helpful/not helpful for learning sensory and motor spinal pathways?	Helpful=1, not-helpful=0, Feature absent in the web-resource=N/A												
1	Organization of information into headings and sub-headings													
2	Table of contents or flow sheet of topics													
3	Hyperlinks embedded within text to interconnect relevant web-segments													
4	Glossary of neuroanatomical terminologies													
5	Summarization of key points at the end of each topic													
E	Would the following features (if present ''in their curent form'' in each web-resource) make the navigation user-friendly?	Helpful=1, not-helpful=0, Feature absent in the web-resource=N/A												
1	Basic features such as forward and backward buttons, main menu, save and exit buttons, zoom in and out options, etc.													
2	Links to all necessary information on the home page.													
3	Interconnectivity of related website segments with links and hyperlinks													
F	were the followings (if present in the web-resource) in their current form; useful/not-useful for learning spinal pathways?	Helpful=1, not-helpful=0, Feature absent in the web-resource=N/A												
1	Diagrams, illustrations, schematics													
2	Pictures of models (plastic, plastinated)													
3	Snapshots of prosections													
4	Radiological images (XRay, CT, MRI)													
5	General text description on web-pages													
6	Lecture notes													
7	Transcripts (for videos/lectures included)													
8	Figure legends													
9	inclusion of audio contetnt (including podcasts)													
10	Videos of the followings:													
	a) Clinical procedures (medical, interventional,													
	b) Clinical neurological examination													
	c) Dissection													
	d) Animations													
	e) Lectures													
	f) Podcasts													
	g) Radiology													

G	Is the choice of colours appropriate for page-background, headers, navigation-posts and links? (Yes=1, No=0)													
H	Is the choice of contrast between colours (in the images) appropriate? (Yes=1, No=0)													
I	Are the web-pages over-cluttered with information? (Yes=1, No=0)													
J	Are the images clear and non-blurry or non-pixilated? (Yes=1, No=0)													
K	Is the text easily readable (font style, font size, colour scheme)? (Yes=1, No=0)													

Appendix 6

Students' Evaluation Form for Assessment of Three Top-Ranked Neuroanatomy Web-Resources

Neuroanatomy web resource evaluation questionnaire

This survey is being conducted by the Department of Anatomy and Neuroscience at University College Cork (UCC), Ireland.

The survey is part of a research project to evaluate the existing web-resources for neuroanatomy education. There will be no personal benefit from completing the survey; however, the data acquired from this survey will help us in creating an online, freely accessible, neuroanatomy web resource.

Please note that your participation in this survey is voluntary and anonymous. Whether you participate or not, will not in any way influence your grades/performance evaluations. You can withdraw from the study at any time with a written/verbal notice.

For comments/questions please contact Dr Muhammad Asim Javaid in the department of Anatomy and Neuroscience at the UCC on Muhammad.ajavaid@ucc.ie. Your feedback is very important for us.

Thank you very much!

INSTRUCTION: This questionnaire is designed to compare various web resources with regards to their information on the learning of neuroanatomical pathways (motor and sensory).

		1. Uni. of British Columbia						**2. Uni. of Texas**						**3. Neuroanatomy lab online**					
		Access the web resource at http://www.neuroanatomy.ca/						Access the web resource at http://nba.uth.tmc.edu/neuroanatomy/ . Please consider 'neuroscience online' as a part of this resource and evaluate both together as 'one'.						Access the web resource at https://oac22.hsc.uth.tmc.edu/courses/neuroanatomy/					
	Then answer the questions below as instructed:																		
		1	**2**	**3**	**4**	**5**	**N/A**	**1**	**2**	**3**	**4**	**5**	**N/A**	**1**	**2**	**3**	**4**	**5**	**N/A**
Q1-	Please rate the clarity of explanations (1: very poor--5: excellent)																		
Q2-	Please rate the usefulness of the following features with regards to learning neuroanatomy (1: not useful at all -- 5: very useful).																		
a-	Explanation of the key-principles of pathway layout (for example, [A] defining 1st-2nd-3rd order neurons, [B] relation of ipsilateral or contralateral deficits with lesions below or above decussation, etc.)																		
b-	Step by step drawings of the neural pathways for students to watch and learn																		
c-	Cross-sectional images at various levels of the spinal cord and thebrainstem to understand location of ascending and descending tracts																		
d-	Summary sheets or tables to compare and differentiate neural pathways (based on type of sensory information, level of decussation, location in white column, etc.)																		
e-	Online quizzes (and feedback)																		
f-	CT and MRI images of brain and spinal cord																		
g-	Animations, videos																		
h-	3D computer models of brain and spinal cord																		
i-	Linking neuroanatomy with relevant neurophysiology																		
j-	Linking neuroanatomy with neuroradiology (e.g. CT, MRI, x-ray)																		
k-	Linking neuroanatomy with relevant head, neck, scalp and skull anatomy																		
l-	Linking neuroanatomy with embryological development																		
Q3-	Please rate the importance of the following features with regards to learning the clinical relevance of neuroanatomical facts (1: not significant to 5 :highly significant).																		
a-	Solving neurological problems (For example, localizing lesions in various sensory and motor deficits)																		
b-	Videos of bedside nervous system examination																		
Q4-	Please rate the usefulness of the following factors to help 3D visualization of neuroanatomical structures and pathways (1: not helpful at all -- 5: very helpful).																		
a-	Images of brain prosections																		
b-	Images of plastic models of brain and spinal cord																		
c-	2D / 3D illustrations																		
d-	3D brain model softwares																		
e-	Animations and / or video lectures																		
f-	Images of sections (horizontal, coronal, sagittal) at various levels of brain and spinal cord																		
g-	CT / MRI (horizontal, coronal, sagittal sections)																		
Q5-	Rate the value of this web resource for learning neuroanatomy (1:Not helpful at all -- 5:Very helpful)																		
Q6-	Rate the level of user-control imparted to students for learning neuroanatomy (1: not useful at all -- 5: very useful).																		
a-	Optional learning levels with varying amount of detail (beginner, intermediate and expert levels)																		
b-	Optional control of the pace of instruction (for example, slowing or fast-forwarding a video)																		
Q7-	Did the web-resource increase your interest in learning the neuroanatomy of the sensory and motor pathways? Please circle your answer.	Yes		No		Neutral		Yes		No		Neutral		Yes		No		Neutral	
Q8-	While learning online, what helps you best to visualize neuroanatomical structures, such as the hippocampus, the basal ganglia or the sensory and motor neuronal pathways?	Please explain:																	
Q9-	When using a neuroanatomy web-resource, what factor helps you most to learn?	Please explain:																	
Q10-	What matters least to you when learning neuroanatomy online?	Please explain:																	

Q11-	Please rate the impact of following teaching components (1=low, 5=high) on your learning of sensory and motor pathways, in each of the three web-resources.			
a-	Diagrams, illustrations, schematics			
b-	Atlas pictures			
c-	Pictures of models (plastic, plastinated)			
d-	Snapshots of prosections			
e-	Radiology images (X-ray, CT, MRI)			
f-	Videos of procedures (medical, interventional, surgical)			
g-	Neurological examination videos			
h-	Dissection videos			
i-	animations			
j-	Lecture videos			
k-	Podcasts			
l-	Radiology videos			
m-	Lectures notes			
n-	Transcripts of videos/lectures			
o-	Games, quizzes			
Q12-	Rank the above-mentioned three web-resources as 1 (best), 2(2nd best) and 3(3rd best) with regards to learning of neuroanatomy of ascending and descending tracts:	1________	2________	3________
	Thank you very much for your participation!			

Appendix 7

Consent Form for Evaluation of Neuroanatomy Web-Resources

Project information for research participants

Assessment of Computer Aided Learning Tools in Neuroanatomy Education

Investigators: Dr Muhammad Asim Javaid, Dr Harriët Schellekens, Prof. John Cryan, Dr André Toulouse

Study Location: Department of Anatomy and Neuroscience, University College Cork, Cork, Ireland

Purpose of the Study. This study is concerned with evaluating existing online neuroanatomy learning web-resources by a broad student cohort including medical (graduate and direct entry), occupational therapy and speech and language sciences, at University College Cork (UCC). The aim is to identify the limitations and strengths of the current resources from the students' perspective and collect useful information to better inform the instructional design of future neuroanatomy web-resources.

What will the study involve? Before the start of the study, you will be asked to sign the attached informed consent form. You can retain this information section. You will be requested to evaluate three web-resources, for 20 minutes each. You will be handed three copies of the same questionnaire before the commencement of the resource-evaluation process. There are 13 items in the questionnaire which take approximately 10 - 15 minutes to answer. You will be asked to complete one questionnaire after each evaluation and to return all three questionnaires to us before leaving the room where the experiment will be conducted.

You have been asked to take part in this study because the overall aim of the research project is to create a novel, online, neuroanatomy learning web-resource to complement neuroanatomy teaching to the students at UCC. The web resource will be created based on the feedback we obtain from your answers.

Your participation is entirely voluntary and we greatly value your input. Whether you participate or not, will not in any way influence your grades or performance evaluations. The survey is anonymous. Please do not add your name or student ID on this form. You can stop participating at any point during the course of the study.

The data will be kept confidential for the duration of the study. On completion of the research project, they will be retained for a duration of seven years with the supervisor and then destroyed. The results will be presented in a PhD thesis and may be published in a research journal.

