ARTICLE
Virtual Dissection Table Case Studies for Undergraduate Neuroanatomy Written Assignments

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Neuroanatomy education benefits from cadaveric specimens, yet challenges with access, cost, and health concerns exist. Virtual Dissection Tables (VDTs) offer digital alternatives to traditional cadaveric learning. This article evaluates the pedagogical value of VDTs in undergraduate neuroanatomy education. While VDTs, primarily Anatomage, offer interactive 3D cadaveric images and customization options, research on their impact on neuroanatomy learning outcomes remain limited. Existing studies suggest comparable knowledge retention between VDTs and cadaveric learning, with varying effects on student satisfaction. Investigations of non-exam-based neuroanatomy assessments, however, are scarce. This study presents a case study using VDTs as the basis for a neuroscience assignment report, exploring its construction, and evaluating its strengths, and weaknesses through a student survey. Implemented in an advanced neuroscience course, the assignment involves analyzing 3D reconstructed MRI scans of neuropathological conditions displayed on the VDT. The task requires students to collate, analyze, and predict symptoms based on the pathology observed, aligning their findings with neuroscience literature. This innovative approach aims to enhance research and academic writing skills while expanding the use of VDTs beyond traditional assessment formats in neuroscience education. We found that the case-study format benefited students' neuroanatomy learning and application ability. Further studies should be conducted, however, to understand the effect of VDT use on learning outcomes in case study contexts.

Key words: neuroanatomy education; Anatomage; case-based learning; virtual dissection; neuropathology

INTRODUCTION

Undergraduate neuroanatomy education, like all anatomy education, is enhanced by learning from cadaveric specimens (Ramsey-Stewart et al., 2010). Human donor material, however, can be difficult to access (Gashegu, 2023), expensive to correctly maintain and may not be suitable for all students (Owolabi et al., 2022). For example, pregnant students are advised to avoid human donor material due to the danger imposed by formaldehyde fumes (Washmuth et al., 2020). There are also ethical restrictions which prevent students from being able to photograph or record cadaveric specimens, temporally restricting their learning value to practical classes. Technology developments now allow for digital modes to engage with cadaveric specimens, and the value of these technologies as pedagogical tools should be evaluated in neuroanatomy education.

Virtual dissection tables (VDT) provide either an alternative, or complement to, cadaveric learning events during anatomy practical classes. The Anatomage table, the market-dominant VDT (Vasil'ev et al., 2023), is a large electronic tablet pre-loaded with reconstructed 3D images of four cadavers: three individuals from the Visible Human Project (Waldby, 2003), and the individual from the Visible Korean Human project (Park et al., 2005). They allow the user to move gradually between the anatomical planes to observe sectional anatomy, prosect the cadaver, view the specimen in a system-wise manner and visualize a customized list of pre-labelled anatomical structures. These images can then be saved and annotated by the user.

VDTs gained public popularity after the Anatomage table, developed in 2011 (White, 2011), was used in a 2012 documentary visualizing Tutankhamen amidst new discoveries surrounding his death and embalming (Periya and Moro, 2019; Sawer, 2013). VDT technology then quickly became a focus of undergraduate medical education research (Fyfe et al., 2013). Recent surveys of institutions in Australia (Newman et al., 2021) and America (McBride and Drake, 2018) suggest that approximately 10% of medical schools deploy this technology. Additionally, the proliferation of open-access human imaging sources creates opportunity for free versions of this technology to be crafted by teaching staff. Given its increasing accessibility, it is important to maximize the benefits VDTs can bring to undergraduate neuroanatomy education.

Evidence of VDTs improving learning outcomes in anatomy students is still nascent. The majority of quasi-experimental studies on this topic suggest that VDTs, when compared to learning from cadaveric specimens, produce similar levels of knowledge retention in follow-up quizzes (Ahmed, 2023; Kavvadia et al., 2023; Periya and Moro, 2019). Many of these studies, however, also cite an increase in student satisfaction or positive perception of VDTs compared to human donor material (Brito et al., 2022; Kavvadia et al., 2023; Periya and Moro, 2019). One study opposes this trend; an Indonesian cohort of medical students taking part in a VDT intervention had a decreased final grade in dermatomusculoskeletal anatomy (Bustamam and Purwaningastuti, 2021). These results cannot necessarily be extrapolated to neuroanatomy contexts as the effect of VDTs on student learning varies depending on the body system under examination (Baratz et al., 2019).

