Aland et al. Smart Learning Environments (2023) 10:66
https://doi.org/10.1186/s40561-023-00285-3

Smart Learning Environments

COMMENTARY

A plethora of choices: an anatomists' practical perspectives for the selection of digital anatomy resources

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Abstract
The use of digital resources in the new learning environment has drastically influenced how human topographic anatomy is taught and assessed. An array of digital technologies for anatomy teaching have been recently adopted in medical and health science schools in both undergraduate and postgraduate courses. This resulted from a surging demand for digital anatomy technologies in the wake of the coronavirus disease 2019 (COVID-19) pandemic and required rapid digital up-skilling of anatomists. Despite the wide adoption of digital technologies in anatomy teaching, there is little comprehensive information on the selection and implementation of these digital resources from a practical perspective. Based on the authors' experience and supported by literature, this article describes their implementation of digital anatomy resources for teaching gross anatomy in eleven Australian universities. This paper highlights the advantages and limitations that the authors encountered and their recommendations for using these current digital technologies in anatomy teaching.

Keywords: Anatomy, Digital technology, Digital learning, Augmented reality, Virtual reality, Virtual dissection

Introduction

Anatomy has been the cornerstone of medical education for centuries. Building a smart learning environment through integrating digital learning strategies and resources represents a future trend of human anatomy education (Adnan & Xiao, 2023; Xiao, 2023). Effective use of digital technologies in the classroom can enhance students' engagement and learning (Wekerle et al., 2022). It also helps academics personalize and scaffold their teaching (Røe et al., 2022), builds student confidence (Landrum, 2020; Smith & Chipley, 2015), and encourages students to take responsibility for their learning (Serdyukova & Serdyukov, 2013). Digital technology can support large class teaching or teaching that is delivered simultaneously in multiple physical locations when the learning activities are interactive and constructive (Wekerle et al., 2022). It permits a more inclusive learning environment in online teaching and socially connects students with peers and academics, which can boost student engagement.

Human anatomy teaching is focused on the three-dimensional (3D) structure of the human body, a challenging task to teach with two-dimensional (2D) books and atlases. Traditionally, cadaveric specimens are utilized to help students learn 3D anatomy. However, reductions in anatomy teaching hours in curricula (Craig et al., 2010; Shin et al., 2022), financial strains on tertiary institutions to resource cadaveric specimens, and recently, forced interruptions to face-to-face teaching because of the coronavirus disease 2019 (COVID-19) pandemic (Pather et al., 2020), have limited the use of dissection classes or cadaveric specimens. This has afforded opportunities for academics to teach anatomy by adopting alternative educational resources.

Students increasingly rely on multimedia resources for learning and use software applications on digital platforms to study anatomy (Barry et al., 2016; Leung et al., 2020). The introduction of digital platforms in the classroom enables an alternative method of learning that can be mastered in a face-to-face environment with immediate feedback with in-person instruction. However, as the pandemic suddenly forced a reassessment of anatomy teaching, some academics struggled to identify the most suitable resource to use in an online-only learning environment (Dulohery et al., 2021). Different criteria determine the suitability of an educational resource. Some criteria are more general, such as easy access to relevant information, or permitting detailed exploration of anatomical regions to aid deep understanding of difficult concepts, while others are more specific, such as including formative assessments, offering engaging activities, or allowing out-of-class access.

There are many excellent digital resources, but they have different strengths and applicability. Several web- or cloud-based anatomy atlases are accessible on computers, tablets, or smartphones, providing mobility and flexibility for learners. Though these resources often allow the 3D manipulation of images for users to explore structures in different planes, the images are ultimately still in a 2D environment. Augmented reality (AR) is defined as the projection of augmented visuals to the user via optical see-through displays or see-through video displays in a live or real-world environment (Duarte et al., 2020; Izard & Méndez, 2021; Moro et al., 2021). In anatomy education, this could be superimposing computer-generated graphics or models onto a user's immediate surroundings, such as a cadaver. Virtual reality (VR) (Zhao et al., 2020) technology, on the other hand, provides an immersive environment where users can freely explore a simulated computer-generated 3D object in real-time without the need for cadavers or other anatomy-specific physical teaching resources. Pedagogically, VR-based modalities have the potential to greatly improve anatomy content retention because learning is by doing, by experience, and thus this constructivist approach (Whitman, 1993) helps to construct and consolidate new knowledge. The delivery of anatomy teaching via VR is ideal for viewing the human body in three dimensions. To fully appreciate and understand anatomical structures and their physical and spatial relationships within the body, they must be viewed in three dimensions, rotated, and dissected (Keenan 2019). More recently, projection-based VR settings became available that provide a mixed reality (MR) environment, allowing users to experience their real and virtual environments simultaneously. This technology also allows the sharing of the experience among multiple users without the need for individual bulky headsets (Uhl et al., 2021; Wickramasinghe et al., 2021). A significant and common finding among all contributors to this paper, regardless of the digital option selected, is the necessity for embedded training for both students and instructors, to ensure optimal implementation to enhance the learning experience and improve attitudes toward anatomy teaching and learning.

Despite the literature commenting on the effectiveness of these resources, little is known about their selection and adoption. Understanding these resources and their benefits and restrictions is critical to further modernizing anatomy education by creating a smart learning environment. As educators reflect on the pandemic teaching and learning approaches and consider learning designs for the future, this paper provides an academic guide and perspectives on the currently available anatomy digital resources, including notes on practical experience about the utility and implementation of these resources as well as recommendations. Table 1 summarizes the applications and features of the anatomy digital resources along with their limitations and initial implementation cost to support colleagues in choosing a suitable resource, pertinent to the post-pandemic phase and beyond. The digital resources that are discussed include Anatomage, Visible Body Human Atlas, BioDigital Human, Virtual Human Dissector, Sectra, Radiopedia, Hololens, 3D Organon, Sharecare YOU VR, and Medicalholodeck.

Commercially available digital resources

Anatomage

Resource application: strengths

The Anatomage Table (Anatomage Inc., Santa Clara, CA) is a virtual dissection table that is used in anatomy practical classes in addition to the cadaveric dissection (Baratz et al., 2019; Bartoletti-Stella et al., 2021; Bork et al., 2019; Orsini et al., 2021). It contains a library of 3D reconstructed cadavers and cadaveric prosections, augmented gross anatomical structures together with radiology images. These images can be displayed on the human-sized touchscreen table (Baratz et al., 2019; Bartoletti-Stella et al., 2021; Bork et al., 2019) and projected onto a separate screen. Via 3D reconstruction, images from the Anatomage library can be analyzed in all planes, dissected in 3D, and subjected to interactive segmentation that allows discrimination of muscular and neurovascular structures within a region of interest or on a desired anatomical plane. The ability to study different parts of the human body in 3D, through longitudinal, sagittal, and horizontal as well as oblique planes, is beneficial to the deep understanding of human structures (Garg et al., 2001; Keenan et al., 2019).