Any questions/queries will be addressed by contacting the researcher, Dr. Muhammad Asim Javaid (Muhammad.ajavaid@ucc.ie).

This study has been reviewed and approved by the Social Research Ethics Committee at University College Cork.

If you agree to take part in the study, please sign the consent form overleaf.

We would like to sincerely than you for your participation in this study.

DEPARTMENT OF
ANATOMY &
NEUROSCIENCE
UNIVERSITY COLLEGE CORK

Consent Form

Assessment of neuroanatomy web-resources; a students' perception at UCC

1. I……………………………………… (BLOCK PRINT) agree to participate in this research study.
2. The purpose and nature of the study has been explained to me in writing.
3. I am participating voluntarily.
4. I give permission for my data to be used for further analysis and research
5. I understand that my participation will not affect in anyway my grades/exam performance.
6. I understand that anonymity will be ensured in the research process.

Signed……………………………………. Date……………….

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Appendix 8

Ethics Approval from SREC for Assessing the Neuroanatomy Web-Resources (Log. No. 2016-108; Approval Granted 08/11/2016)

ETHICS APPROVAL FORM

Social Research Ethics Committee (SREC)

UCC
University College Cork, Ireland
Coláiste na hOllscoile Corcaigh

Introduction

UCC academic staff and postgraduate research students who are seeking ethical approval should use this approval form. Ethical review by SREC is strongly recommended where the methodology is not clinical or therapeutic in nature and proposes to involve:

- Direct interaction with human participants for the purpose of data collection using research methods such as questionnaires, interviews, observations, focus groups etc.
- Indirect observation with human participant for example using observation, web surveys etc.
- Access to, or utilization of, data concerning identifiable individuals.

Application Checklist

This checklist includes all of the items that are required for an application to be deemed complete. In the event that any of these are not present, the application will be returned to the applicant without having been sent to review. Please ensure that your application includes all of these prior to submission. Thank you.

Completed Application Checklist	X
Completed Ethical Approval Self-Evaluation	X
Completed Description of Project	X
Information Sheet(s)	X
Consent Sheet(s)	X
Psychometric Instruments / Interview / Focus Group Schedules	X (Questionnaire)
I have consulted the UCC *Code of Research Conduct* and believe my proposal is in line with its requirements	X
If you are under academic supervision, your supervisor has approved the wording of and co-signed this application prior to submission	X

Please note that you must confirm you have taken account of the University's Code of Research Conduct in order for your application to be considered by SREC
(http://www.ucc.ie/en/media/research/researchatucc/documents/CodeofGoodConductinResearch_000.pdf)

APPLICANT DETAILS

Name of applicant(s)	Dr Muhammad Asim Javaid	**Date**	Sep 5th, 2016
Department/School/Unit, & Supervisor's Name	Department of Anatomy and Neuroscience , Dr André Toulouse	**Phone**	(021) 4205477
Correspondence Address	Room 2.33, Western Gateway Building	**Email**	A.Toulouse@ucc.ie
Title of Project	Assessment of Computer Aided Learning Tools in Neuroanatomy Education		

ETHICAL APPROVAL SELF-EVALUATION

		YES	NO
1	Do you consider that this project has significant ethical implications?		X
2	Will you describe the main research procedures to participants in advance, so that they are informed about what to expect?	X	
3	Will participation be voluntary?	X	
4	Will you obtain informed consent in writing from participants?	X	
5	Will you tell participants that they may withdraw from the research at any time and for any reason, and (where relevant) omit questionnaire items to which they do not wish to respond?	X	
6	Will data be treated with full confidentiality / anonymity (as appropriate)?	X	
7	Will data be securely held for a minimum period of seven years after the completion of a research project, in line with the University's Code of Research Conduct?	X	
8	If results are published, will anonymity be maintained and participants not identified?	X	
9	Will you debrief participants at the end of their participation (i.e. give them a brief explanation of the study)?	X	
10	Will your project involve deliberately misleading participants in any way?		X
11	Will your participants include children (under 18 years of age)?		X
12	Will your participants include people with learning or communication difficulties?		X
13	Will your participants include patients?		X
14	Will your participants include people in custody?		X
15	Will your participants include people engaged in illegal activities (e.g. drug taking; illegal Internet behaviour)?		X
16	Is there a realistic risk of participants experiencing either physical or psychological distress?		X
17	If yes to 16, has a proposed procedure, including the name of a contact person, been given? (see no 25)	N/A	
18	If yes to 11, is your research informed by the UCC Child Protection Policy? http://www.ucc.ie/en/ocla/policy/	N/A	

DESCRIPTION OF THE PROJECT

19. Aims of the project (briefly)
To identify and review the limitations of existing neuroanatomy web-resources from a student perspective to inform the creation of an online, case-based, interactive neuroanatomy learning web-resource to complement teaching in the areas identified.

20. Brief description and justification of methods and measures to be used (attach research questions / copy of questionnaire / interview protocol / discussion guide / etc.)
Once the information about the study has been provided and consent obtained, three copies of a self-administered web-resource evaluation questionnaire will be distributed among the student cohorts (direct and graduate entry medicine, occupational sciences, speech and hearing sciences). The questions will pertain to (1) aesthetic appeal of the web-resource (2) layout of content (3) motivational and interest-enhancing factors in the resource (4) user-friendliness and intuitiveness of the navigation and (5) the impact of the various teaching components of the resource. The survey will comprise of 12 closed-ended and one open-ended questions. Likert scale based and rating (scale of 1 to 5) questions will be used (please find a copy of the questionnaire attached with the application). This survey-based study is very important as the feedback obtained from the students will guide us in designing a novel online neuroanatomy learning web-resource.

21. Participants: recruitment methods, number, age, gender, exclusion/inclusion criteria, detail permissions
2nd year medical (graduate and direct entry) and 3rd year occupational sciences, speech and language sciences students, at UCC will be invited as the potential participants. The study will take place in the anatomy teaching facility (FLAME laboratory, WGB 3.59) at UCC at a time that is suitable to the various groups of volunteers. Participants will be requested to evaluate three pre-selected web-resources, one by one, and fill in an evaluation questionnaire for each resource. Questionnaires will be collected at the end of the session. We aim to recruit approximately 40 participants across the four programs. Participation will be voluntary, we therefore expect that the gender, race or age balance will be reflective of the student cohorts selected. Informed consent will be obtained and queries will be addressed when arising.

22. Concise statement of ethical issues raised by the project and how you intend to deal with them
We don't envisage any ethical issues raised by the project. The forms will be anonymous and will be secured in a locked cabinet inside the principal investigator's office with limited access only to the named investigators. The data will be entered online and secured in a password protected computer. Complete anonymity will be ensured throughout the processes of the data analysis and publication. Participation will have no bearing on classroom assessment and performance.

23. Arrangements for informing participants about the nature of the study (cf. Question 3)
An information session will be held in each class and written information regarding the study will be provided to the participants as part of the consent process (see attached consent form).

Participation will be entirely voluntary. Any questions/queries will be addressed verbally or in writing, if any arise.

24. How you will obtain Informed Consent - cf. Question 4 (attach relevant form[s])
Written informed consent forms will be distributed for signing before the commencement of the study (please find the informed consent form attached with the application).

25. Outline of debriefing process (cf. Question 9). If you answered YES to Question 16, give details here. State what you will advise participants to do if they should experience problems (e.g. who to contact for help).
We don't envision any problem or discomfort arising among the participants after filling in the questionnaire. However, any questions/queries will be addressed; before as well as after the study. For additional questions/comments later on, participants would have the option of contacting the researcher at the following email address: Muhammad.ajavaid@ucc.ie

26. Estimated start date and duration of project
October 2016 to December 2017 (duration = 1 year and 3 months)

Signed ________________________________ Date ___05/09/2016________
Applicant

Signed ________________________________ Date ___05/09/2016________
Research Supervisor/Principal Investigator (if applicable)

Appendix 9

Neuroanatomy Knowledge Quiz 1

Please answer the following questions:

The questions are being asked by the Department of Anatomy and Neuroscience at University College Cork (UCC), Ireland to inquire about your knowledge of neuroanatomy. There will be no personal benefit from completing the questionnaire; however, the data acquired from this survey will guide us in assessing an online, freely accessible, neuroanatomy web resource to meet the needs of undergraduate students. Please note that your participation in this survey is voluntary. Whether you participate or not, will not in any way influence your grades/performance evaluations. For comments/questions please contact Dr. Muhammad Asim Javaid in the department of Anatomy and Neuroscience at UCC on muhammad.ajavaid@ucc.ie. Your feedback is very important for us.

Question 1:
Which of the followings marks the **location** of fasciculus cuneatus?

A. Posterior white column
B. Anterior white column
C. Lateral white column
D. Anterior grey horn
E. Posterior grey horn
F. Lateral grey horn

Question 2:
What **functional impairment** could result by a lesion in the fasciculus gracilis?

A. Motor weakness in leg
B. Motor weakness in arm
C. Loss of pain and temperature perception in leg
D. Loss of pain and temperature perception in arm
E. Loss of perception of vibration and 2-point discrimination in leg
F. Loss of perception of vibration and 2-point discrimination in arm
G. Motor weakness of axial or postural musculature

Question 3:
Which of the followings **crossover (decussate)** to the opposite side of the neural axis?