There is little research examining the use of VDTs in neuroscience education. Anand and Singel (2021) found that replacing cadaveric learning opportunities with VDTs for neuroanatomy students did not affect their exam performance. Kusumaningtyas and colleagues (2021) examined the potential effect of instead combining VDT learning opportunities with traditional cadaveric learning for neuroanatomy students; students who received both learning opportunities were able to improve their test scores by a greater margin compared to students who solely engaged with physical cadaveric specimens. One study examining VDTs for neuropathology learning has reported a positive impact on knowledge retention (Sadiq et al., 2023). Another neuroanatomy-specific study suggests that VDTs provide a disproportionate knowledge retention benefit to students with previously poor exam performance (Bhadoria, 2021).

Together, the literature reviewed above demonstrates that VDTs can be beneficial in neuroanatomy education. Most existing studies on VDTs and neuroanatomy learning, however examine the same outcome: knowledge retention in a post-intervention quiz, or an analysis of exam performance. To the best of the authors' knowledge, no studies currently exist examining the use of VDTs in non-exam neuroanatomy learning assessment. We therefore aim to expand the contexts in which VDTs are used and evaluated in neuroscience education.

Given that VDTs can store student-gathered screenshots for later presentation, VDTs can also be utilised as a tool for constructing authentic course assignments. For example, an oral examination of Indian MBBS students found increased scores and student satisfaction with VDT compared to traditional cadaver (Fulmali and Mishra, 2022). Another recently published reflection by Rompolski (2023) demonstrates the use of VDTs in a general anatomy course assessment taking the form of peer-teaching. Anatomage is also amenable to peer teaching and case-based learning scenarios in undergraduate neuroanatomy (Yaqinuddin et al., 2022). Lastly, Ward and colleagues (2018) documented the novel use of a VDT as the basis for a student developing a radiography course poster presentation. Currently the use of VDTs as an assessment tool remains relatively under-researched, especially in neuroscience contexts. To address this gap, this article presents a case study of our use of a VDT as the basis for a neuroscience assignment report. We provide a detailed account of its construction to allow for easy adoption by other neuroscience educators, as well as an evaluation of our approach's strengths and weaknesses through analyzing student survey results.

CASE STUDY CONTEXT

Our case study is implemented in LQB571: Neuroscience, a subject taken by students in the 3rd full-time year of the Bachelor of Biomedical Science at Queensland University of Technology. The subject is only taken by students who have chosen either an anatomy and/or physiology major/minor. This cohort therefore represents a more advanced student with specialized interest in neuroscience, compared to the general 1st year medical student cohorts in which VDTs have commonly been assessed. LQB571: Neuroscience typically enrolls 100 students per semester.

Students are provided with two synchronous learning opportunities each week: a two-hour lecture and a three-hour practical class. The lectures initially cover advanced neuroanatomy, followed by advanced neurophysiology and finish the semester by covering emerging areas of neuroscience research. Practical classes are designed to revise and extend the corresponding week's lecture learning objectives. Practical classes are run with class sizes of approximately 50 students rotating through four main learning resources: plastic 3D neuroanatomical models, a human cadaveric nervous system prosection, light microscopes set up with neurohistological slides, and a VDT with a relevant neuropathology case study (Figure 1A-B). The facilitation of these activities is performed by a lecturer and two teaching staff per practical session. Each station is supported by a member of the teaching team to answer student queries and facilitate their engagement with the resources.

