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SkilletonVR: Canine Skeleton VR

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Abstract Traditionally Veterinary degrees are taught using 2D images which show fixed viewpoints and cadaveric dissections which are an expensive resource and in limited supply. This lack of interactive, educational resources available for veterinary students makes learning the anatomy of different animals difficult. Over the years with the development of innovative technologies, more resources have been developed to aid the learning of medical and veterinarian students. However, these advances have been more prominent in the medical sector.

This study aimed to contribute filling in the gap of technological resources available to veterinary students by creating an educational VR simulation about the canine vertebral column. This research also aimed to supply a backbone for other applications of its kind to be developed for other areas in veterinary science by providing the methodologies and workflows to design the application. Overall, this research supplies an insight into the difficulties to learning the various anatomies of different animals and provides the building blocks to create solutions for these issues.

Key Words Veterinary Sciences, Canine Vertebrae, Application Development Process, Virtual Reality, Education.

1 Introduction

Veterinary medicine is traditionally taught with two dimensional (2D) diagrams, medical imaging scans and photographs which are all fixed viewports. The representation of a three-dimensional (3D) object on a 2D surface can lead to the loss of spatial information, which in turn can lead to problems implementing the knowledge into real life (Raffan, et al., 2017). Cadaveric dissections are also used in the teaching of gross anatomy of animals however this resource has financial, ethical and supervisory limitations (Moro, et al., 2017). Over the years there has been a gradual progression to move towards digital modes of learning including interactive 3D models to try and engage the user to learn and consolidate knowledge (Christ, et al., 2018). In medical training technological advances have become established with interactive 3D models, however this is yet to be carried over to veterinary education. The use of Mixed Reality has shown a positive impact on student learning and should be brought into the education system to help with student engagement with the learning materials and to allow a larger understanding of the field of interest (Guze, 2015).

The implication of interactive 3D models in medical education has become established with increasing popularity, however these technological advances have yet to be carried over into veterinary training. These limited resources are one of the key reasons for this research as it aims to add a technological advancement into veterinary education. This will offer new opportunities for enhanced visual and interactive 3D models within veterinary training.

This research aims to provide a learning application about the canine skeleton for undergraduate veterinary students as to date there is no such application available to students.

This will be achieved by (1) building a body of knowledge to understand and assess the impact of resources currently available to veterinary students and identify the gaps in their education; (2) designing and developing an interactive VR application which provides a visualisation of anatomically accurate models building upon a medical dataset. Finally, the design and development process will be critically analysed.

1.1 Research Questions

This research will undertake multiple research questions to explore. Firstly, to what extent do traditional resources allow undergraduate veterinary students to understand the canine anatomy? Secondly, can a viable technological and methodological framework for creating VR resources for veterinary education be created?

2 Related Work

For over 250 years, veterinary anatomy has been taught, with Claude Bourgelat opening the first veterinary school in 1761 (RCVS Knowledge, 2021). The understanding of veterinary anatomy had expanded greatly over the years however, the methods of teaching and learning it have hardly changed (Guevar, 2020). Challenges have emerged and these need to be addressed. Recent changes in technology, such as the development of AR and VR, have allowed for new methods of learning to become available that aid the traditional resources (Guze, 2015).

2.1 Traditional Learning Resources

From the traditional methods of teaching anatomy, there are multiple difficulties that affect the efficiency of learning the subject matter. This can be due to a lack in availability of the resource, or it can involve ethical and budgeting limitations. There can also be a lack or an overload of information. It can also be noted that there is a lack of engagement in the resources and a lack of resources that aid in the learning of spatial relationships of the anatomical structures. Another issue to note is studies have shown that students are being given less time to focus on learning anatomy as a change in curriculum has put more emphasis on the learning of the clinical aspects of veterinary education however this does not make the learning of anatomy any less important (Guze, 2015; Christ, et al., 2018; Guevar, 2020).