A. Fasciculus gracilis
B. Fasciculus cuneatus
C. Medial leminiscus
D. Internal arcuate fibres
E. LMN of corticospinal tract

Question4:
A hemi-section involving the right half of spinal cord in the cervical region would result in which of the followings? Choose one best answer:

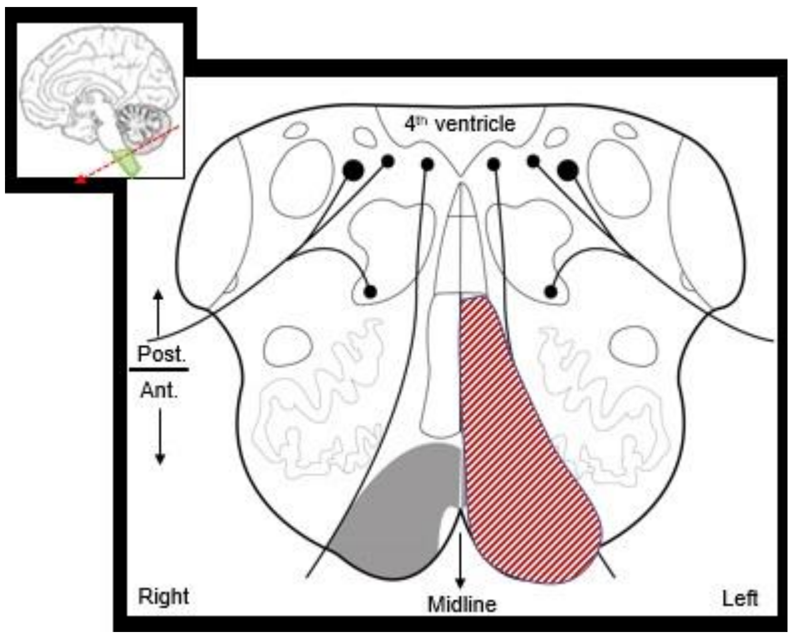
A. Loss of vibration sensation in the leg ipsilateral to lesion-side
B. Loss of vibration sensation in the arm contralateral to lesion-side
C. Loss of 2-point discrimination sensation in the arm ipsilateral to lesion-side

D. Loss of 2-point discrimination sensation in the arm and leg ipsilateral to lesion-side

Question5:
Match neuronal fibers with their location of the cells of their **termination**:

Tract	Cell of termination
1. Fasciculus gracilis (C)	A. Neuromuscular junction
2. Fasciculus cuneatus (E)	B. Anterior horn cells of spinal cord
3. Medial leminiscus (D)	C. Nucleus gracilis
4. LMN of corticospinal tract (A)	D. Ventral posterior lateral nucleus
5. UMN of corticospinal tract (B)	E. Nucleus cuneatus

Question 6:
Which of the followings is true for a lesion in the red shaded-area in the diagram below? Choose one best answer:



A. Ipsilateral loss of vibration and 2-point discrimination sensations
B. Ipsilateral loss of pain and temperature sensations
C. Ipsilateral motor weakness of muscles in arms and legs
D. Contralateral loss of vibration and 2-point discrimination sensations
E. Contralateral loss of vibration and contralateral motor weakness in arms and legs
F. Contralateral motor weakness of muscles in arms and legs

Question 7:
Arrange the following structures in **ascending chronological order** for the dorsal column medial-leminiscal pathway: DBEGFCHA
A. Primary sensory cortex

B. Posterior horn of spinal cord
C. Tegmentum
D. Pacinnian corpuscle/sensory receptor
E. Posterior column of spinal cord
F. Basal part of pons
G. Medulla oblongata
H. Thalamus

Question 8:
A lacunar infarct in the **left thalamus** would most likely result in which of the followings?
A. Weakness of right arm and leg
B. Weakness of left arm and leg
C. Loss of vibration and 2-point discrimination sensation in right arm and leg
D. Loss of vibration and 2-point discrimination sensation in left arm and leg
E. Loss of pain and temperature sensation in left arm and leg

Question 9:
A 41-year-old had woman presented with an oculomotor nerve palsy on the left side (paralysis of the left extraocular muscles except the lateral rectus and the superior oblique muscles, plus absent light and accommodation reflexes on the left side). There was weakness of muscles of the lower part of the face on the right side and spastic paralysis of the right arm and leg as well. Which of the following areas could this lesion be related to?
A. Medulla
B. Pons
C. Mid-brain
D. Medial surface of cerebral cortex with sparing of the superolateral surface
E. Spinal cord

Question 10:
Which of the followings marks the **location** of nucleus gracilis?
A. Medulla oblongata
B. Pons
C. Mid-brain
D. Thalamus
E. Pre-motor cortex

Question 11:
What **functional impairment** could result by a lesion in the lateral corticospinal tract?
A. Motor weakness in distal muscles of arms and legs
B. Loss of pain and temperature perception in arms and legs
C. Motor weakness of axial or postural musculature
D. Loss of perception of vibration and 2-point discrimination in arms and legs

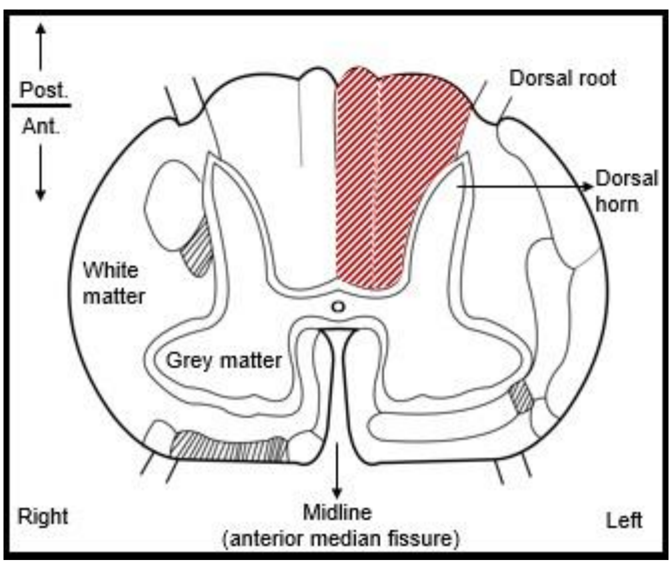
Question 12:
Match neuronal fibers with their location of the cell bodies of their **origin**: you can select >1 options on the right for the neural fibers on the left.

Tract	Cell bodies of origin
1. Fasciculus gracilis (D)	A. Pyramidal cells of betz
2. Fasciculus cuneatus (D)	B. Anterior horn of spinal cord
3. LMN of corticospinal tract (B)	C. Nucleus gracilis, nucleus cuneatus
4. Internal arcuate fibres (C)	D. Dorsal root (spinal) ganglion
5. UMN of corticospinal tract (A)	

Question 13:
A 60-year-old man presented to neurology clinic with muscle weakness and sensory loss in his right arm and forearm. His lower limb sensations were intact. Would could be the likely **site of the infarct** in this patient?

A. Left anterior and middle cerebral artery
B. Left middle cerebral artery
C. Left anterior cerebral artery
D. Right middle cerebral artery
E. Right anterior cerebral artery
F. Right anterior and middle cerebral artery

Question 14:
Which of the followings would result with a lesion in the red shaded-area in the diagram below?



A. Ipsilateral loss of vibration and 2-point discrimination sensations
B. Ipsilateral loss of pain and temperature sensations
C. Contralateral loss of pain and temperature sensations
D. Contralateral loss of vibration and 2-point discrimination sensations

Question 15:
Which of the followings does **NOT** contain corticospinal fibers?
A. Pyramid of medulla oblongata
B. Lateral white column of the spinal cord
C. Cerebral peduncle of midbrain
D. Anterior limb of internal capsule
E. Corona radiata

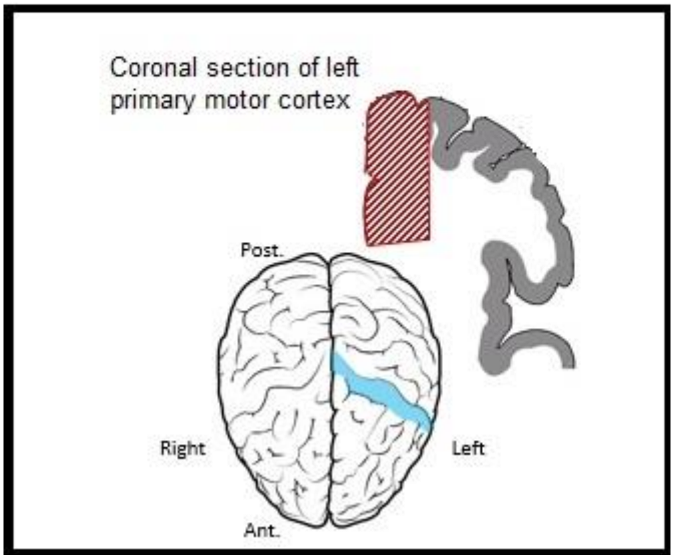
Question 16:
Which of the followings marks the **location** of corticospinal tract?
A. Posterior white column
B. Lateral white column
C. Posterior grey horn
D. Lateral grey horn