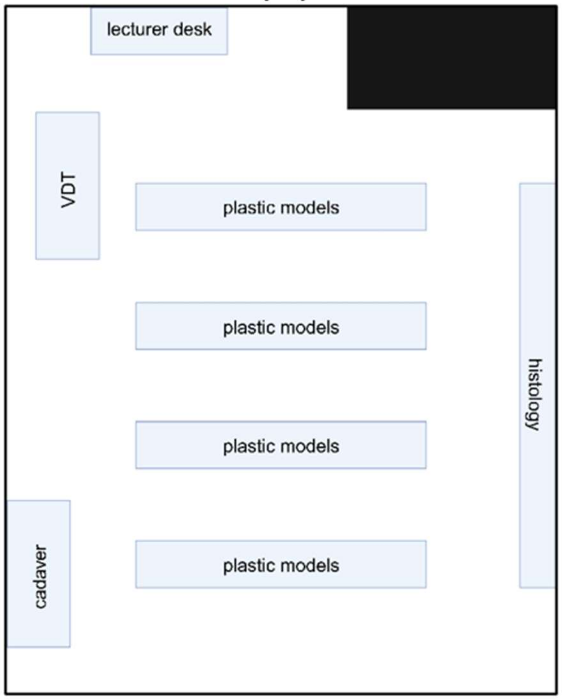
CASE STUDY DESCRIPTION

Institutional ethics approval was obtained to examine the use of Anatomage case study assignments in this Neuroscience unit (approval number: 8109-HE09). Each semester, a new case study is used, however all involve some form of visible pathology in defined central nervous system regions. The examples provided in this article are those of a traumatic brain injury and a gunshot wound. Three-dimensional reconstructed MRI scans of the affected individual are then displayed on the VDT for students to assess during their practical classes. Students are able to virtually rotate, prosect, label and save these scans to use in their assignment. Students are given the following instructions in their task sheet:

"*You need to collate and analyse MRI images in Anatomage to obtain images covering the affected brain areas by the [specific pathology]. You may use three dimensional images to identify what brain areas might have been affected. You can use the MRI brain images and brain sections (plastic models available in practical class) to detect the affected brain areas and to identify the potential damaged brain structures. You need to save your images in a folder in an Anatomage table which will then be uploaded by the unit coordinator on the [Learning Management System].*"

These VDT images then form the basis for the students' case study report, worth 30% of their final grade for the subject (Figure 1C). The report focusses on developing students' research and academic writing abilities by

(A)



(B)

	plastic models	histology	cadaver	VDT
4:10-4:50pm	1	2	3	4
4:50-5:30pm	4	1	2	3
5:30-6:10pm	3	4	1	2
6:10-6:50pm	2	3	4	1

(C)

assessment item	weighting
VDT Case Study	30%
Neurophysiology experiment report	30%
Final Exam	40%

Figure 1: Context of Virtual Dissection Table (VDT) used in LQB571: Neuroscience. *(A)* Floor plan of laboratory classroom, with each learning activity marked. *(B)* Schedule of rotation for students in an example 4pm-7pm class. Students spend 40 mins with each learning resource, including the VDT. *(C)* Assessment breakdown.