Cadaveric Dissections and Prosections

For centuries cadaveric dissections have been used to both learn and understand anatomy in humans and animals alike (Guevar, 2020). Using dissection techniques allows the student to observe three dimensional (3D) structures in spatial relation to each other. It also allows the student to opportunity to observe the anatomical and pathological variations that occur naturally in the specimens. Students can also familiarise themselves with the different textures and strengths of individual tissues in the body (Aziz, et al., 2019). The first-hand experience that cadaveric dissections allow, have shown to give students the opportunity to deepen their understanding of anatomy and to improve their recall of what they have learned. It has also been reported that students find the learning material more interesting and engage better when presented the opportunity to use cadaveric dissections (Dissabandara, et al., 2015). It is agreed overall that the gold standard for learning anatomy is with cadaveric dissections however, there are many restrictions to the use of cadavers in the classroom (Moro, et al., 2017). One of the biggest restrictions is the lack of availability of cadavers especially in veterinary education as it would require multiple cadavers of multiple species to cover the anatomical knowledge of all the different animals that veterinarians deal with (Guevar, 2020). Another restriction is the preservation and storage of the bodies which the educational institute would need to take into consideration (Aziz, et al., 2019). The institute would also need to be able to provide the qualified staff for the teaching and overseeing of the dissections, as well as adhere to all the ethical guidelines (Aziz, et al., 2019). Ethical and financial circumstances also limit the use of cadavers in anatomical education as does having the students subjected to levels of formaldehyde which is the key substance used to preserve the bodies (Aziz, et al., 2019). Yet another limitation is that dissecting a cadaver is time consuming. One of the ways to overcome some of the disadvantages of cadaveric dissections is with the use of prosections (Guevar, 2020).

Prosections are an area of the specimen that has been dissected by an expert anatomist that is then fixed and preserved. Advantages of prosections are the students can investigate the various structures of the specimen without needing to spend time dissecting them. Prosections are also clean, odourless, nontoxic, dry, and durable allowing them to be removed from the classroom as they do not require any special storage conditions and can be touched without the use of gloves (Aziz, et al., 2019). For these reasons prosections are ideal for tutoring small groups and enhancing the ability to identify anatomical structures in relation to others. Although prosections are useful they do still have disadvantages to the learning of anatomy. For example, the students won't be able to perform their own dissections missing out on learning the techniques used to uncover the various anatomical structures (Dissabandara, et al., 2015). Also, prosections can have damage to the various structures depending on the skill level of the dissector and the structures might even be removed meaning a full understanding of the spatial relationship between the various structures could be lost (Aziz, et al., 2019).

Textbooks

Textbooks can be considered the backbone for learning in most aspects of education and anatomy is no different. The vast amount of theoretical knowledge contained within textbooks allows for educators to base bits of their lectures on them as they provide text and diagrams to aid the learning of the reader. Textbooks also allow for the student to learn independently out with the classroom (Codd, et al., 2011). Despite textbooks being so widely used they do have limitations, for example the visual information displayed is only non-interactive 2D images and diagrams. This can cause difficulties for the reader as they try to understand the spatial comparison of the various anatomical structures (Guevar, 2020). The other downside to textbooks is that they can contain information that is too advanced or sometimes not advanced enough which can hinder the readers learning trying to decipher what they are reading (Codd, et al., 2011).

Imaging Anatomy

X-rays, CT scans, and MRI (Magnetic Resonance Imaging) scans are diagnostic imaging techniques that are incredibly important in the education of anatomy (Guevar, 2020). Clinical diagnostics use these imaging techniques as one of the main ways to visualise anatomy in both medical and veterinarian professions (Schramek, et al., 2013). Using imaging anatomy within education allows for the efficiency and quality of the anatomical lessons to be strengthened as it allows the viewer to develop an understanding of the volumetric of organs (Guevar, 2020). Using imaging anatomy can cause difficulties for the learner in the same way that textbooks do. The viewer must relate 2D images with 3D structures which can be exceedingly difficult. Despite this, studies have shown that early exposure to imaging anatomy early on in education can help to improve the student's spatial ability (Guevar, 2020).

Films/Videos

It has been shown that the use of films and videos can benefit the student because they are a widely available format on the internet, allowing for self-paced learning (Al-Khalili, et al., 2014). Films and videos are considered great tools for studying as they are less time consuming than cadaveric dissections (Guevar, 2020). Despite films and videos being an excellent resource for receiving anatomical information, they are classed as a passive learning tool (Combes, 2003). This is because it is all too easy for the student to not take in the information being presented due to this resource being dependant on the student's engagement (Guevar, 2020). Due to this reason, it is recommended that films and videos are used only as a supplementary resource of learning.

Models, Mannequins, Simulators

Models, mannequins, and simulators are another excellent resource available as it aids the memory and recall of information (Guevar, 2020). The use of models has multiple educational benefits especially 3D printed models as they are anatomically accurate (McMenamin, et al., 2014). This is because not only can they be used to educate students but also in explaining and demonstrating an illness to the owner of a pet or patient. For the teaching of clinical skills such as hand-eye coordination, equipment handling, suturing, etc. the use of mannequins and simulators is beneficial as they provide lifelike representations of models and situations (Guevar, 2020). Another benefit is that techniques can be practiced without the worry of dealing with ethical and cultural issues that are associated with cadaveric dissections (Preece, et al., 2013). The limitations of these resources are that they are not the real thing, therefore the textures of the mannequins will feel different for example learning to place a catheter in an arm (Preece, et al., 2013). On a model you are pushing the needle through a rubber like material whereas skin is softer and easier to puncture. These resources also do not allow the user to observe any natural variations that can be seen in humans and animals (Guevar, 2020). The other drawback is that models, mannequins, and simulators can be expensive making them not as widely available as some other resources (Guevar, 2020).