Question 17:
What **functional impairment** could result by a lesion in the fasciculus cuneatus?
A. Motor weakness in legs
B. Motor weakness in arms
C. Loss of pain and temperature perception in legs
D. Loss of pain and temperature perception in arms
E. Loss of perception of vibration and 2-point discrimination in legs
F. Loss of perception of vibration and 2-point discrimination in arms
G. Motor weakness of axial or postural musculature

Question 18:
Which level does the anterior corticospinal pathway **decussate**?
A. Pons
B. Medulla
C. Mid-brain
D. Thalamus
E. Internal capsule
F. Spinal cord

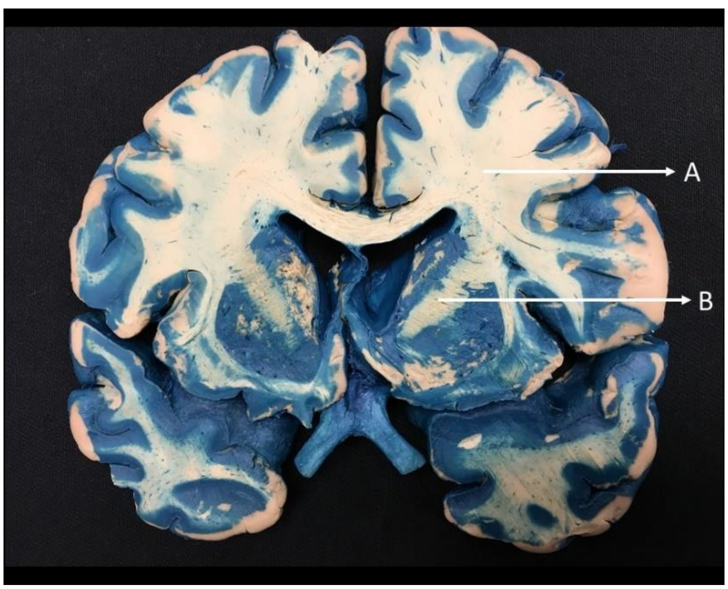
Question 19:
A 70-year-old woman presented to neurology clinic with muscle weakness and sensory loss in her right arm and leg. Her facial sensations were intact. Would could be the likely **site of the infarct** in this patient? Choose one best answer:
A. Left middle cerebral artery
B. Left anterior cerebral artery
C. Right middle cerebral artery
D. Right anterior cerebral artery
E. Right anterior cerebral and middle cerebral artery
F. Left anterior cerebral and middle cerebral artery

Question 20:
Which of the followings is true for a lesion in the red shaded-area in the diagram below affecting the primary motor cortex?



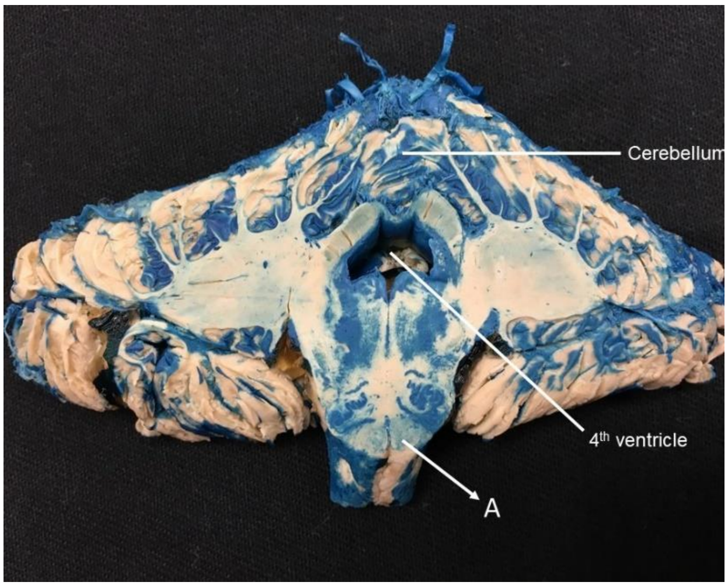
A. Ipsilateral loss of vibration and 2-point discrimination sensations in arms and legs
B. Ipsilateral loss of pain and temperature sensations in legs
C. Ipsilateral weakness of muscles in arms and legs
D. Contralateral loss of pain and temperature sensations in arms
E. Contralateral motor weakness in legs

Question 21:
Identify the structures labelled A and B in the coronal section shown below:
A=____________________, B=____________________



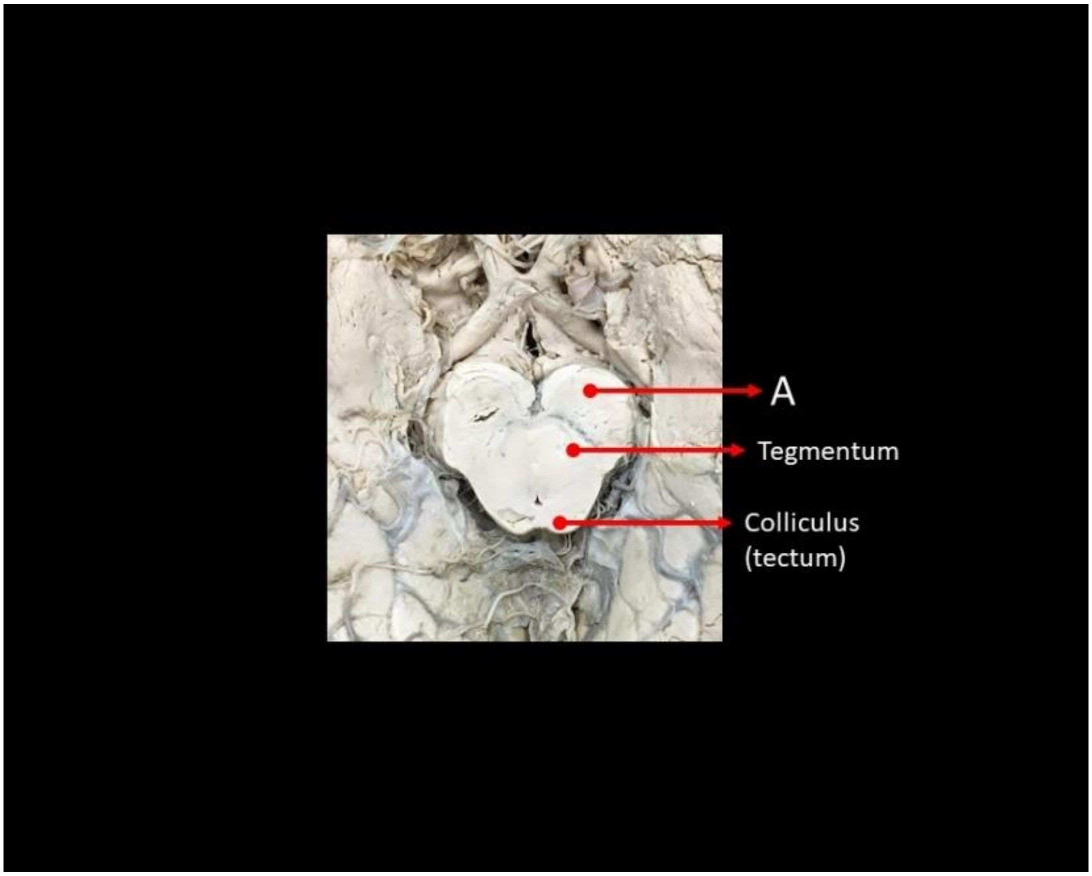
A. Corona radiata (A)
B. Crus cerebrum
C. Ventral pons
D. Pyramid
E. Internal capsule (B)
F. Lateral white column
G. Thalamus

Question 22:
Identify the structures labelled A in the horizontal section shown below:



A. Corona radiata
B. Crus cerebrum
C. Ventral pons
D. Pyramid
E. Internal capsule
F. Lateral white column
G. Thalamus

Question 23:
Identify the structure labelled A in the figure below:



A. Corona radiata
B. Crus cerebrum
C. Pre-central gyrus
D. Internal capsule
E. Lateral white column
F. Post-central gyrus
G. Thalamus
H. pyramid

Question 24:
Which of the followings marks the **location** of ventral posterior lateral (VPL) nucleus?
A. Medulla oblongata
B. Pons
C. Mid-brain
D. Thalamus
E. Pre-motor cortex
F. Spinal cord

Appendix 10

Neuroanatomy Knowledge Quiz 2

Please answer the following questions:

The questions are being asked by the Department of Anatomy and Neuroscience at University College Cork (UCC), Ireland to inquire about your knowledge of neuroanatomy. There will be no personal benefit from completing the questionnaire; however, the data acquired from this survey will guide us in assessing an online, freely accessible, neuroanatomy web resource to meet the needs of undergraduate students. Please note that your participation in this survey is voluntary. Whether you participate or not, will not in any way influence your grades/performance evaluations. For comments/questions please contact Dr. Muhammad Asim Javaid in the department of Anatomy and Neuroscience at UCC on muhammad.ajavaid@ucc.ie. Your feedback is very important for us.