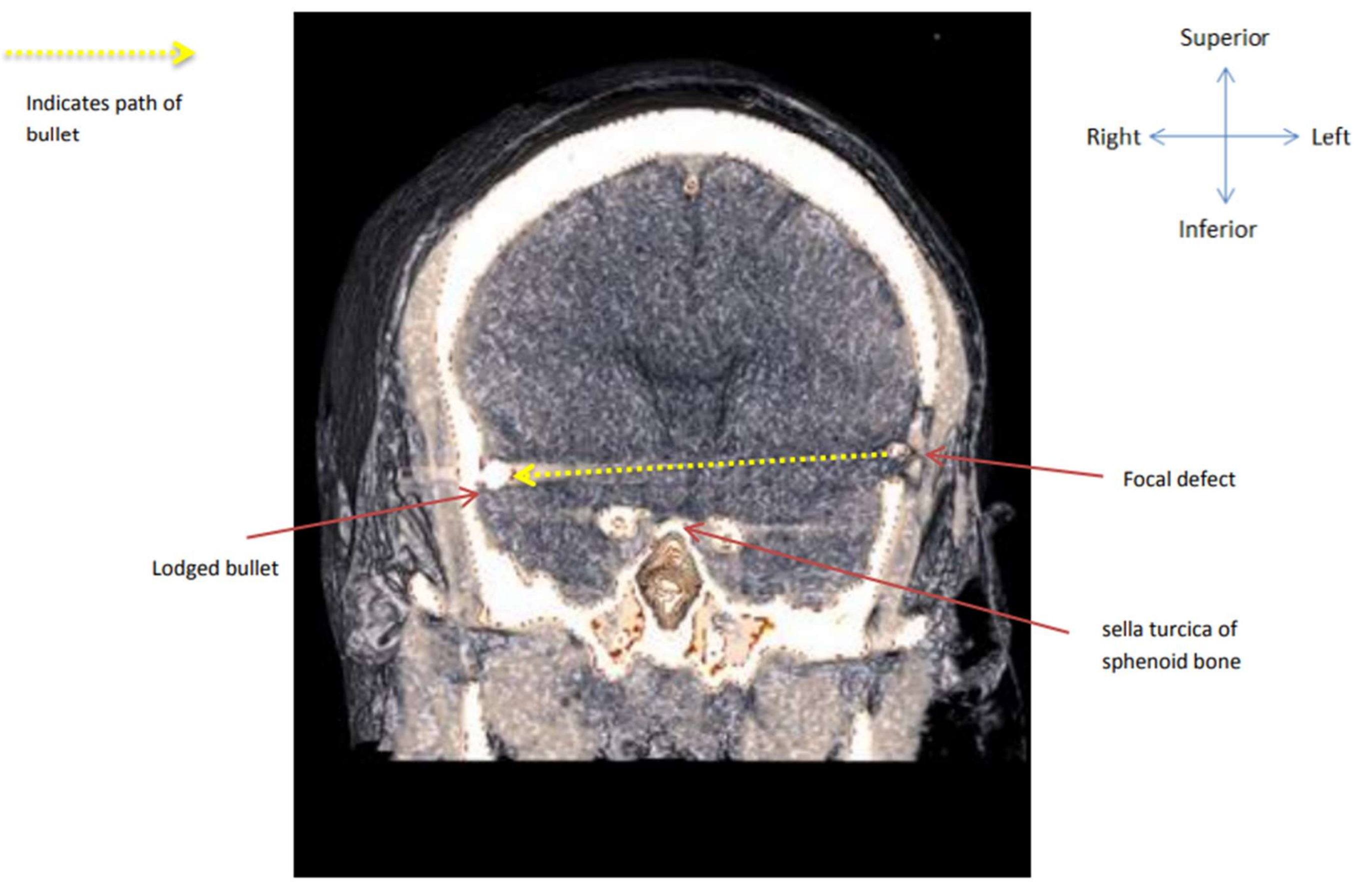


Figure 2: One student example from the LQB571: Neuroscience ‘Bullet in the Brain’ case study assessment using the Context of Virtual Dissection Table (VDT).

requiring them to link their analysis of the VDT case study to wider neuroscience literature. Students first provide a short review of the pathology, then present their images in a logical manner to clearly outline the affected regions. Then, the students are required to utilize their knowledge of functional anatomy, in combination with neuroscience literature, to predict the specific symptoms the VDT patient two would have been experiencing. Here we provide examples of the figures that students generated (Figure 2, Figure 3), as well as the most recent marking rubric used to grade this case study (Table 1).

CASE STUDY EVALUATION AND DISCUSSION

This case study adds to a small pre-existing pool of research on VDT use in neuroscience education. To the best of the authors' knowledge, this is the first published account of a VDT being used as the basis for a neuroscience course report. Providing students with specific neuropathology cases provides contextualized neuroanatomy learning, which has recently been shown to improve student success (Yaqinuddin et al., 2022). It can be difficult, however, for universities to accumulate sufficient pathological specimens, which are likely also stored in 'pots' making them unable to be handled or dissected. The Anatomage VDT used for this case study has a plethora of pathology case studies to use (for example, there are over 20 different glioblastoma cases alone). The use of VDTs also bypasses the otherwise lengthy process of gathering ethical approval from hospitals to use patient scans. To evaluate the effectiveness of our case study, we implemented a short optional survey completed by 23 students after completing their assignment (Ethics Approval Number: 8109-HE09). The results are presented below with mean±standard deviation results representing the average student opinion on a Likert scale (i.e., 5=strongly agree, 1=strongly disagree; Table 2). Two open ended questions were also presented to students, asking about what they liked and disliked about using the VDT respectively. Selected quotes from these answers are also presented alongside the evaluation analysis.