An Anatomage Table can be used as an in-person virtual dissection table for teaching both systemic and regional anatomy as well as neuroanatomy (Table 1, Xiao & Adnan, 2022a). Learners can isolate a single organ in situ by digitally 'dissecting' structures from superficial to deep, or through 'dissecting' surrounding organs and neurovascular structures. Additionally, structures are annotated and can be highlighted in different colors to visualize their relationship to each other. In doing so, learners can study structures within a specific anatomical region or plane. Formative or summative quizzes with feedback can be deployed on the Anatomage Table for in-class practical assessments. Pertinent to practical classes for teaching clinically oriented anatomy, there are preinstalled medical images including Computed Tomography (CT) and Magnetic Resonance

Table 1 Applications and features of AR and VR anatomy resources

Digital anatomy resources		Applicable anatomy content	Identified limitations	Curricula recommendation	User training requirement	Initial setup cost ($AUD)
AR	Anatomage Table	Systemic (somatic and visceral) anatomy Regional anatomy Neuroanatomy Pathophysiology	Image resolution and fidelity needs to improve Some fine neurovascular structures and variations are missing	Undergraduate anatomy courses Combine with a second digital tool with complementary features	Required for learners and educators Manageable for novice users	> $120,000 per hardware and software package Annual software upgrade optional
	Visible Body	Systematic, regional Neuroanatomy Common pathologies	Stylized images	Undergraduate anatomy courses	Required for learners and educators Manageable for novice users	~ $40/year/license/person Institution packages available
	Biodigital	Systemic (somatic and visceral) anatomy Regional anatomy Pathophysiology	If students do not have access to Studio view this can limit functionality of embedded links	Undergraduate anatomy courses Student-led independent study	Required for learners and educators Manageable for novice users	~ $20/year/license/person Institution package available
	VH dissector	Systemic (somatic and visceral) anatomy Regional anatomy Neuroanatomy	2D images only	Undergraduate anatomy courses Postgraduate anatomy courses Combine with another digital tool with complementary features	Minimum training required Manageable for novice users	~ $1,000 per software Touchscreen optional
	Sectra Table	Regional anatomy Neuroanatomy Pathophysiology	Substantial initial set up and ongoing license cost Stable internet connection required	Advanced anatomy curricula including medicine	Required for learners More in-depth training required for educators	~ $200,000 /hardware and software package Substantial ongoing license fee for instructor and student subscriptions
	Radiopaedia	Systemic (somatic and visceral) anatomy Regional anatomy Neuroanatomy Radiographic imaging	Currently available in English language only Basic user interface	Advanced anatomy curricula including medicine	Training not required	Free to access

Table 1 (continued)

Digital anatomy resources		Applicable anatomy content	Identified limitations	Curricula recommendation	User training requirement	Initial setup cost ($AUD)
VR	HoloLens	Systemic (somatic and visceral) anatomy Regional anatomy Neuroanatomy Pathology	Cost and equipment availability Limited for large cohort teaching simultaneously Choice of apps limit use	Undergraduate anatomy Postgraduate anatomy including procedural training	Required for learners and educators	~ $5500 per headset Apps can be developed in-house or purchased Individual subscription or institution package available
	3D Organon	Systemic (somatic and visceral) anatomy Regional anatomy	Require VR headset Require adequate user space Motion sickness	Undergraduate anatomy courses	Required for learners and educators Manageable for novice users	~ $600/ software license/year ~ $500/VR headset (128 GB)
	Sharecare YOU	Systemic (somatic and visceral) anatomy Regional anatomy Neuroanatomy Pathophysiology	Lack details in some body systems (e.g. neuroanatomy) Requires VR headset Adequate space for use, motion sickness	Undergraduate anatomy Combine with a second digital tool with complementary features	Required for learners and educators Manageable for novice users	~ $1000/software Additional cost for VR headsets Annual software upgrade optional
	Medicalholodeck	Systemic (somatic and visceral) anatomy Regional anatomy Pathology (Medical Imaging XR only)	File downloading time consuming Require stable internet connection Require VR headset Require adequate user space Motion sickness	Advanced anatomy courses including medicine	Required for learners and educators Manageable for novice users	~ $3000 for 3-part suite software $1000 for XR only

The name of each resource (underlined) is embedded with a hyperlink and hence shown as being underlined

Imaging (MRI), as well as photographic images of cryosections, which are useful for teaching anatomy and application in a clinical scenario. The touchscreen table can be digitally split into two smaller screens, allowing students to compare the same organ or region using a 3D reconstructed cadaveric prosection, an augmented anatomical image, or a medical image (CT or MRI). With regards to the class setting, images from an Anatomage Table can be projected onto a separate screen, suitable for lectures, tutorials, and workshops.

Resource application: limitations

Whilst the Anatomage Table is reasonably accurate in representing some fine structures (for example, extranodal extension in head and neck cancer (Tirelli et al., 2021)), the overall image resolution and fidelity still require improvements (Table 1). Variations, such as supernumerary muscles, or variations in nerves and blood vessels, are not represented on an Anatomage Table. In particular, image resolution sufficient to identify elements of the fascial system is absent in most anatomical regions. The origins of major nerves can be easily identified; however, their terminal nerve branches are not always present and often cannot be highlighted by filters, making them difficult to localize. Some important features such as haptics are missing in the latest version of Anatomage Table (Anatomage Table 10). The image control lies on a local Anatomage Table and is not accessible on the Cloud, which precludes learners from hands-on experience in a remote setting. Therefore, an Anatomage Table is recommended for an onsite interactive class setting where digital resources are readily accessible to both students and educators. There is also a lack of animation features in the current version of the Anatomage Table. Taken together, the limitations of an Anatomage Table in its current version are largely technical, relating to restricted table position, image resolution, fidelity and access (Table 1). In addition, the initial setup cost for hardware and software purchases is substantial (Table 1).

Author experience in resource implementation

Anatomage Tables are used for teaching systemic and regional anatomy at Swinburne University of Technology (SUT), to over 1000 undergraduate and postgraduate students enrolled in health sciences, nursing, physiotherapy, and occupational therapy courses. To evaluate the usefulness of this resource in anatomy laboratory classes, students of the third-year undergraduate Biomedical Science Major and the postgraduate Master of Physiotherapy were invited to participate in an online anonymous survey (Microsoft Forms, Microsoft Corp., Redmond, WA) (Human Ethics approval: 20,215,673–6867) regarding their perception of anatomy learning using the Anatomage Table. Data from the 66 respondents identified that 75.6% of undergraduate students (34/45) and 64% of postgraduate students (32/50) rated their experience of using the Anatomage table 5 out of 5. Most students and educators who used the Anatomage Table at SUT consistently found it was easy to access and use. Considering its broad applications, it is suitable for a broad range of undergraduate anatomy curricula including systemic and regional anatomy as well as neuroanatomy (Xiao, 2023; Xiao & Adnan, 2022a). Taken together, the authors recommend combining it with another anatomy tool that possesses complementary features for use in advanced anatomy curricula.

Visible Body Human Anatomy Atlas

Resource application: strengths

The Visible Body Human Anatomy Atlas (VB) with AR (Argosy Publishing, 2020 Inc., Newton, MA) is a digital atlas that covers most systems of the body (Chakraborty & Cooperstein, 2018). Like similar products, such as Essential Anatomy 5 and Complete Anatomy, it contains a library of augmented gross anatomical structures. VB allows in-depth analyses of diverse bodies including both internal and external genitalia such as the penis, testes, vagina, ovaries, and uterus, written descriptions of anatomical structures, quizzes, virtual dissections, and the ability to bookmark content (Table 1) (Chakraborty & Cooperstein, 2018). The benefits of this resource are centred around providing students with unique opportunities to easily learn complex anatomy and understand spatial relationships within the body (Fig. 1A) that are unrestricted by time or physical location (Schwartzman & Ramamurti, 2021). Students' ability to change magnification and rotate any structure of interest, including microanatomy, enhances their learning and experience (Siegle, 2018). VB allows students to perceive a complete 3D 360-degree view (Jacobsen & McMurray, 2020). As an additional benefit, VB has built-in AR. The immersive AR function is most commonly used via a handheld portable device (i.e., tablet or smartphone) (Moro et al., 2021), superimposing computer-generated graphics or models onto a user's immediate surroundings (such as a cadaver) to enhance learning (Duarte et al., 2020). VB is unique as it also includes animations of individual anatomical structures, built-in quizzes, and related pathologies (Chakraborty & Cooperstein, 2018).