Question 1:
Which of the followings marks the location of fasciculus gracilis?
A. Posterior white column
B. Anterior white column
C. Lateral white column
D. Anterior grey horn
E. Posterior grey horn
F. Lateral grey horn

Question 2:
What functional impairment could result by a lesion in the anterior corticospinal tract?
A. Motor weakness in distal muscles of arms and legs
B. Loss of pain and temperature perception
C. Motor weakness of axial or postural musculature
D. Loss of perception of vibration and 2-point discrimination

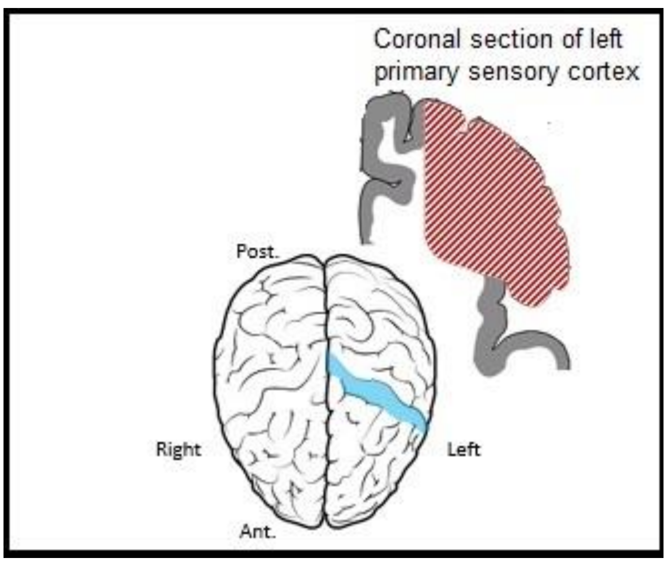
Question 3:
Match the spinal tracts with their functions:

Tract	Function
1. Fasciculus gracilis (D)	A. Sensory perception of vibration, conscious proprioception, 2-point discrimination from arms
2. Spinocerebellar tracts (F)	B. Motor control of distal limb muscles such as fingers
3. Spinothalamic tracts (E)	C. Control of axial musculature for postural balance/maintenance
4. Lateral corticospinal tract (B)	D. Sensory perception of vibration, conscious proprioception, 2-point discrimination from legs
5. Fasciculus cuneatus (A)	E. Pain and temperature sensations
6. Anterior corticospinal tract (C)	F. Proprioception-perception (subconscious)

Question 4:
Which level does the lateral corticospinal pathway decussate?
A. Pons
B. Medulla
C. Mid-brain
D. Thalamus
E. Internal capsule
F. Spinal cord

Question 5:
A 60-year-old man presented to the neurology clinic with muscle weakness and sensory loss in his left leg only. His upper limb sensations and facial sensations were intact. Would could be the likely site of the infarct in this patient? Choose one best answer:
A. Left middle cerebral artery
B. Left anterior cerebral artery
C. Left anterior and middle cerebral artery
D. Right middle cerebral artery
E. Right anterior cerebral artery

Question 6:
Which of the followings is true for a lesion in the red shaded-area in the diagram below affecting the primary sensory cortex? Choose one best answer:



A. Contralateral loss of vibration and 2-point discrimination in legs
B. Contralateral loss of vibration and 2-point discrimination sensations in arms
C. Ipsilateral loss of pain and temperature sensations in legs
D. Ipsilateral weakness of muscles in arms and legs
E. Contralateral loss of pain and temperature sensations in legs
F. Contralateral motor weakness in legs

Question 7:
Which of the followings does **NOT** contain dorsal column-medial leminiscal fibers?

A. Pyramid of medulla oblongata
B. Posterior white column of the spinal cord
C. Tegmentum of midbrain
D. Ventral posterior lateral nucleus
E. Cerebral cortex broadman's area 3,1,2

Question 8:
What functional impairment could result by a lesion in the spinocerebellar tract?

A. Motor weakness in legs
B. Motor weakness in arms
C. Loss of proprioceptive information
D. Loss of pain and temperature sensation in arms
E. Loss of pain and temperature sensation in arms and legs
F. Loss of perception of vibration and 2-point discrimination in legs
G. Loss of perception of vibration and 2-point discrimination in arms

Question 9:
Which of the followings crossover (decussate) to the opposite side of neural axis?

A. 1st order sensory neuron
B. 2nd order sensory neuron
C. 3rd order sensory neuron
D. Lower motor neuron

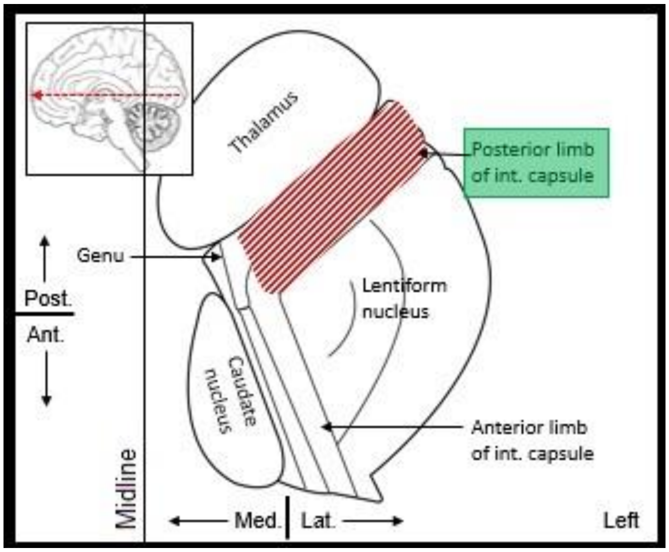
Question 10:
A hemi-section involving the right half of spinal cord in the lumbar region would result in which of the followings? Choose one best answer:

A. Loss of vibration sensation in the leg ipsilateral to lesion-side
B. Loss of vibration sensation in the arm contralateral to lesion-side
C. Loss of 2-point discrimination sensation in the arm ipsilateral to lesion-side
D. Loss of 2-point discrimination sensation in the arm and leg ipsilateral to lesion-side

Question 11:
Which level does the dorsal column-medial leminiscus pathway decussate?

A. Pons
B. Medulla
C. Mid-brain
D. Thalamus
E. Internal capsule
F. Spinal cord

Question 12:
Which of the followings would result with a lesion in the red shaded-area in the diagram below? Select the best possible answer:



A. Ipsilateral loss of vibration and 2-point discrimination sensations in arms and legs
B. Ipsilateral loss of pain and temperature sensations in legs
C. Ipsilateral weakness of muscles in arms and legs
D. Contralateral loss of pain and temperature sensations in arms
E. Contralateral motor weakness in arms and legs

Question 13:
Arrange the following structures in descending chronological order for the corticospinal tract: ADIBGHFCE
A. Primary motor cortex
B. Crus cerebrum
C. Anterior horn of spinal cord
D. Corona radiata
E. Skeletal muscle
F. Lateral column of spinal cord
G. Basal part of pons
H. Pyramid
I. Internal capsule

Question 14:
A lacunar infarct in the posterior limb of left internal capsule would most likely result in which of the followings?
A. Weakness of right arm and leg
B. Weakness of left arm and leg
C. Loss of vibration and 2-point discrimination sensation in right arm and leg
D. Loss of pain and temperature sensation in left arm and leg

Question 15:
A 10-year-old presented to clinic with weakness of her right face and flattening of her nasolabial fold and loss of frowning on forehead on the right side as well. She complained that the food always sticks inside her right cheek. On examination, there was definitive weakness of facial muscles on the right side. However, weakness was elicited on the left side in her arms and legs. Which of the following areas could this lesion be related to?

A. Medulla
B. Pons
C. Mid-brain
D. Medial surface of cerebral cortex with sparing the superolateral surface
E. Internal capsule

Question 16:
Which of the followings marks the location of nucleus cuneatus?

A. Medulla oblongata
B. Pons
C. Mid-brain
D. Thalamus
E. Pre-motor cortex

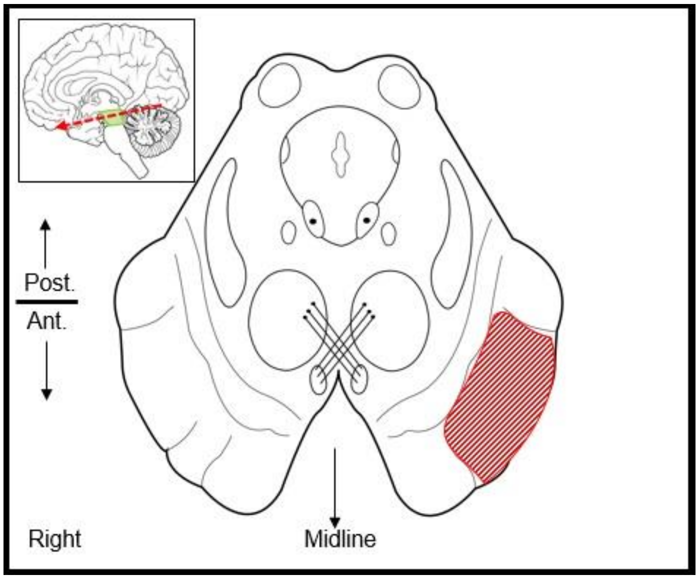
Question 17:
What functional impairment could result by a lesion in the spinothalamic tract?