The results firstly demonstrate that the assignment overall benefited most students' perceived confidence in learning neuroanatomy (3.87±1.01) and their ability to apply neuroanatomical knowledge to clinical settings (4.17±0.78). Students described the case study as "a new experience", "learning about real pathology" and "the opportunity of the

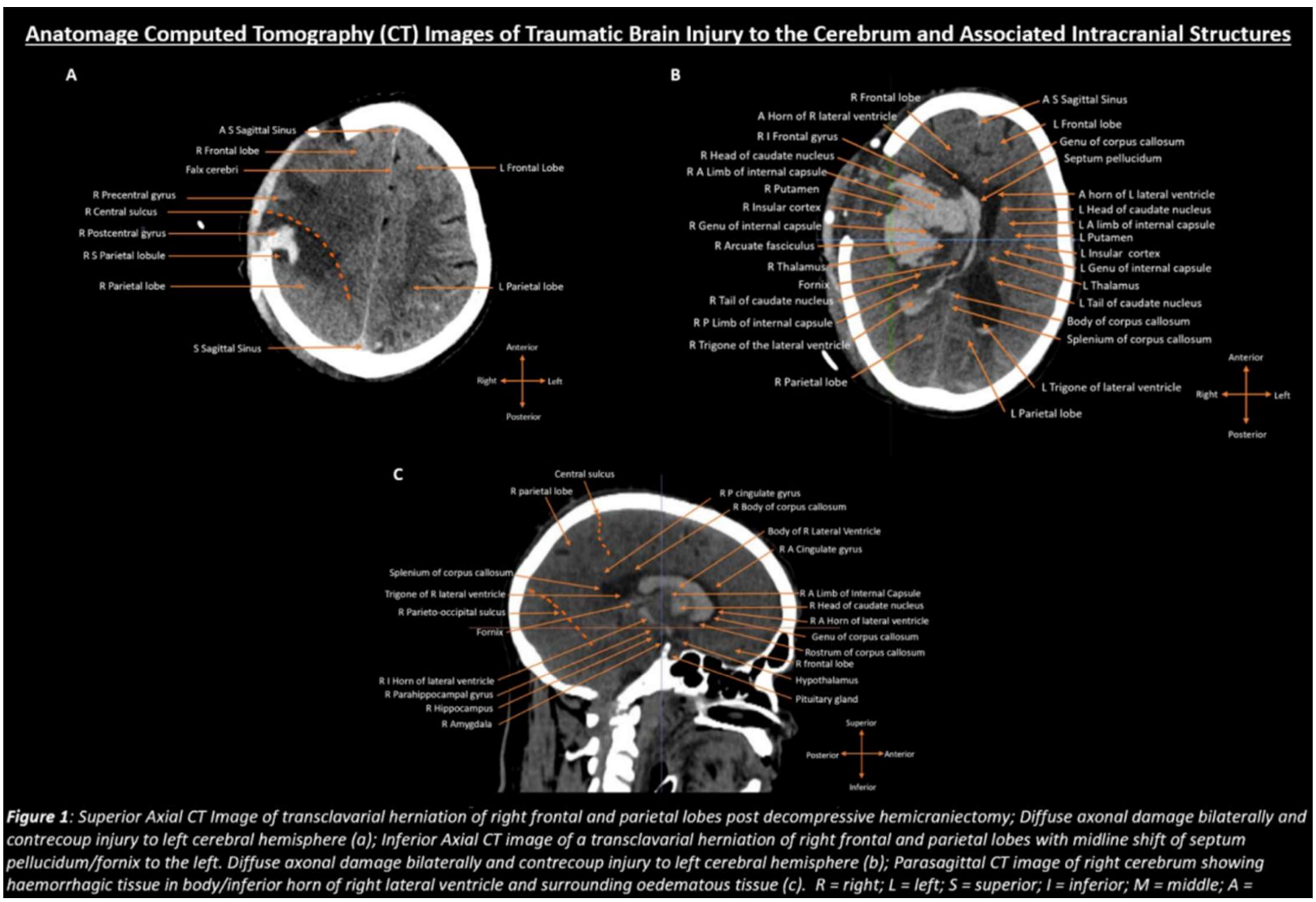


Figure 1: Superior Axial CT Image of transclavarial herniation of right frontal and parietal lobes post decompressive hemicraniectomy; Diffuse axonal damage bilaterally and contrecoup injury to left cerebral hemisphere (a); Inferior Axial CT image of a transclavarial herniation of right frontal and parietal lobes with midline shift of septum pellucidum/fornix to the left. Diffuse axonal damage bilaterally and contrecoup injury to left cerebral hemisphere (b); Parasagittal CT image of right cerebrum showing haemorrhagic tissue in body/inferior horn of right lateral ventricle and surrounding oedematous tissue (c). R = right; L = left; S = superior; I = inferior; M = middle; A =

Figure 3: A student example from the LQB571: Neuroscience 'Traumatic Brain Injury' case study assessment using the Context of Virtual Dissection Table (VDT).

Section	High distinction (100%)	Distinction (85%)	Credit (75%)	Pass (65%)	Marginal fail (50%)	Fail (40%)	Low fail (25%)	No evidence (0%)	Total marks
Introduction	The information covers at least 5 different aspects of glioblastoma in depth. The introduction is written to a very high standard and flows well.	The information covers at least 5 different aspects of glioblastoma in depth. The introduction is written to a high standard and flows well.	The information covers at least 4 different aspects of glioblastoma in depth. The introduction is written to a high standard and flows well.	The information covers at least 3 different aspects of glioblastoma in depth. The introduction is written to an acceptable standard and flows well.	The information covers at least 3 different aspects of glioblastoma in depth. The introduction is not written to an acceptable standard and writing is not presented in a logical sequence.	The information covers at least 2 different aspects of glioblastoma in depth. The introduction is not written to an acceptable standard and writing is not presented in a logical sequence.	The information does not cover at least 2 different aspects of glioblastoma in depth. The introduction is written poorly.	No evidence provided	/4