From a curricular design perspective**,** VB offers scaffolding and virtual dissection. Scaffolding allows a step-by-step pedagogical approach, which permits self-paced and problem-based explorative learning (Jacobsen & McMurray, 2020; Moro et al., 2021;

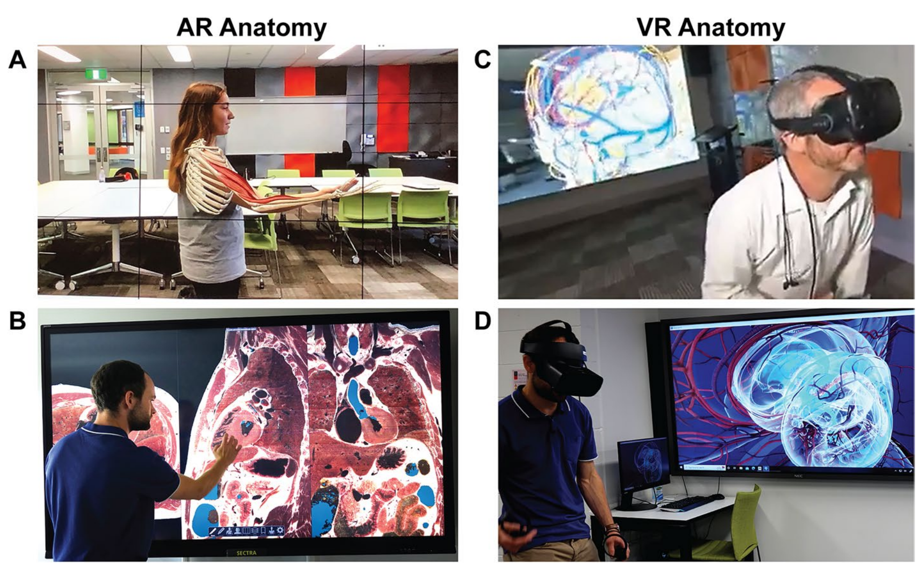

Fig. 1 Representative digital anatomy images with AR and VR platforms. **A**, **B** Demonstration of the use of the Visible Body Human Atlas App (**A**) and Virtual Human Dissector (**B**) with Augmented Reality (AR). Depictions of anatomical structures and systems via Visible Body Human Atlas AR with high fidelity. **C**, **D** Demonstration of the use of the 3D organon (**C**) and ShareCare YOU Virtual reality (VR) program with an Oculus Quest 2 headset, offering an immersive experience of human anatomy

Siegle, 2018), and effectively alleviates students' cognitive overload when learning anatomy (Izard & Méndez, 2021).

Resource application: limitations

Similar to many other digital anatomy resources, most images included in the VB library are stylized (Table 1). Limitations remain in the level of detail and accuracy of these applications. Notably, anatomical accuracy was found to rapidly decrease at the level of microstructures such as the branching of the trigeminal nerve, the muscles of the pharynx, or the anatomical borders of the inguinal canal (Lewis et al., 2014), particularly for advanced anatomy curricula. Indeed, there is a lack of formal studies on the anatomical accuracy of portable tablet applications. In addition, the yearly subscription fee plus additional costs for in-app purchases were viewed as an affordability concern for large-scale implementation (Schwartzman & Ramamurti, 2021).

Author experience in resource implementation

Approximately half of the reported universities in Australia and New Zealand implemented VB for online anatomy learning since the beginning of the COVID-19 pandemic in 2020 (Pather et al., 2020). A study conducted at the Queen Mary University of London suggested that students found using the VB modeling software helpful, particularly when approaching more challenging content, in particular, concepts that are difficult to understand in 2D format (Flynn et al., 2021). For these reasons, VB has been implemented in anatomy units for several undergraduate anatomy courses including biomedical science, health science, and exercise science at La Trobe University (LTU). This included students accessing VB during face-to-face classes, online interactive classes, and during self-led study. To encourage student uptake and engagement with the VB platform, the authors from La Trobe University chose to incorporate the resource in weekly activities, which were promoted and supported by teaching staff. Therefore, self-paced VB-specific pre-, in-class, and post-practical activities should be designed and implemented within the subject manual for students to complete each week of the entire semester. To analyze the effectiveness of this implementation process, students and educators of a 2nd-year anatomy subject (2019) were asked to complete a specific questionnaire (using Qualtrics) on their experiences. Of the 265 enrolled students, there were 101 respondents (38.1% response rate). This study (Human Ethics approval: HEC19052), identified that students were overall supportive of the implementation of VB. Comments included (1) ease of use: "*It's very easy to use and quite helpful as a supplement to the videos and our weekly lab activities*"; (2) enjoyability: "*Having the ability to use different platforms to learn. This enhances stimulation of the subject and made it more enjoyable*"; and (3) usefulness: "*It's something new and invites a new way of learning, useful in the future*". However, as noted above, integration into weekly activities is essential. Students mentioned "*I think it is good, but we just need to use it more*" and "*Integrate the system more in class*" and staff also had a similar perspective: "*One of my thoughts is continual use, so it's not just a gimmick… it has to be embedded in the anatomy curriculum, it needs to be part of everyday activity*".

Training is an essential component when introducing all digital resources, including VB, as a new teaching technology. User training is required for both students and instructors and is likely to influence their attitude toward anatomy teaching and learning. Most students who used VB to study anatomy at LTU found it was easy to use and increased their engagement with the content. Anatomy educators at LTU, however, had a divided opinion about using VB. Approximately half of the teaching staff found VB to be enjoyable and an effective teaching resource, while the others did not. Further analysis revealed that the staff members who were strongly opposed to this new resource did not attend the training session and may therefore have been less capable of using this new resource for teaching, reiterating the importance of instruction before use. Following the move to online-only teaching with the COVID-19 pandemic, the LTU anatomy teaching team has found VB to be an essential teaching tool as the face-to-face resources were ineffective. Taken together, the authors conclude that users can make better use of this digital resource following training and that VB is suitable for both face-to-face and online learning.

BioDigital Human

Resource application: strengths

The BioDigital Human (BioDigital, NY, USA) is a cloud-based app developed in 2016. It was initially set up as a free online program, (Mitrousias et al., 2018) but the current version is accessed via subscription. Like other similar digital tools such as the Visible Body Human Anatomy Atlas, the BioDigital Human library comprises diverse bodies including varying skin tones, internal and external genitalia, along with animations of movements and pathophysiology from selected regions. Images are suitable for download to all devices that enable students to view anatomy as 3D data that is projected onto a screen (Table 1). Studio view that enables students to use BioDigital Human as a study tool is also available, but the access is subject to subscription. Although BioDigital Human is a cloud-based app, once each model is downloaded, its content can be viewed without the need for an internet connection. Users can choose which system, or structure they wish to view or remove. A chosen structure can be viewed in isolation and rotated in all directions to appreciate its structure more fully. The image can be downloaded as a PDF. The URL of the body view in BioDigital can also be embedded in teaching materials provided to students. The latter is particularly useful to illustrate a specific muscle or muscles or to share an animation. This ability to separately bookmark structures is useful, as, although students may have university-provided access to the program, they may be overwhelmed or distracted by the content if using this software unguided. The study reported that the BioDigital Human has been used in practical classes for teaching musculoskeletal anatomy and compared with the traditional teaching resource (cadaveric prosections). Although students' satisfaction with the digital and traditional resources remained similar, students who used the BioDigital Human outperformed their counterparts using only traditional resources in examinations (Mitrousias et al., 2018), indicative of a positive learning outcome.

Resource application: limitations

The main limitations in the current version of BioDigital Human are related to the cloud-based setting and image fidelity. Although once downloaded, the content of BioDigital Human can be viewed offline and does not require the use of a VR headset. However, a high-speed internet connection is pivotal to the application of BioDigital Human in an anatomy laboratory class due to the cloud-based access setting. Delays in downloading content have been reported by students, although the cloud-based access enables flexible learning in- and outside of the anatomy laboratory. Moreover, having an appropriate browser that supports WebGL, the technology that powers the BioDigital graphics, is critical to content access and download.