A. Motor weakness in distal muscles of arms and legs
B. Loss of pain and temperature perception
C. Motor weakness of axial or postural musculature
D. Loss of perception of vibration and 2-point discrimination

Question 18:
Match the location of corticospinal tract in various parts of central nervous system:

Location of corticospinal tract	**Parts of central nervous system**
1. Cerebral cortex (D)	A. Pyramid
2. Diencephalon (E)	B. Crus cerebrum
3. Mid-brain (B)	C. Corona radiata
4. Medulla oblongata (A)	D. Primary and pre-motor areas
5. Spinal cord (F)	E. Posterior limb of internal capsule
6. Subcortical white matter (C)	F. Lateral white column

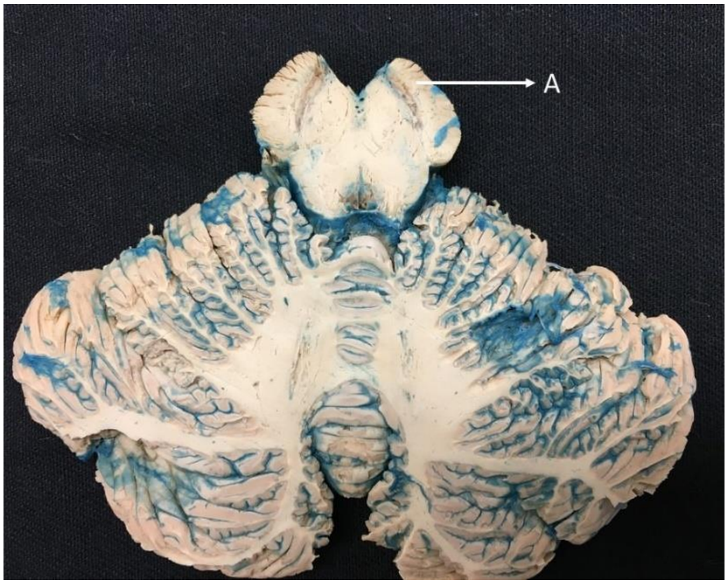
Question 19:
Which of the followings would result with a lesion in the red shaded-area in the diagram below?



A. Ipsilateral loss of vibration and 2-point discrimination sensations
B. Ipsilateral loss of pain and temperature sensations
C. Ipsilateral weakness of muscles in arms and legs
D. Contralateral loss of pain and temperature sensations
E. Contralateral motor weakness in arms and legs

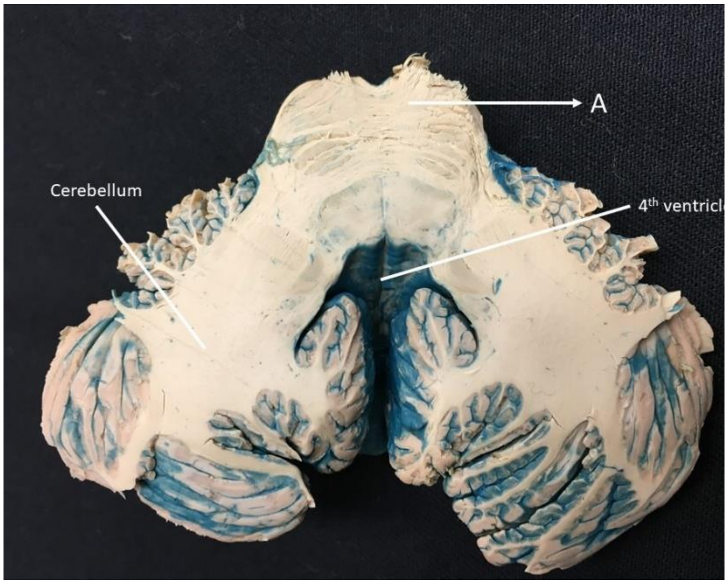
Question 20:
A hemorrhagic infarct in the right crus of mid-brain would most likely result in which of the followings?
A. Weakness of right arm and leg
B. Weakness of left arm and leg
C. Loss of vibration and 2-point discrimination sensation in right arm and leg
D. Loss of pain and temperature sensation in left arm and leg

Question 21:
Identify the structure labelled A in the horizontal section shown below:



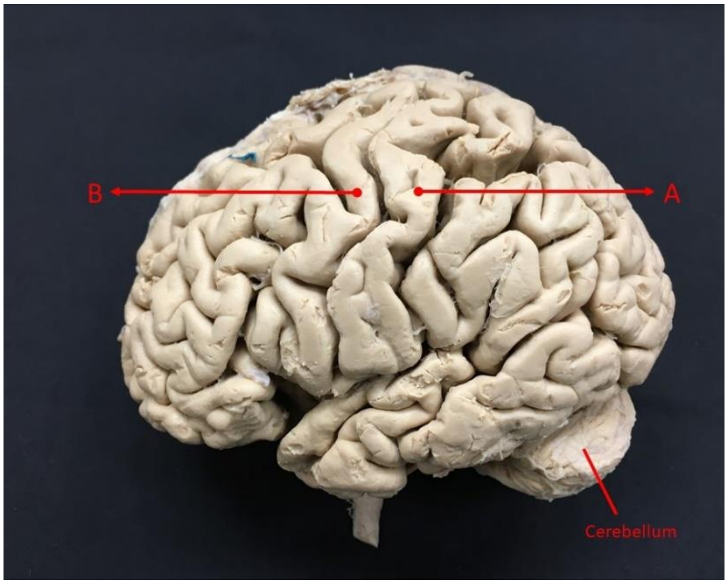
A. Corona radiata
B. Crus cerebrum
C. Ventral pons
D. Pyramid
E. Internal capsule
F. Lateral white column
G. Thalamus

Question 22:
Identify the structure labelled A in the horizontal section shown below:



A. Corona radiata
B. Crus cerebrum
C. Ventral pons
D. Pyramid
E. Internal capsule
F. Lateral white column
G. Thalamus

Question 23:
Identify the structures labelled A and B in the figure below:
A=____________________, B=____________________



A. Corona radiata
B. Crus cerebrum
C. Pre-central gyrus
D. Internal capsule
E. Lateral white column
F. Post-central gyrus
G. Thalamus
H. pyramid

Question 24:
A hemi-section involving the left half of spinal cord in the cervical region would result in which of the followings? Choose one best answer:
A. Loss of vibration sensation in the left leg
B. Loss of vibration sensation in the right arm
C. Loss of 2-point discrimination sensation in the left arm
D. Loss of 2-point discrimination sensation in the left arm and leg

Appendix 11

Student Perception Questionnaire Regarding the Allocated Neuroanatomy Web-Resource

	PLEASE FILL IN THE GREY BOXES BELOW:										
Q1											
A.	Did you use the online resource provided to you, for learning spinal pathways?	Yes					No				
B.	If yes, then:										
a.	How many times did you access the online tool?										
b.	Which days of the week did you access the tool?										
c.	On average, **for each single day:**										
	1. How many times did you access the online tool?										
	2. How much time (in minutes) each day did you actively spent using the online tool?										
d.	Which time of the day did you use the tool, the most? You can chose >1 options, if required:	Morning		Afternoon			Evening			Night	
e.	Wheres did you use the online tool provided?	On-campus			Off-campus				Both		
C.	Did you use any other resource along with the online tool to learn spinal pathways?	Yes					No				
	If yes, please explain what you used?										
		1 = very poor	2	3	4	5	6	7	8	9 = excellent	N/A
Q2	Rate the online learning resource provided, for:										
1	Its clarity of explanation										
2	Enhancing interest in learning neuroanatomy of spinal pathways										
Q3	Rate the USEFULNESS of the following features of the online resource for learning the spinal pathways:										
1	Explanation of the key principles of pathway layout (for example [A] what are 1st-2nd-3rd order neurons, [B] how to relate ipsilateral and contralateral deficits with lesions being below and above decussation).										
2	Step by step drawings of neural pathways										
3	Cross-sectional images with ascending and descending tracts										
4	Summarization of information (summary sheets, tables, etc.)										
5	Quizzes and feedback										
6	CT and MRI images										
7	3D computer models										

Q4	**Rate the USEFULNESS of the online resource for learning the followings:**										
1	Clinical relevance of neuroanatomy of sensory and motor tracts										
2	Localization of neurological lesions										
3	Dimensional relationship of neuroanatomical structures										
4	Identification of neuroanatomical structures on CT and MRI images										
5	Explaining the objectives mentioned in the learning outcomes										
Q5	**Rate the USEFULNESS of the following features of the online resource to aid in the 3D visualization of neuroanatomical structures and spinal pathways:**										
1	Images of brain prosections										
2	2D / 3D illustrations										
3	3D brain models										
4	Animations and / or video lectures										
5	Images of cross-sections (horizontal, coronal, sagittal) at various levels of brain prosections										
6	CT / MRI sections (horizontal, coronal, sagittal)										
		1 = very poor	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9 = excellent**	**N/A**
Q6	**After using the resource provided, your interest in learning neuroanatomy is:**										
		1 = very easy	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9 = very difficult**	**N/A**
Q7	**Learning neuroanatomy using the resource-provided was:**										
Q8	**For the online resource provided, rate the MENTAL EFFORT associated with the followings:**	**1 = Very low**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9 = Very high**	**N/A**
1	Finding the necessary information mentioned in the learning outcomes										
2	Learning the relationship of neuroanatomical structures										
3	Understanding cross-sectional images of various levels of brain prosections										
4	Learning to identify neuroanatomical structures on CT and MRI images										
5	Learning the clinical relevance of neuroanatomy of sensory and motor tracts										
6	Identifying the localization of neurological lesions										
Q9	**Plase feel free to leave any additional comments on the online resource you have used:**										

Appendix 12

Consent Form for Evaluation of the Allocated Neuroanatomy Learning Web-Resource

Department of Anatomy and Neuroscience, UCC

Project information for research participants

Investigators: Dr. Andre Toulouse, Dr. Harriet Schellekens, Prof. John Cryan, Dr. Muhammad Asim Javaid

Study Location: Department of Anatomy and Neuroscience, University College Cork, Cork, Ireland

Purpose of the study: This study is concerned with the development and assessment of the impact of a novel, neuroanatomy learning online tool on improving student performance. The aim of the study is to design an online neuroanatomy learning tool for undergraduate medical and clinical therapy (occupational and speech and language sciences) students at University College Cork (UCC).