Methods, Image labelling	The images are presented as two panels. The labelling is correct, complete and covers all affected areas. It refers to specific structures. It is clear, neat and readable, correctly formatted including heading and navigation. It does have comprehensive and correct figure legends.	The images are presented as two panels. The labelling is correct, complete and covers affected areas with very minor omission. It refers to specific structures. It is clear neat and readable and correct format including heading and navigations. It does have complete and correct figure legends with very minor errors.	The images are presented as two panels. The labelling is correct, complete and covers affected areas with minor omission. It refers to specific structures. It is clear neat and readable and correct format including heading and navigations. It does have complete and correct figure legends with minor errors.	The images are presented as panels. The labelling is correct, complete and covers affected areas with some omission. It may not always refer to specific structures. It is clear neat and readable and correct format including heading and navigations. It does have complete and correct figure legends with very minor errors.	The images are not presented as panels. There are some errors in labelling, not all affected areas included. It may not refer to specific structures. The images may not be clear neat and readable or correctly format. Heading and navigations are missing. It does have complete and correct figure legends with some errors.	The images are not presented as panels. There are many errors in labelling, not all affected areas included. It may not refer to specific structures. The images may not be clear neat and readable or correctly format. Heading and navigations are missing. Figure legends are absent or contain many errors or not complete.	The images are not presented as panels. Your images were not fully formatted according to the instructions, for example labelling is missing. Figure legends are absent.	No evidence provided	/6
Analysis	Analysis is accurate and it is linked to the affected areas of the images. It refers to specific structures and covers all affected areas. Analysis always refers to specific	Analysis is accurate and it is linked to the affected areas of the images with very minor errors. It refers to specific structures and covers all affected	Analysis is accurate and it is linked to the affected areas of the images with minor errors. It refers to specific structures and covers most affected areas with	Analysis is accurate and it is not linked to some of the affected areas of the images. It refers to some specific structures and does not adequately cover affected	Analysis is not accurate, and it is not linked to some of the affected areas of the images. It refers to some specific structures and does not adequately	Analysis is not accurate, and it is not linked to the affected areas of the images. It does not refer to specific structures and does not adequately cover affected	Analysis is extremely poor, and it is not linked to the affected areas of the images.	No evidence provided	/7