2.2 Alternative Approaches to Learning Anatomy

The aforementioned challenges represented a motivation for seeking new ways of engagement with anatomy education. Multimedia computer simulations are experiencing a growing interest as they allow self-study outside the classroom (Guevar, 2020). The term multimedia computer simulations can be broken down into different areas: (1) computer assisted learning which are websites that combine notes, images, videos, and quizzes together to make learning more interactive (Guze, 2015). For example, Anatomy.TV is a website in the medical sector that combines anatomical information with interactable 3D models to supplement the learning. (2) Applications designed for phones which allows the student to always have access to study material so long as they have their phone on them. iMedicalApps.com is a website that provides information on various mobile applications that can help with studying allowing the student to find the app that will best suit them (Guze, 2015). (3) games and simulations that are accessible digitally that provide training tools in engaging environments. These are mostly targeted towards surgeons to help them practice their hand-eye coordination skills (Guze, 2015).

There is a process called gamification which has been researched and shown to support learning as students find learning to be fun, interactive, and engaging (Sanglier Contreras et al., 2021). Gamification has been shown to increase the students desire to come back and study more as it doesn't feel like a chore to do so. This approach can also allow the leaner to experience real-world applications with real time feedback enhancing the learning experience (Insights, 2018). The engagement of students has improved with the implementing of these innovative technologies by encouraging independent learning and the technological advances have also increased the areas of teaching (Dai, et al., 2012). Despite technologies such as virtual reality (VR) and augmented reality (AR) making leaps and bounds in the medical education sector, they have yet to take off in veterinary education (Christ, et al., 2018).

Two popular technologies in the education sector are AR and VR (Bui, 2020). This is because they can allow the student to visualise and interact with 3D structures which allows for a fuller understanding of complex structures and their spatial relationships to other structures which they couldn't obtain from 2D images (Bui, 2020).

AR overlays digital information on the real world using a device such as a smart phone, which allows for an enhanced version of reality (Munzer, et al., 2019). One example of AR is the Ikea place app currently available for iOS phones. This app allows the user to view what the piece of furniture would look like in their home before buying it (https://www.ikea.com/gb/en/customer-service/mobile-apps/).

Whereas VR provides a degree of immersion to the application as the user can only see the interactive, real-time, 3D environment (Kiber, 2020). VR usually requires special equipment which can be a headset designed to provide full immersion of the user within the digital environment.

AR and VR have been shown to aid students learning experiences especially when applied to the learning of 3D structures (Uruthiralingam, et al., 2020). The computer-generated environments not only provide enhanced environments that allow for realistic visualisation but also provides a safe and controlled environment for learning (Ardiny, et al., 2018). Due to the learner being able to repeat their practice of material it can lead to improvements in their skill coordination and enhanced perceptual variation (Ardiny, et al., 2018).

Although VR brings multiple advantages to the education system, it is still in debate as to whether it benefits learning (Uruthiralingam, et al., 2020). This is partially due to unmitigated cybersickness which can occur from prolonged exposure periods in VR (Kiber, 2020).

Another reason for the debate of AR and VR being beneficial in education is because some studies found that implementing these two technologies into the education sector did not improve the participants test scores (Uruthiralingam, et al., 2020). Various procedures are now taught to doctors and medical interns using VR and it has even been introduced to the education of undergraduate students (Kiber, 2020; SimX, 2020; Osso VR, 2021; vStream Health, 2021). Despite this ongoing debate multiple studies (Codd, et al., 2011; Guze, 2015; Peterson, et al., 2016; Moro, et al., 2017; Ardiny, et al., 2018; Christ, et al., 2018; Office, 2018; DeBose, 2020; Guevar, 2020; Uruthiralingam, et al., 2020) conclude that the use of VR in education is a positive thing that aids the learning experience when supplemented with the traditional resources of teaching,

Within medical education VR has come in leaps and bounds as there are now multiple applications that provide different learning experiences whether is a doctor brushing up on their knowledge or an undergraduate student learning something new (Guze, 2015). Multiple platforms such as OssOVR, touch surgery, and the Airway EX Virtual Surgery Simulator App provide training simulations to surgeons that teach them how to use new equipment and how to perform procedures (Guides.dml.georgetown.edu., 2021). There are other VR applications such as Bacteria VR 3D, Bard VR, Medical Realities and the VLIPPmed App which all provide educational animations and 360° videos about the human body and microscopic level surgical procedures (Guides.dml.georgetown.edu., 2021). Some examples of educational games are Precision Genomics VR and InMind VR which engage the user in a unique and interactive way making learning more fun. These examples are only a few of many more VR applications with new ones being created to be implemented with the traditional methods of learning anatomy (Guze, 2015).