What will the study involve? Before the start of the study (in mid-September), you will be asked to sign the attached informed consent form. You can retain this information section. While inside the lecture room, you will be briefed about the study and those willing to participate in the research will be requested to fill in a questionnaire comprising of 20 questions. These will take approximately 15-20 minutes to answer.

Later, in early-October, the online neuroanatomy tool for learning the sensory and motor neuronal pathways will be provided to you through the Blackboard. Based on whichever group you are enrolled in (control/experimental) you will be requested to use the provided-resource to learn the spinal tracts' anatomy. The resources will be kept available to the participants for one week. All students who are willing to engage in the research will be randomly assigned to control and experimental groups to assess the efficacy of newly designed web-application for enhancing student neuroanatomy learning compared to the currently available top-rated resource. The control group will not use the novel-tool during the one-week long experimental phase, however, all students will be provided access to the application immediately after the end of the experiment via Blackboard. The quantitative knowledge assessments will be done before and after the experimental session. Moreover, information regarding participants' perception about various instructional design features of the learning tool will also be inquired about at the end of the experiment.

You have been asked to take part in this study because the overall aim of the research project is to create a novel, online, neuroanatomy web-resource to enhance student learning at UCC. The feedback obtained from your answers will help us in optimizing and assessing the design of the final product.

Your participation is entirely voluntary and we greatly value your input. Whether you participate or not, will not in any way influence your grades or performance evaluations and you will not receive any favor or disfavor by deciding to take part or not to take part in the research. You have the option of withdrawing before the study commences or discontinue after data collection has started.

The data will be kept confidential for the duration of the study. On completion of the experiment, they will be retained for further ten years and then destroyed. The results will be presented in a PhD thesis and may be published in a research journal. I will ensure that no clues to your identity appear in the thesis. Any extracts from what you say that are quoted in the thesis will be entirely anonymous.

I don't envisage any negative consequences for you in taking part. At the end of the procedure, I will discuss with you how you found the experience and how you are feeling. Any further questions/queries will be addressed by contacting the researcher, Dr. Muhammad Asim Javaid (Muhammad.ajavaid@ucc.ie).

This study has been reviewed and approved by the Social Research Ethics Committee at University College Cork.

If you agree to take part in the study, please sign the consent for overleaf.

We would like to sincerely thank you for your participation in this study.

DEPARTMENT OF ANATOMY & NEUROSCIENCE
UNIVERSITY COLLEGE CORK

Consent Form

Development and assessment of a Novel Neuroanatomy Learning Web-Application at UCC

1. I……………………………………… (BLOCK PRINT) agree to participate in this research study.
2. The purpose and nature of the study has been explained to me in writing.
3. I am participating voluntarily.
4. I give permission for my data to be used for further analysis and research.
5. I understand that I can withdraw from the study, without repercussions, at any time, whether before it starts or while I am participating.
6. I understand that I can withdraw permission to use the data within two weeks of the study, in which case the material will be deleted.
7. I understand that anonymity will be ensured in the write-up by disguising my identity.
8. I understand that disguised extracts from my assessment questionnaires may be quoted in the thesis and any subsequent publications if I give permission below:

(Please tick one box :)

I agree to quotation/publication of extracts from my interview ☐

I do not agree to quotation/publication of extracts from my interview ☐

Signed: ……………………………………. Date: ………………..

PRINT NAME: …………………………………….

Appendix 13

Ethics Approval from SREC for Evaluation of Allocated Neuroanatomy Learning Web-Resource (Log. No. 2017-101; Approval Granted 18/10/2017)

UCC University College Cork, Ireland Coláiste na hOllscoile Corcaigh	**ETHICS APPROVAL FORM** **Social Research Ethics Committee (SREC)** ✉ srec@ucc.ie

Introduction

UCC academic staff and postgraduate research students who are seeking ethical approval should complete this approval form. Ethical review by the Social Research Ethics Committee (SREC) is required where the methodology is not clinical or therapeutic in nature and proposes to involve:

- direct interaction with human participants for the purpose of data collection using research methods such as questionnaires, interviews, observations, focus groups etc.;
- indirect observation with human participants for example using observation, web surveys etc.;
- access to, or utilization of, anonymized datasets;
- Access to, or utilization of, data concerning identifiable individuals.

SREC @ UCC considers itself an enabling committee, promoting strong research ethics amongst UCC's community of staff and student researchers. We are open to all types of research in the social research domain and if your research approach does not readily fit into this research form, do not be discouraged. Please add additional relevant notes to convey what you think is pertinent about the ethical aspects of your study.

Application Checklist

This checklist includes all of the items that are required for an application to be deemed complete. In the event that any of these are not present, the application will be returned to the applicant ***without*** having been sent for review. Please ensure that your application includes all of these prior to submission. Thank you and best of luck with your research.

All relevant files are combined into **one PDF** file (SREC application form, consent forms, information sheets, data collection instruments, permission letters, etc.)	Yes
Completed SREC Application Form	Yes
Information Sheet(s) / Information Statement (i.e. at the beginning of an electronic survey) included	Yes
Consent Sheet(s) / Consent Statement (i.e. at the beginning of an electronic survey) included	Yes
Data Collection Instrument: Psychometric Instruments / Interview Guide / Focus Group Schedule / Survey Questionnaire / etc. included	Yes
Copy of permission letters to undertake research from relevant agencies/services included (if available)	No
If you are under academic supervision, your supervisor(s) have approved the wording of and co-signed this application prior to submission	Yes
If this is a resubmission, all the revised and new text is highlighted in yellow	Yes

APPLICANT(S) DETAILS

Name of UCC applicant(s)	Dr. Andre Toulouse	**Date**	May 29th, 2017
Department / School / Research Institute / Centre / Unit / College	Department of Anatomy and Neuroscience	**Contact No.**	(021) 4205477
Correspondence Address	Dr. Andre Toulouse, Department of Anatomy and Neuroscience, University College Cork, muhammad.ajavaid@ucc.ie	**Email Address**	Muhammad.ajavaid@ucc.ie
Name and year of course (students only)		**Name of supervisor(s)** (students only)	
Is this a resubmission?	No	SREC Log No. (if known):	
What type of SREC approval are you seeking?	Full approval [X]	Outline approval [ ]	Funding approval [ ]

Obtaining ethical approval from SREC does not free you from securing permissions and approvals from other institutional decision-makers and agency ethical review bodies. These bodies may accept the SREC approval,
but researchers are responsible for ensuring they are compliant in advance of collecting data.

Project working title	Development and assessment of a Novel Neuroanatomy Learning Online Tool

If this is a collaborative project / community-based participatory research project / *joint* application with another agency, please complete this additional section:

Names of research partners / civil society organisations collaborating on this project (this section must be completed for participatory / community-based participatory research studies)	
Agency contact person and position	
Agency address	
Details of the partnership (roles, type of partnership, etc.)	

ETHICAL APPROVAL SELF-EVALUATION

If your answer falls into any of the shaded boxes below, please address each point later on in the application form

		YES	NO
1	Do you consider that this project has significant ethical implications?		X
2	Will you describe the main research procedures to participants in advance, so that they are informed about what to expect?	X	
3	Will participation be voluntary?	X	
4	Will you obtain informed consent in writing from participants?	X	
5	Will you tell participants that they may withdraw from the research at any time and for any reason, and (where relevant) omit questionnaire items / questions to which they do not wish to respond?	X	
6	Will data be treated with full confidentiality / anonymity (as appropriate)?	X	
7	Will data be securely held for a minimum period of ten years after the completion of a research project, in line with the University's *Code of Research Conduct* (2016)?	X	
8	If results are published, will anonymity be maintained and participants not identified? (see Q. 30 below regarding open data considerations, if relevant)	X	
9	Will you debrief participants at the end of their participation (i.e. give them a brief explanation of the study)?	X	
10	Will your project involve deliberately misleading participants in any way?		X
11	Will your participants include children / young persons (under 18 years of age)?		X
12	If yes to question 11, is your research informed by the UCC *Child Protection Policy*? http://www.ucc.ie/en/ocla/policy/	NA	NA
13	Will your project require you to carry out "relevant work" as defined in the National Vetting Bureau (Children and Vulnerable Persons) Acts 2012 to 2016?		X
14	Do you require official Garda Vetting through UCC before collecting data from children or vulnerable adults?		X
15	Will your participants include people with learning or communication difficulties?		X
16	Will your participants include patients / service users / clients?		X
17	Will your participants include people in custody?		X
18	Will your participants include people engaged in illegal activities (e.g. drug taking, illegal Internet behavior, crime, etc.)?		X
19a	Is there a realistic risk of participants experiencing either physical or psychological distress?		X
19b	Is there a realistic risk of the researcher experiencing either physical or psychological distress?		X