Author experience in resource implementation

Considering its flexible remote access to a large volume of images under a relatively low subscription fee (Table 1), BioDigital Human has been integrated into anatomy teaching for the first-year biomedical science program (approximately 350 students) at the University of Sunshine Coast, Australia. It was used as a supplementary tool to elegantly illustrate concepts in recorded lectures and live online workshops, and for students to undertake independent study. In the experience of academics in a mixed cohort of 1st year students at the University of the Sunshine Coast, BioDigital Human made teaching anatomy easier in a blended mode of delivery imposed by COVID-19 restrictions, although not all students found the program easy to use for their independent study. This was because in the current version some anatomical detail, such as the separation of muscles into subdivisions, was missing, which may be important within specific teaching settings. Some students also reported trouble downloading content either due to poor internet connection or the use of a browser that did not support WebGL. Taken together, the authors recommend that BioDigital Human is a suitable substitute for small-class anatomy teaching in a learning environment where there is a stable and high-speed internet connection.

Virtual Human Dissector

Resource application: strengths

Virtual Human Dissector (VHD) (Touch of Life Technologies, Inc. Aurora, CO) is a software suite for studying regional and cross-sectional anatomy using 2D images on a computer but not on tablets or smartphones (Donnelly et al., 2009; Houser & Kondrashov, 2018). It has been used for anatomy teaching since 2009 (Donnelly et al., 2009), giving it a longer history than other digital anatomy tools. The 2D images presented in VHD are augmented digitized cadaveric images, which provide a link between the cadaveric laboratory and medical imaging, pertinent for those with limited access to cadavers. VHD software can be used on PC and Macintosh computers and importantly allows the display of selected structures or regions from three planes (coronal, sagittal and axial) on one device. Therefore, 2D images of structures or regions can be viewed from the three planes concurrently on one computer screen. This is one of the biggest advantages of learning anatomy via VHD. Users can both view and label a specific structure or a region of interest from three planes simultaneously (Fig. 1B). At present, this is a unique feature of VHD that is not available in any other digital anatomy tool, which is particularly helpful for students to establish a dynamic 3D understanding of anatomical structures relative to their surroundings. VHD has been successfully implemented in medical and health science schools with positive student feedback on improvements in their ability to interpret cross-sectional images and understand anatomical relationships (Houser &

Kondrashov, 2018; Xiao & Adnan, 2022a). In one study, medical students reported that using VHD helped them interpret radiological images in clinical rotations during their clinical clerkship (Houser & Kondrashov, 2018).

Resource application: limitations

VHD only provides 2D images, the pool of which is fixed in capacity and cannot be expanded by the user's own images. There is also a lack of images that display pathological conditions. Considering these limitations, VHD is not suitable for teaching systemic anatomy but possesses a clear advantage for establishing relative spatial awareness of internal structures. Therefore, VHD is recommended for regional anatomy curricula for a range of disciplines, including medicine (Table 1).

Author experience in resource implementation

Considering its unique image viewing feature and the suitability for interactive classes, VHD has been implemented in practical laboratory classes and tutorials for teaching several anatomy curricula in the undergraduate (Houser & Kondrashov, 2018; Xiao & Adnan, 2022a) and postgraduate courses including health sciences, nursing, and allied health (approximately 500 students) at SUT. Both students and educators who used VHR at SUT consistently found it was easy to access and user-friendly with minimum training required, hence suitable for both novice and experienced users (Table 1). Image loading and selection were achieved using both the computer mouse and a touchscreen feature, the latter of which was found to be more interactive. VHD's unique application that enables users to view and label a structure or a region of interest from three planes simultaneously was most welcomed by both parties. This feature in VHD fills a current gap in most digital anatomy tools. It is therefore recommended that VHD be combined with another digital tool with complementary features. To understand students' perception of using the VHR in anatomy laboratory classes, in 2021, the third-year undergraduate biomedical science major students (n = 45) were invited to participate in an online anonymous survey (Microsoft Forms, Microsoft Corp., Redmond, WA) (Human Ethics approval: 20,215,673–6867). VHR was overwhelmingly welcomed by students in their anatomy laboratory classes. Comments included (1) ease of use: "*Using virtual human dissector is very straightforward*"; (2) enjoyability: "*I wish I have used the virtual human dissector earlier*"; and (3) usefulness: "*The virtual human dissector is extremely useful for studying sectional/regional anatomy*" and "i*t is exciting to use virtual human dissector to study anatomy together with other tools*". Taken together, the authors recommend combining VHD with another AR or VR digital anatomy tool for anatomy teaching. It is recommended for small-class tutorials or hands-on practical classes using a computer with a touch screen function.

Sectra Table

Resource application: strengths

The Sectra Table (Sectra AB, Linkping, Sweden) is a touch screen visualization tool used for anatomy teaching in several disciplines including medicine (Shi et al., 2019), nursing (Jason et al., 2021), and health sciences (Xiao & Adnan, 2022b). The software embedded in the table contains a large pool of CT, MRI, and ultrasound (US) images, depicting both healthy and pathological conditions. It also includes a virtual dissection feature, through which learners can simulate the dissection of selected structures. From a class setting perspective, the Sectra Table can be positioned vertically against a wall or horizontally as a table surface. After trialing both conditions, a Sectra Table in a vertical setting was found more practical and interactive for team-based teaching compared to a horizontal setting, as the content was visible for more learners under the same orientation. Depending on the type of subscription licenses, images can be viewed either on-site where a Sectra Table is located, or online via a web-based program. While both on-site and remote teaching are feasible using a Sectra Table library, for interactive learning, on-site teaching with a touch screen feature is recommended. Images of the Sectra library are supplied by academic institutes or tertiary hospitals and are suitable for clinically oriented teaching, including pathology and pathophysiology. Using the embedded image library, instructors can build anatomy case stories for problem-based learning. Anatomists can also upload in-house developed anatomy resources onto the Sectra Library and share them within the Sectra user community. Furthermore, a Sectra Table has recently been integrated for virtual clinical simulation for ultrasound training (Shi et al., 2019), improving trainees' self-confidence and performance, thus establishing an innovative approach for applied practical class teaching.

Resource application: limitations

The initial setup cost of a Sectra Table plus subsequent subscription license fees is substantial (Table 1), presenting a clear financial constraint for some universities where there is limited funding. Moreover, while the Sectra Table possesses a digital dissection feature, this application is limited and is only feasible for a selected region and at a smaller scale compared to other products such as an Anatomage Table, the latter of which is available for full-body virtual dissection. In addition, the extent of clinical information details relating to case-based images in the Sectra library is variable. Whilst story preparation is a key feature of Sectra for conducting case-based studies, this can be time-consuming if users are unfamiliar with the Sectra image portal content. Therefore, adequate training and content familiarization is essential for instructors and course developers.

Author experience in resource implementation

An advantage of the Sectra Table is a large library of high-fidelity patient images (2D and 3D), covering a broad range of body systems and pathologies. For this reason, at SUT, Sectra has been used as a complementary digital tool in neuroanatomy and regional (visceral) anatomy curricula for undergraduate health science students majoring in neuroscience or biomedical science, and allied health postgraduate students (approximately 500 students). In 2021, 145 undergraduate students in the Bachelor of Health Science course participated in an online anonymous survey (Microsoft Forms, Microsoft Corp., Redmond, WA) (Human Ethics approval: 20,215,673–6867) regarding their perception of Sectra Table usage in their anatomy laboratory. Responses from 118 participants (response rate 81.4%) were supportive of using Sectra Table for anatomy teaching in a practical class setting. The Sectra images are re-constructed CTs, MRIs, or ultrasounds, some of which could be challenging for novice learners to interpret. Therefore, Sectra is recommended as a digital anatomy resource for more advanced or clinically oriented anatomy curricula such as medicine and pre-vocational clinical training (Table 1).