	structures. Correct terminology is used throughout.	areas with very minor errors. Correct terminology is used throughout.	minor errors. Correct terminology is used throughout with minor errors.	areas. Terminology used with some errors.	cover affected areas. Terminology used with many errors.	areas. Terminology used with many errors.			
Discussion	Discussion is accurate and it is linked to the affected areas of the analysis. It refers to specific structures and covers all symptoms. Correct terminology is used throughout.	Discussion is accurate and it is linked to the affected areas of the analysis with very minor errors. It refers to specific structures and covers all symptoms with very minor errors. Correct terminology is used throughout.	Discussion is accurate and it is linked to the affected areas of the analysis with minor errors. It refers to specific structures and covers most symptoms with minor errors. Correct terminology is used throughout with minor errors.	Discussion is accurate and it is linked to the affected areas of the analysis with some errors. It refers to specific structures and covers most symptoms with some errors. Correct terminology is used throughout with minor errors.	Discussion is not accurate, and it is not linked to some of the affected areas of the analysis. It refers to some specific structures and does not adequately cover symptoms of the affected areas. Terminology used with many errors.	Analysis is not accurate, and it is not linked to the affected areas of the analysis. It does not refer to specific structures and does not adequately cover symptoms of affected areas. Terminology used with many errors.	Discussion is extremely poor, and it is not linked to the affected areas.	No evidence provided	/10
References and formatting	You have referenced according to APA style without errors or inconsistency. You have included in-text citations with your introduction and discussion. You have cited at least 14 primary references.	You have referenced according to APA style with very minor errors or inconsistency. You have included in-text citations with your introduction and discussion. You have cited at least 14 primary references.	You have referenced according to APA style with minor errors or inconsistency. You have included in-text citations with your introduction and discussion. You have cited at least 14 primary references.	You have referenced according to APA style with some errors or inconsistency. You have included in-text citations with your introduction and discussion. You have not cited at least 14 primary references.	You have not referenced according to APA style, there were some errors and inconsistency. In-text citations is lacking. You have not cited at least 14 primary references.	You have not referenced according to APA style, there were many errors and inconsistency. In-text citations is lacking. You have not cited at least 14 primary references.	Your reference formatting is of extremely poor quality. You have not cited at least 14 primary references.	No evidence provided	/3
								Final Grade:	/30

Table 1. Marking Rubric for VDT Case Study.

five weeks on knowledge between structure and function." By using a case study report format, students must think deeply about what images they choose to select for their report. This approach differs from most literature on VDTs which only examines knowledge retention in medical student cohorts. The VDT images act as a base for which students then need to read primary literature to understand the functional anatomy. These transferable research skills have been recently recognized as important graduate outcomes for undergraduate neuroscience students (Cook-Snyder, 2017; Morrison et al., 2020; Rollins, 2020).

For large student cohorts, it can be difficult to ensure each student has access to the VDT for a sufficient period of time. As shown in our class layout, laboratory space is precious, and as a result our students are often squeezed around the table. Fortunately, almost all survey respondents felt that they had adequate access to the VDT in order to complete their assignment (4.61±0.58), indicating that the lesson planning used in this case study is effective. For educators without the funding or adequate space to provide