20	If yes to question 19a, has a proposed procedure for linking the participants to an appropriate support, including the name of a contact person, been given? (see Q. 33)	NA	NA
21	If yes to question 19b, has a proposed procedure/support structure been identified?	NA	NA
22	Are your research participants students with whom you have some current/previous connection (module coordinator, research supervisor, professional tutor, etc.)?		X
23	Will your study participants receive payment / gifts / voucher / etc. for participating in this study?		X

DESCRIPTION OF THE PROJECT

*Ethical review requires that you **reflect** and seek to **anticipate** ethical issues that may arise, rather than reproduce copious text from existing research proposals into these boxes. Entries should be **concise** and relevant to the point / question.*

24. Very brief description of your study (15-25 words max.) [i.e. This is a qualitative study of primary school teachers' attitudes towards religious teaching using focus groups to collect original data]
This is a combined qualitative and quantitative study of undergraduate medical and clinical therapy students towards assessing the impact of a novel online tool on neuroanatomy learning.
25. What is your study about? (100-200 words max.)
Medical students and young doctors associate their lack of understanding of basic neuroanatomical concepts with their impaired confidence of managing neurological patients. The issue of addressing impaired understanding of basic sciences among students becomes even more challenging due to a reduction in teaching hours and decline in availability of experienced faculty members. In this context, the current study aims to assess the impact of a novel neuroanatomy learning tool on students' performance. A randomized, case-control study possessing a within and between-subject design has been formulated. Undergraduate medical and clinical therapy students; occupational and speech and language sciences, will be invited to participate in the study. The participants in experimental group will employ the newly formulated learning-tool along with traditional textbook while the participants in the control group will be offered the best-rated available neuroanatomy learning resource along with textbooks. Both groups will be provided with a study guideline (instructions) to enable them to use the provided resources in a standardized manner, to learn neuroanatomy of motor and sensory pathways. Subjects' performance before and after the experiment will serve as indicators for gauging their performance improvement and quantifying their attitudes towards the new tool.
26. What are your research questions?
Does the novel prospective tool serve as a better adjunctive pedagogy for significantly improving neuroanatomy learning of undergraduate students compared to the top-rated freely available online resource?
27. Brief description and justification of methods and measures to be used (attach questionnaire / interview protocol / discussion guide / etc. for **full** SREC approval. **Not** required for SREC outline approval)
Information about the study will be provided to the students during the last 15-20 minutes of the introductory lecture of the neuroanatomy module commencing in the first semester. Once the consent has been acquired, participants' knowledge of neuroanatomy will be assessed by a list of 20 questions incorporating multiple-choice, matching-items and clinical-scenario-based questions. These will be designed to assess students' ability to recall facts as well as their deeper understanding of the neuroanatomical concepts. Students' identification numbers will be used to keep track of their performance analytics. The assessments will be conducted on standardized pieces of paper inside the lecture-room and participants will be requested to return them before leaving. Here we want to especially emphasize that there will be no pressure on the students to participate in the study. And we will ensure that those students who decided against participating in the study will not be obvious in their non-participation. This will be done distributing the assessment questionnaires to all available but providing them with the opportunity to not write their student no. on the questionnaire before handing it over and consequently the questionnaires from students who chose to do so, will not only be excluded from the research study but at the same time their non-participation will not become obvious either. Later, during the week 6 of the first semester, when students would have received their lectures on sensory and/or motor neuronal pathways, participants willing to engage in the research will be randomly assigned to control and experimental groups. The control group will receive the top-

selected neuroanatomy learning resource while the experimental group will receive the novel learning tool (created in power point and uploaded on OneDrive). Links to both resources will be provided to the students through Blackboard along with the PDF of the selected section of a standardized textbook and neuroanatomy atlas. The online links will be made available to participants for a duration of one week, following which they will be re-assessed using an additional list of 20 questions. These will be different from the earlier assessment-questions, however, will be having a difficulty-level like the questions included in the previous assessment. In addition, information regarding the analytics pertaining to the usage of tools will be acquired subjectively from participants. The participants will also be requested to fill in a qualitative questionnaire, if they will, regarding their perception of the usefulness of various aspects of the learning tool provided and suggestions for potential improvement in the instructional design. We intend to investigate any difference in impact of the newly designed tool (experimental group) on neuroanatomy learning compared to already available freely assessable online resources. Pre- and post-study quantitative assessments (MCQs) will be conducted to measure any improvement in neuroanatomy knowledge compared to baseline. This study is very important as the feedback and assessment results obtained from the students will help us in assessing the impact of our novel, web-application on neuroanatomy learning of undergraduate medical and therapies' students.
28. Participants (recruitment methods, number, age, gender, exclusion/inclusion criteria, detail permissions to be sought / secured already)
Second year direct entry medical and third year clinical therapy (occupational and speech and language sciences') students at UCC, Ireland will act as potential participants. All students from above-mentioned cohorts will be invited to participate in the study on a voluntary basis. We aim to recruit approximately 120 participants. Participation will be voluntary, we therefore expect that the gender, race or age balance will be reflective of the students' cohorts selected. Prior informed consent will be obtained and queries will be addressed. The participants will have the option of withdrawing from the research at any time. If they decide to so, they will simply have to notify the principal investigator via email and their data will not be included in any part of the research.
29. Concise statement of *anticipated* ethical issues raised by your project. How do you intend to deal with them? Please address *all* items where your answers fell into a shaded box in the self-evaluation above. (350 words max.)
We don't envisage any ethical issues raised by the project. The control groups will be provided access to the new learning tool via Blackboard, immediately after the experiment finishes. The forms and questionnaires will be secured in a locked filing cabinet inside the principal investigator's office with limited access to only to the named investigators. The data will be entered online and secured in a password protected computer. Participation will have no bearing on classroom assessment and grading. Moreover, the students/participants will not experience any favour of disfavour by deciding to take part or not to take part in the research. We especially emphasize that the principal investigator (Dr. Andre Toulouse) is not involved in delivering lectures and conducting practical lab sessions for any of the participant cohorts, thus eliminating the chances of pressurizing the students to participate in the research and consequently avoiding any potential ethical implications arising from such an act.
30. Data: **(a) What type of data will you be storing?** **(b) How and where will you store your data?** (Provide details for both physical *and* electronic documents). **(c) For how long will you store the data?** (A minimum storage period of 10 years is required) **(d) Who will have access to the dataset?** (*Sample* prompts: If you plan to make your raw research dataset available publicly as part of the open data movement, please address your protocol here. For collaborative/community-based participatory research, please address issues

such as shared ownership of data, publication of findings, etc. If your funder contractually requires you to give them access to the 'raw' dataset, examine relevant implications, including appropriate anonymisation, protocols for secure access to the dataset, etc.). **(e) If you are planning to analyse an existing dataset, please outline how the original consent process allows for your analysis.**
Data will be acquired through quantitative assessments (in the form of MCQs; matching-items and clinical scenario-based questions) and perception questionnaires inquiring about students' usage of the learning tools. Participants will play around with the learning tool online at their own convenient time. Pre- and post-assessments will be conducted manually on pieces of paper. The data will be entered on an excel sheet and will be stored in a password protected and encrypted computer in principal investigator's office. In addition, the forms and questionnaires will be secured in a locked filing cabinet inside the principal investigator's office with limited access to only to the named investigators. All data forms will be stored for a duration of 10 years.
31. Arrangements for informing participants about the nature of the study (cf. Question 3)
Participants will be informed about the details of the study inside the classroom, on the day of the orientation session for upcoming Neuroanatomy module. Participation will be voluntary. Written informed consent will then be distributed among participants.
32. How you will obtain Informed Consent? (cf. Question 4 - attach relevant form(s)
Written informed consent form will be obtained before commencement of the study (please find the informed consent form attached with the application).
33. Outline of debriefing process (cf. Question 9). If you answered YES to Questions 19a or 19b, give details here. State what you will advise participants to do if they should experience problems (e.g. who to contact for help).
We don't envisage any problem or discomfort arising among participants during the experiment and after filling in the questionnaires and assessments. However, any question(s)/quer(ies) will be addressed; before and after the study. For additional questions/comments later, participants will have the option of contacting the researcher at the following email address: Muhammad.ajavaid@ucc.ie
34. Estimated start date and duration of project
September 2017 to December 2017 (duration 4 months)
35. Additional information of relevance to your application
Please find the list of quantitative assessment questions and attached. These will randomly assorted to the pre- and post-quantitative assessment questionnaires while maintaining a similar difficulty-level. The perception questionnaire for acquiring the qualitative data has been attached with the application as well.

36. Declarations	
I/we agree that should there be unexpected ethical issues arising during the course of this study, that I/we will utilize my/our professional/disciplinary code of ethics, and/or notify UCC SREC, where appropriate	Yes
I/we have consulted the UCC *Code of Research Conduct* (2016) and believe my/our proposal is in line with its requirements	Yes
I/we have consulted the UCC *Child Protection Policy* and believe my/our proposal is in line with its requirements	NA

37. Signatures	
UCC Applicant(s)	**Academic Supervisor / Tutor / Principal Investigator** (where applicable)
Date: 04-10-2017	Date: 04-10-2017

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