Radiopaedia

Resource application: strengths

Radiopaedia (radiopaedia.org) is a repository of peer-reviewed radiology images including X-ray radiography, MRI, CT, and positron emission tomography (PET) supplemented with brief medical history. It is a free online radiology resource developed by Professor Frank Gaillard (currently Founder and Editor in Chief of Radiopaedia and Director of Research, at the University of Melbourne, Department of Radiology at the Royal Melbourne Hospital, Australia). Its open platform allows contributions from members on topics of relevance to radiology practice. As such, it consists of two main sections: (a) articles and (b) cases, in which real patient cases and pathologies are presented using interactive (scrollable) radiographic images. These are written by members and edited for accuracy, quality standards, and privacy requirements by a board of directors and expert advisors. It also offers an array of courses and lecture collections at low cost (which are free in low and middle-income regions of the world), and quizzes on case studies, which enable medical students and professionals to supplement their learning. The "Playlist" feature of Radiopaedia, for example, allows students to asynchronously view cases and reference material in preparation for synchronous workshops or laboratory classes. Anderson and colleagues (Anderson et al., 2020a, 2020b) reported the advantages of playlists and case study files on Radiopaedia for trainee radiologists, noting the ease and ability to access from any device. A recent study conducted at the University of Pittsburgh found undergraduate students in the web-based (Radiopaedia) group achieved substantially higher mean scores in assessment compared with the "traditional learning" group ((El-Ali et al., 2019).

Images on Radiopaedia are open source and downloadable and can be easily used in other anatomy teaching material including lectures, workshops, and assessments. Radiopaedia also offers several scrollable anatomically labelled radiology images, and students have responded positively to this additional learning resource. As Radiopaedia is a fully online source, it can be readily integrated into synchronous, asynchronous, and/or blended learning modes for remote learning. The large repository of radiology images is an extremely useful educational resource for a broad range of users from undergraduate health science and medical students to prevocational radiology trainees. While Radiopaedia images can be accessed and downloaded for free, authors' contributions should be acknowledged when the images are used in anatomy teaching.

Resource application: limitations

The Radiopaedia only contains radiology images, which may not be suitable for novice learners. While there is a large pool of high-fidelity radiology images (2D and 3D), the current interface of Radiopaedia provides limited features for interactive teaching.

Author experience in resource implementation

Considering the large pool and a diverse range of radiographic images, Radiopaedia is used extensively as a complementary tool in the Anatomical Imaging Course at

Queensland University of Technology (QUT), where clinical case studies are used in workshops, and images are used in laboratory classes of approximately 120 students. Images are also used in 1st-year anatomy courses and the more advanced 3rd-year neuroanatomy courses. Given the content available in Radiopaedia, we have been able to successfully implement this resource into neuroanatomy and regional anatomy curricula of the Bachelor of Health Science course at SUT (approximately 300 students) for both lectures and laboratory sessions. An advantage of using Radiopaedia is its extensive database of articles and clinical cases. Students can examine real life cases of disease, anatomical variations, and pathologies from real patients, where scientifically and medically qualified editors have ensured high standards of accuracy. Students are encouraged to undertake the quizzes for formative assessment purposes. It is also of use to anatomy students who have an interest in radiology, or in studying medicine—many students undertake the Anatomical Imaging Course at QUT with these goals in mind. This platform therefore has applicability for use in both graduate and postgraduate medical courses. Taken together, the authors recommend that Radiopaedia is suitable for a broad range of anatomy curricula including foundation level and medical clerkship, face-to-face and remote learning, synchronous and asynchronous large class teaching.

HoloLens

Resource application: strengths

The HoloLens™ (Microsoft, WA, USA) is a consumer-grade mixed reality (MR) head-mounted device developed in 2015 (Stojanovska et al., 2020). Since then, it has been increasingly used in anatomy teaching in different programs, including pre-clinical, and clinical training settings. The HoloLens™ allows binocular depth perception, permitting the display of 3D visuals against real-world structures (Moro et al., 2021), such as overlaying digital information on cadavers (Maniam et al., 2019). Such visualization can be manipulated and controlled by the user, facilitating their use in spatial learning (Bogomolova et al., 2020).

Technically the HoloLens uses the Windows operating system, facilitating adoption by staff and students (Ogdon, 2019). Various applications can be used with the HoloLens, such as HoloHuman for anatomy (https://www.gigxr.com/holohuman). Wi-Fi connectivity is the minimum required to run these applications (Wish-Baratz et al., 2020), as the HoloHuman application uses diagrammatic pre-set images of human anatomy (Zafar & Zachar, 2020). The HoloMedicine (ApoQlar, GmBH, Hamburg, Germany) app is designed for clinical use, but can be adapted for anatomy education and permits the use of individualized images such as 3D reconstructions from patient or cadaver imaging. When the HoloLens is used with the Azure Kinect camera (Castelan et al., 2021) for simultaneous body-tracking and anatomy overlay, it provides a dynamic learning experience for the user.

Practically, the HoloLens is suited for small group tutorials (students and instructors do not need to be in the same location). The HoloLens operates with hand gestures and voice commands, allowing hands-free operation, and facilitating use in anatomy laboratories (Ogdon, 2019; Pratt et al., 2018). Some of the apps can also be shown in 2D via a computer link to projectors in a teaching room, from an educator wearing a headset, enabling the use of the HoloLens to a wider audience without all students requiring headsets. However, the best experience of these apps is through using them on the HoloLens. Teaching with the HoloLens generally was found to improve the student experience in learning anatomy (Moro et al., 2017a). Students acquire the same anatomy knowledge in less time than with traditional cadaver teaching (Wish-Baratz et al., 2019 et al., 2019) while examination performance is similar (Cercenelli et al., 2022; Stojanovska et al., 2020).

Resource application: limitations

The cost of individual headsets is substantial (Table 1), which may limit their broad adoption use for a large class setting (Keenan and Awadh, 2019). The HoloLens permits individualized learning within large cohorts (Moro & Gregory, 2019; Stirling & Moro, 2020) if there is a sufficient number of headsets for individual access. In addition, like other VR anatomy tools (Moro et al., 2017a, 2017b), motion sickness from HoloLens use has been reported in some students (Moro et al., 2021). Although students enjoy using xR technologies (Moro et al., 2017a), the impact of HoloLens™ on learning effectiveness compared to the traditional teaching setting remains unclear (Zafar & Zachar, 2020).

Author experience in resource implementation

Considering the 3D visualization that facilitates spatial learning of anatomy, the HoloLens has been used for anatomy teaching within nursing and year 1 medical program (approximately 450–480 students) at The University of Queensland using HoloHuman and VSI HoloMedicine apps. An individual HoloLens was used by a staff member, narrated by a second staff member, with simultaneous transmission of images via a web-based app to individual desktop computers and large room screens. In general, feedback was positive for the inclusion of this type of technology within teaching, although it would have been preferable for students to have individual headsets and work collaboratively. Due to the limited number of headsets, 3D visualization of selected structures was recorded by staff using the Hololens, and the recording was subsequently incorporated within online blended learning material shared via the learning management system such as Blackboard or LearnX, using HoloHuman of VSI HoloMedicine apps. Such delivery setting has enabled instructors to produce a set of learning resources tailored towards different anatomy curricula with large student cohorts, albeit not fully exploiting the interactive and individualized features that were possible when students had individual headsets. Taken together, the authors recommend that the HoloLens can be used for both asynchronous or synchronous teaching, small or large class settings, however individual learning experience in a hands-on practical class is contingent on the number of headsets.