	Student Response					
Survey Statement	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree	Mean±SD
Overall, I enjoyed using the Anatomage table to support my case study assignment	7 (30.43%)	6 (26.09%)	0	4 (17.39%)	6 (26.09%)	3.17±1.67
I was able to better identify impacted brain structures by using the Anatomage table	3 (13.04%)	6 (26.09%)	5 (21.74%)	6 (26.09%)	3 (13.04%)	3.00±1.28
I was able to have enough time at the Anatomage table to collected the images needed for my assignment	15 (65.22%)	7 (30.43%)	1 (4.35%)	0	0	4.61±0.58
Incorporating Anatomage images into my case study reinforced my anatomical labelling skills	9 (39.13%)	8 (34.78%)	1 (4.35%)	3 (13.04%)	2 (8.70%)	3.83±1.34
I am more confident with neuroanatomy learning after the Anatomage Study	6 (26.09%)	11 (47.83%)	4 (17.39%)	1 (4.35%)	1 (4.35%)	3.87±1.01
The case study assignment helped me to apply my knowledge to real neurobiological conditions	8 (34.78%)	12 (52.17%)	2 (8.70%)	1 (4.35%)	0	4.17±0.78

Table 2. Quantitative results of evaluation survey (n=23).

Database	Contents	Modalities	Cases
Digital Brain Bank (open.win.ox.ac.uk/DigitalBrainBank)	Digital Anatomist: datasets for detailed neuroanatomical investigations. Digital Brain Zoo: datasets for comparative neuroanatomy. Digital Pathologist: datasets for neuropathology investigations.	Post-mortem MRI, including diffusion MRI, with complementary microscopy data (e.g., immunohistochemistry or PLI) included with Digital Pathology datasets.	21 distinct whole-brain post-mortem MRI datasets -human; 14 non-human primate; 12 Amyotrophic lateral sclerosis (ALS) human brains and 3 control brains.
NOWinBRAIN repository (www.nowinbrain.org)	Spatially corresponding dual 2D–2D/3D neuroimages.	Atlas created from multiple *in vivo* 3 and 7 Tesla (T) MRI and high-resolution CT scans of the same male, normal head specimen. These scans were spatially co-registered and converted into 3D virtual models. 7700 neuro-images.	Undetermined.
3D brain structure app (https://dnalc.cshl.edu/resources/products/3d-brain-app.html) Cold Spring Harbor Laboratory	3D models of brain structures that can be displayed and rotated, with short descriptions.	29 interactive structures. Each detailed structure comes with information on functions, disorders, brain damage, case studies, and links to modern research.	Undetermined.
Functional neuroanatomy (https://www.neuroanatomy.ca/index.html) University of British Columbia	Comprehensive neuroanatomy online resource including learning modules, images of sliced brains, 3D models, videos and more.	Very basic labelling. Stroke model. MRI model.	Stroke models included.

Table 3. Free, asynchronous alternatives to the VDT neuropathology case study.

be used in place of a VDT to implement a similar learning activity and assessment to what we have described (see students with physical access to a VDT, we have provided an overview of alternative, free, online resources that could Table 3). We also recommend Cook-Snyder and Ehlinger's (2022) guide for designing case study learning in neuroscience in asynchronous contexts.

While the case study format itself was effective for students' neuroanatomy learning, it is unclear from our evaluation whether the VDT was a factor in this success. Students' enjoyment of using the VDT (3.17±1.67) and perceived ability to identify brain structures using the VDT (3.00±1.28) are polarized. Some students specifically appreciated "seeing the Donor material and how it looked in live models", having a brain that "can be seen in any plane" and having "a lot of control over which structures we wanted to see and which slices we wanted". One student, however, instead stated, "I would rather have images provided and research about it without the Anatomage". Of the 15 students that answered the elective question about aspects of the VDT they disliked, all mentioned low image quality once downloaded from the VDT. Issues with image download quality are therefore a potential barrier to effectively integrate VDT written assignments into neuroscience curriculum. Future research could consider comparative experimental conditions, providing one cohort with VDT access, and another cohort with pre-printed images to definitively understand the effectiveness of VDTs in this style of assessment. In conclusion, the above analysis demonstrates the effectiveness of clinical case-studies with authentic donor images for neuroanatomy learning, labelling and confidence. The use of VDTs in this intervention received polarizing reactions from survey respondents, indicating a need for future research into their use for neuroanatomy learning.

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