3D Organon

Resource application: strengths

3D Organon (Medis Media, QLD, Australia) is a comprehensive virtual anatomy teaching tool used on VR headsets, mobile devices, desktops, and tablets. The 2021 upgrade features 10,000 anatomical structures within 15 body systems, both somatic and visceral. 3D Organon also presents some microscopic structures in considerable detail, such as skin, enabling users to "walk-through" structures and view all layers of the structure, from superficial to deep. The best immersive experience is via the untethered Oculus Quest 2 headset (Fig. 1C). Using hand-held ergonomically designed controllers, the user can remove parts of organs or bones and rotate them in space to examine them in more detail. Muscular attachments are defined and accompanying information about anatomical structures is provided. There is also written information on the pathophysiology of the organ being viewed. Compared to other VR-based modalities, 3D Organon stands up to the level of detail required for foundation undergraduate anatomy teaching (servicing health-related degrees such as occupational therapy or clinical exercise physiology) and clinician-patient presentations. A premium institutional license enables 10 students (with the option for upgrade to 100 students) and an educator to connect in a virtual room, at no cost to the student (Table 1). With the educator wearing the headset, 3D Organon can be used to create pre-recorded videos, or deliver teaching live, and screen-casting to online or physically present students. Students can wear the headset in the anatomy laboratory for a more fully immersive experience.

Resource application: limitations

Despite the utility of 3D Organon, a limitation perceived by others (Weyant & Woodward, 2021) is the requirement of sufficient space for its operation, however, all aspects of the software (except for the walk-through of organs) are fully accommodated by the stationary, sit-down mode, which can be set in the Oculus Quest 2 headset. The cadaveric content contained in 3D Organon is 2D (with 3D from simulated animations). Although pathophysiology content is also available in 3D Organon, they are mainly descriptive. Hence the strength of this program lies in the anatomy. In addition, like other VR anatomy tools, motion sickness from 3D Organon use has also been reported in some students (Moro et al., 2021).

Author experience in resource implementation

Considering the level of detail required for foundation undergraduate anatomy teaching as well as case-based presentations, the 3D Organon has been adopted at the LTU and SUT since 2019, although it was unable to be utilized in 2020–2021 due to extensive COVID-19 lockdowns in Victoria, Australia. During the 2019 incorporation of 3D Organon, the software and HTC Vive headsets were made available to students in metropolitan and regional campuses via the University libraries. In-class use was also promoted, with 3D Organon initially available to students enrolled in a second-year, generalist anatomy subject. In addition to skeletons, models, and prosected cadaveric specimens, students were provided with activities using 3D Organon. They were asked to identify a specific structure (or structures) and discuss their functions. Screens were provided so students could work in small groups and observe what the operator controlling the device. They could discuss answers to questions in a peer-teaching environment. A study (Human Ethics approval: HEC19052) using anonymous surveys of students on their engagement and opinions of the technology, was conducted at LTU, with a response rate of 39% from approximately 260 students. With regards to the usage of 3D Organon, Likert responses indicated that 47% of respondents agreed with the statement that "*3D Organon helped me study anatomy*". Only 15% felt that it did not help with anatomy study and 38% of respondents indicated that they were unsure whether 3D Organon was helpful in their anatomy studies. Similarly, while only 11% of respondents thought that utilizing the VR made them less likely to engage with the subject, and 51% of respondents agreed that 3D Organon made them more likely to engage with the subject, the remaining 38% of students were unsure of the impact of 3D Organon on their engagement. Three students wrote comments indicating that they experienced some sort of nausea or motion sickness, while two students wrote that the system was difficult to use; 54% of respondents, however, indicated that the system was user-friendly. With respect to ease-of-use, 32% of students wrote comments indicating that they would like some sort of training resource. Three students also took the time to comment that the VR needed a larger workspace while, interestingly, one student commented that they felt "on display" while using the resource. When asked their best impressions of 3D Organon and VR technology as an anatomical learning tool, students wrote "*I agree with the idea of using VR; it is a good idea,*" and "*it has sort of helped learning placement of muscles*". Other comments included "*how detailed it is,*" and "*it's very helpful with placement and where to find muscles, bones,* etc." This reinforces VR as a useful tool for the development of spatial awareness. When asked what could be improved when using the VR technology, student comments included "*more encouragement to use it, other students seem very hesitant to use it,*" and "*better instruction/demonstration about how to use it.*" This shows that students were receptive to the use of 3D Organon but wanted more support from instructors. Overall, 3D Organon helped students to develop spatial awareness while studying anatomy. Students showed great enthusiasm for this resource, however, academics need to be cognizant that students may prefer a large, private area to work through activities in groups, and that students want more training and incorporation of VR into their classes. For these reasons, 3D Organon has been broadly implemented at LTU. Taken together, the authors recommend that 3D Organon is suitable for both large and small interactive anatomy classes.

Sharecare YOU VR

Resource application: strengths

Sharecare YOU VR (Sharecare Inc, Atlanta, GA) is a virtual anatomy software that provides high-quality, anatomically detailed simulated representations of major body systems in an interactive and immersive user interface. Similar to many VR-based modalities, Sharecare YOU VR enables a systemic overview of the anatomy pertinent to both musculoskeletal and visceral systems required for foundation undergraduate anatomy teaching (Table 1). It is relatively inexpensive (Table 1) and currently compatible with all major VR headsets. Once downloaded and installed onto a local computer, can be used with or without an internet connection. Strengths of the software lie in the user experience with an easy-to-navigate menu allowing system or organ-based selections of relevant anatomy, and the ability to test learning with formative assessment questions.

What sets this application apart from other commercially available VR resources is its integration with pathophysiology. Students and educators can visualize pathologies within the application and sometimes can adjust the severity of the pathology to see the extent to which it distorts normal anatomy or changes physiological parameters. Moreover, Sharecare YOU VR includes embedded simulation videos that combine anatomy and physiology for viscera and visceral systems such as the cardiovascular and endocrine systems. Within the cardiovascular system, for example, students can visualize an anatomically detailed heart and adjust heart rate in real-time. Students can also visualize the ‘patients’ ECG and integrate the knowledge of the conducting system of the heart with the anatomy. Examples of valvular disease and common arrhythmias are included, allowing students to see the effect of these pathologies and integrate this with their clinical skills and knowledge (normal and abnormal heart sounds).

Resource application: limitations

While Sharecare YOU VR enables an immersive visualization of multiple body systems, the current version lacks the breadth of information available in other VR programs such as 3D Organon. It is not currently comprehensive enough to be utilized as the only resource a student would require for the study of anatomy (Alcala et al., 2021). As such, it is best suited to integration with additional digital anatomy atlases or similar. In addition, motion sickness is another common factor reported by some students.

Author experience in resource implementation

Considering its broad utility in anatomy curriculum and a user-friendly interface as well as low program cost, the Sharecare YOU VR has been incorporated into health science, medical, and allied health subjects for teaching systemic and regional anatomy as well as neuroanatomy (Fig. 1D) at Bond University and SUT. Within the preclinical stage of the medical program at Bond University, student cohorts in years 1 and 2 of the program (approximately 375 students), have Sharecare YOU VR integrated within many of their anatomy labs and dissection sessions. At SUT, Sharecare YOU VR is implemented in most anatomy laboratory sessions for the year 1 and year 3 programs of the Bachelor of Health Science course as well as postgraduate allied health courses (approximately 500 students). Cognizant of potential motion sickness experienced by some users, students work in pairs when using Sharecare YOU VR to study anatomy and spend limited time (no more than 30 min) for each session. Taken together, the authors recommend that Sharecare YOU VR be adopted for a range of undergraduate and postgraduate anatomy curricula and is suitable for both novice and experienced users.

Medicalholodeck

Resource application: strengths

The Medicalholodeck comprises a suite of VR programs (Dissection Master XR, Medical Imaging XR, and Anatomy Master XR) (Medicalholodeck, Zurich, Switzerland), which are designed to enable surgical planning in and outside the operating room and medical education in teams. Pitched at medical students, Dissection Master XR is unique in that it enables virtual dissection of human cadaveric images, as users scroll through layers in regions of the body (anterior, posterior, lateral, and medial aspects of the head and thorax, upper and lower limbs, abdomen, and pelvis). Structures are resolved at high fidelity, labels can be toggled on or off, and bodies can be annotated by users and rotated in all directions. What sets the Medicalholodeck program apart from others is the application for clinical settings, as diverse patient image resources can be uploaded and presented in 3D, better informing clinicians in their clinical decisions. Dissection Master XR can authentically simulate viewing a cadaver, circumventing ethical and practical concerns of cadaver access, including those resulting from the COVID-19 pandemic (Rajasekhar & Dinesh Kumar, 2021). Anatomy Master XR is similar to 3D Organon, where anatomy is presented as illustrated 3D structures.

Resource application: limitations

An obvious limitation of both Dissection Master XR and Medical Imaging XR is a lack of haptic feedback, given this program is pitched to medical trainees for surgical planning and practice, surgical trainees in simulating scenarios, and radiologists who can share 3D radiological images with surgeons in surgical planning. The role of touch in the tactile discrimination of vessels, nerves, muscles, and other tissues is essential as students train to become surgeons. The haptic feature may soon be possible, as affordable haptic gloves compatible with the Oculus Quest 2 have been designed and released on the market (Tactglove made by bHaptics). From a practical perspective, a high-quality internet connection is essential in the operation of the Medical Holodeck suite of programs, particularly the Medical Imaging XR, as downloading large files takes time. However, once downloaded, the app can be used without an internet connection.

Author experience in resource implementation

While the Medicalholodeck suite of VR programs is an emerging VR tool with a greater promise for future anatomy teaching in medical programs, they have not been widely adopted by Australian universities, which could be primarily due to its targeted application designed to enable surgical planning. The Dissection Master XR has been trialed as a means of reinforcing anatomical concepts taught to first-year students enrolled in the Postgraduate Doctor of Medicine degree at the Griffith University (Australia), Sunshine Coast campus. As always, student experience and satisfaction are essential aspects when introducing new learning resources. The polled data of students' experience in using Medicalholodeck indicated that most students supported the idea of introducing Medicalholodeck VR for teaching anatomy during their first-year foundation course. Therefore, the introduction of Medicalholodeck to a foundation anatomy curriculum may be a viable option for medical students. It is for this reason that the Medicalholodeck suite of programs (particularly Dissection XR) is recommended for junior medical student anatomy teaching.

Discussion: considerations for implementation

From the authors' perspectives who have trialed an array of digital technologies for anatomy teaching, we believe there are general characteristics as to what makes a particular digital technology useful and what limitations were encountered. The "digitization" attempt is not a simple matter of replacing one with another, but an evolving process to continuously improve the learning experience and outcome.

Suitability

Mindful that our experiences may not be the same as others, our extensive use of digital technologies has led us to propose the following three key features for successful implementation and uptake. Firstly, the tool must be *fit for purpose.* This may seem obvious but before purchase, the institute or university should invest time in developing a proposal, with a clear need for the digital technology, and how this will be sustainably supported, both financially and by learning experts. Academics may not have the time, resources, or technical expertise to support training and development and these skills need to be supported by educational designers with experience in digital technology (Shih et al., 2017). Secondly, address the *cohort size* that will be using the intended tool, and whether the resource is high fidelity (interactive and applicable for small group learning) or low fidelity (adaptable and flexible for large group learning). For example, technologies such as the Sectra and the Anatomage Table will not be suitable for a large cohort but are excellent for team teaching and are great supplements to practical dissection classes. Additionally, if there is an absence of cadaveric specimens, they can provide the 3D context that may be needed for a particular cohort or education program. The third consideration is the *pedagogy and learning frameworks* that have been applied to use the tool such as social and constructivist approaches where knowledge is developed through collaborative interactions with others (Philpott & Batty, 2009) and is student-led (Hrynchak & Batty, 2012) and whether there is evidence that student and facilitator perceptions and student knowledge or grade scores benefit from the purchase. To determine the success of the tool, outcomes from both facilitators and students are imperative to enable "buy-in" from both educators and learners. Analysis including the perception of the tool, accessibility, interactivity, engagement, and motivation along with authentic assessment derived from clear learning objectives should provide an informed decision as to whether the tool is fit for purpose. The authors further deliberate these considerations and present a roadmap in Future Perspectives.

Despite the utilities and advantages, the applications of current digital anatomy resources are still limited due to their nascent nature connected to hardware and software issues (Wickramasinghe et al., 2022). Barriers to adopting VR-based digital anatomy resources also include user discomfort and navigation difficulty (Wickramasinghe et al., 2022). However, considering the ongoing and significant advances in hardware and software, this technical aspect of limitation associated with digital anatomy resources will diminish further in the fullness of time. A clear positive trend surrounding user satisfaction, convenience, and learning performance has been reported for digital anatomy resources (Adnan & Xiao, 2023). While initial setup cost is required and can be substantial (Wickramasinghe et al., 2022), digital resources could provide a cost-effective approach to realizing high-quality outcomes in anatomy learning over the long term (Duarte et al., 2020).

Assessment

Consideration of whether the digital tool will be used as part of the assessment is essential. If students are expected to know how to use the digital tool, the knowledge gained should be informed by the learning objectives. Additionally, instructors should consider the opportunity for students to receive formative feedback before summative assessment as either high- or low- fidelity learning activity. Of the described digital anatomy resource tools, most AR and VR tools allow educators to add quizzes via assessment platforms such as 'Quiz Mode' in the Anatomage Table, 'Flashcard Game Show' or Quizzes in Visible Body Human Anatomy Atlas, 'Out-of-the-Box Quizzes' in BioDigital Human, and interactive quizzes in the ShareCare YOU VR Lab. Moreover, some digital tools such as the Anatomage Table and the Sectra Table allow educators to design in-house quizzes tailored towards a specific curriculum. Many resources have an overwhelmingly large bank of images that need to be carefully curated for students. The ability of an instructor to tailor resources to suit the curriculum is essential to direct effective student learning. Several resources have in-built formative quizzing. This may be problematic if not written by the instructor as it may give students a false impression of the breadth and depth of knowledge required in summative assessments.

Recommendations for using built-in quizzes through a digital anatomy tool include following the principles defined by Michaelsen and Sweet (2008) in a team-based learning approach. Assessments such as quizzes through using a digital anatomy tool can be easily and quickly utilized to complete individual and team readiness assurance tests or used as a tool to actively engage and motivate students during or at the end of class to consolidate knowledge and concepts. Built-in assessments used in this approach should enable immediate feedback (either online or face-to-face when held in class by the facilitator) to focus discussion on misconceptions or allow the student to identify their individual learning needs. Collectively, quizzes built within the digital anatomy resources (if designed properly) offer a broad range of applications pertinent to both individual and team-based assessments with immediate feedback, representing a new means of motivating peer-peer team collaboration and student engagement.

Student satisfaction and engagement with quiz-based teaching in health sciences have been reported as positive, especially when the game design offers rewards such as badges, stickers, or trophies for completing a task or answering questions correctly (Ahmed et al., 2015; Muntasir et al., 2015; McCoy et al., 2016; Bigdeli & Kaufman, 2017; Nicola et al., 2017). Leader boards and achievement records have also been shown to improve engagement or intrinsic motivation (Hamari et al., 2014; Youhasan & Raheem, 2019). As with all learning tools, educators are encouraged to select the platform or software that is fit for purpose, improves learning outcomes, is financially viable for widespread access, is easy to use, and promotes positive uptake for learners and educators.

Overall, using digital resources, as with using any anatomical resources, has positives and negatives. As always, the cost of using any of these digital resources must be taken into consideration, and commercially available products can have substantial initial setup costs (Wickramasinghe, 2022). Other digital resources that utilize stylized non-cadaveric images or have only 2D images may be a disadvantage to learners as 3D resources may improve anatomical knowledge, student motivation, and interest compared to traditional methods (Triepels et al., 2020).

Future perspectives

The development of digital anatomy resources has progressed rapidly (Adnan & Xiao, 2023), accelerating markedly with the increased reliance on online learning driven by the COVID-19 pandemic. Each resource has its strengths and limitations. One strength of systems that allow for remote user access is that students can access resources on their personal electronic devices for asynchronous and self-paced learning (Fiorella & Mayer, 2016; Moorhouse & Wong, 2022; Pan & Wu, 2012). Initial poor resolution of images that limited some technologies has now been largely overcome, but at the expense of larger data files and potentially slower download speeds which can limit their use in areas with poor internet access or if remote access is required. Some systems are also restricted by a lack of cadaveric images, poor resolution of small structures, and omission of anatomical variations or pathologies. The 2D representations may be a strength, improving spatial awareness in radiography, which, however, poses a limitation when viewing 3D relationships. VR and AR seem to be the 'way of the future', however currently cost, scalability, and equity of access can be limiting factors. While many technologies give good 3D representation, the lack of haptic feedback can restrict their usefulness in some situations e.g., surgical training.

The move towards adopting digital technologies in anatomy teaching is inevitable. To support this new development, the authors presented a roadmap (Fig. 2), illustrating the recommended pathway and factors for the implementation of new digital technologies in anatomy teaching. Educators are recommended to undertake a comprehensive product review of digital anatomy resources (as presented in Table 1) such as accessibility, usability, and course suitability together with the budget (cost), and infrastructure support (e.g., IT and class space) before curricular preparation. Initial set-up cost, space, training, and IT support are key factors for consideration during the early phase of digital anatomy resource selection (Fig. 2, Phase 1) together with the compatibility with existing resources such as cadavers, models, skeletons, all of which are critical to the success of subsequent implementation. Indeed, a limitation reported in the literature

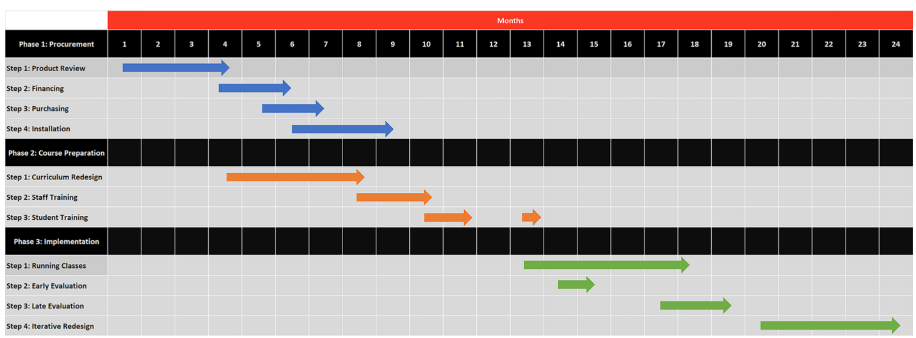

Fig. 2 Recommended Roadmap for Implementing Digital Anatomy Resources. Phase 1: Procurement. Step 1: Review products presented in Table 1: Accessibility (resources required; where can the resources be used); Usability (suited to your teaching needs e.g., individuals; small groups; larger groups; online teaching; technical difficulties); Cost; Technical support; Accuracy; Subject/course suitability (year level; content depth); Product training sessions. Step 2: Contact providers: Institutional or individual licenses; Can you create your own resources using new technologies (copyright). Step 3: Institutional legalities; payment. Step 4: IT help; Designated rooms; Maintenance booking. Phase 2: Course Preparation. Step 1: Must include new technologies into regularly scheduled activities (need to be supported and not perceived as just a gimmick); Include asynchronous activities; Include in lectures or video clips where possible; Include in assessments. Step 2: Must ensure staff are aware of your vision and want to be part of it; Essential to ensure all staff are adept at using these technologies; Create informative training videos. Step 3: Create specific training sessions for students; Create informative video clips (how to access, features, etc.). All staff must show that they support these resources to ensure student uptake; Reinforcing training at the start of a course. Phase 3: Implementation. Step 1: Ensure resources including a protocol for technical issues and trouble-shoot are fully in place PRIOR to regular class; Integrate technical resources with existing resources (cadavers, models, skeletons, etc. where possible). Step 2: Initial check-in survey (after about week 2): Ask tutors or demonstrators to gauge student interaction with new technologies; Ask the tutors or demonstrators if they are using the resources as requested; Survey students for any concerns; Are the resources being used as per your vision. Step 3: End-of-term staff and student surveys; Determine if the resources were effective. Step 4: Improve curriculum design based on staff and student feedback

relating to VR anatomy is the requirement of sufficient space for its operation (Weyant & Woodward, 2021). The authors identified that adequate technical support such as a stable internet connection is required for all aspects of the software access, particularly for interactive classes. Moreover, user training is an essential element of digital anatomy curricular preparation when introducing new digital technologies and is required for both students and instructors (Fig. 2, Phase 2). Users' competency with the provided digital anatomy technologies is likely to influence their attitude toward anatomy teaching and learning. Hence, providing a dedicated pre-class training session to students and instructors focusing on digital technologies is recommended (Xiao & Adnan, 2022). Moreover, students will likely lose interest if resources are not easy to use, therefore having a protocol for technical issues and troubleshooting is recommended (Fig. 2, Phase 3). There is a plethora of choices in the selection of digital anatomy technologies (with many described within this manuscript) reporting on the innovative approaches introduced. Implementing digital resources in anatomy teaching must not be a simple matter of switching from traditional teaching tools to digitized resources, but rather 'an approach of better'. A careful and considered approach is required to ensure effective resource selection. Educators must apply an evidence-based and iterative approach to their curriculum redesign, through analysis of contemporary teaching literature and introduction of course-specific evaluation tools to ensure improved learning experiences and outcomes.

Conclusions

As with the introduction of any new teaching tool, careful planning of classroom integration is essential. The introduction of digital teaching resources is no exception and, when done correctly, these new resources can have a major benefit to student learning and experience when studying anatomy. Dedication to training both educators and students on the most effective ways to utilize a new digital technology does take time. And with too few hours in a day already, there can be a strong motivation against adding these new resources. Or, perhaps more disappointingly, resources are included with no consideration of how educators are expected to use them to teach, or how students are expected to navigate the massive content resource. No single anatomy resource provides a solution to all teaching requirements; therefore, it is recommended that tools be used in combination to provide an effective learning experience for students and importantly tailored for course design, student cohort, and pedagogy frameworks.

The authors hope to have provided evidence that the introduction of digital resources can improve the anatomy learning environment via accessibility to anatomical learning resources, reinforcing scaffolding, along with providing resources for students to learn at their own pace. Additionally, many institutions have continued to provide students with online learning options following the COVID-19 pandemic (Xiao and Evans, 2022), and therefore the use of these digital resources are invaluable teaching tools. Future research is required to understand the effect that the digital approaches adopted have had on the learning gain of students. The evolution of digital learning in anatomy education will succeed only when novel resources are fully embraced and properly adopted for a smart learning environment.

Abbreviations

2D	Two-dimensional
3D	Three-dimensional
AR	Augmented reality
COVID-19	The coronavirus disease 2019
CT	Computed tomography
MRI	LTU: La Trobe University, Magnetic Resonance Imaging
MR	Mixed reality
QUT	Queensland University of Technology
SUT	Swinburne University of Technology
VB	Visible body human anatomy atlas
VHD	Virtual Human Dissector
VR	Virtual reality

Acknowledgements
We would like to thank Mr Patrick Michael from Swinburne University of Technology for assisting with the figure preparation.

Author contributions
Conceptualization and writing (initial draft preparation and editing): R.C.A., H.H., A.B., R.D., A.M., H.M., J.N., H.R., A.S., M.T., K.V., and J.X.; Final editing, review and project administration: J.X.; all authors approved the final version for submission.

Funding
Work conducted in this study was not funded.

Availability of data and materials
The datasets used and/or analyzed during the currently study are available from the corresponding author upon reasonable request.

Declarations

Competing interests
The authors declare no conflict of financial or no-financial interests.

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Received: 5 September 2023 Accepted: 4 December 2023
Published online: 12 December 2023

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