Although there have been technological advances made within veterinary education there is still a noticeable lack of VR applications, especially when compared to the various platforms designed for medical students (Christ, et al., 2018). For the Oculus Quest, VXR.Direct created a series of dissection minigames which introduces animal dissections to secondary school children (https://vxr.direct/category/subject/science/life-science/dissections/). Although this is a fantastic resource of younger children it does not have the in-depth knowledge required for the education of undergraduate students. Numerous studies, (Franz Luebbers, et al., 2020; Chang-Gonzalez, et al., 2021) have developed VR applications aimed to aid the education of veterinary students however these studies found limitations with their applications. For example, some found the models within the application were not realistic enough making the learning experience not as engaging as they had hoped. It could also be noted that all these applications focused on the learning of canine anatomy and although in first year of veterinary school the focus is on the canine anatomy for their cadaveric dissections (DeBose, 2020), other applications will be required for the other various species so that all areas of veterinary anatomy are covered. There have been other VR platforms such as 360° videos and virtual exam rooms designed for veterinary education (Wuest, 2021) however they are not up to the same standard as the ones in medical education.

The development of engaging and novel methods of presenting anatomical structures have stemmed from the advancement in technology (Uruthiralingam, et al., 2020). Having the access to these technologies has allowed students the opportunity to gain experience learning complex anatomical structures and to gain an understanding of the spatial relationships between various anatomical structures (DeBose, 2020). There are a handful of studies that have shown inexperienced surgeons significantly and rapidly improving their surgical skills when repeatedly using VR simulations (Moro, et al., 2017). It has been proposed that the routine use of VR is likely to increase not only the depth of understanding of anatomy but also substantially improve a student's long-term retention of the material (Peterson, et al., 2016).

Overall it is agreed that AR and VR should not replace cadaveric dissections or any of the other traditional methods for learning anatomy but instead be used alongside these methods providing students with a larger variety of resources for them to use in their learning of anatomy (Uruthiralingam, et al., 2020).

3 Methods and Materials

3.1 Materials

To create the VR application a variety of materials were used including a full CT scan data set of a canine to create the models, the details of this data set is shown in table 1. To use this data set ethical approval was applied for and granted by The University of Glasgow. The other materials used were varying hardware and software shown in tables 2 and 3, and assets and packages used in the application, a note of which can be seen in table 4. These materials were used to develop the models and VR application.

Table 1 Dataset and its series acquired for viewing and segmentation of the data to create 3D models.

Dataset (DICOM)	Type	NO. of Series	Series NO.	Region	NO. of Slices	Slice Width	Series Size
Adult Female Canine	Full Body CT scan	11	2	Head	176	1mm	512 x 512
			3	Head + Ears	176		
			5	Neck	145		
			6	Neck + Paws	145		
			7	Thorax + Elbows	171		
			8	Thorax	171		
			9	Lumbar	165		
			10	Pelvis + Limbs	152		
			11	Pelvis	152		
			12	Tail + Limbs	176		
			13	Tail	78		

Table 2 Software used, what it was used for and the web link for each one.

Software	Logo	Purpose	Web Link
Unity 2019.4.28f1	unity	Interactive Application Design	https://Unity.com/
3DS Max 2020	AUTODESK 3DS MAX	Modelling and retopology of segmentations	https://www.autodesk.co.uk/products/3ds-max/overview
3D Slicer 4.11.20210226	3DSlicer	View and segment CT data to generate 3D models	https://www.slicer.org/
Adobe Photoshop 2020	Ps	Editing and creating images for the application	https://www.adobe.com/uk/products/photoshop.html
Oculus Developer	oculus	Uploading the application to the oculus quest	https://developer.oculus.com/

Table 3 Hardware used to create the application

Hardware	Purpose
Computer - HP Intel Core i5, 12GB RAM	To run the software to create the application
Oculus Quest 2 oculus	Troubleshooting and running the application

Table 4 Premade assets used from various websites to aid in the creation of the application and the packages that were used/installed into the Unity project.

Asset/Package	Creator/Version	Website	Web Link
HQ PBR Old Retro Radio (Free)	PHOS digital	Unity Asset Store	https://assetstore.Unity.com/packages/3d/props/hq-pbr-old-retro-radio-free-180303
Gridbox Prototype Materials	Ciathyza	Unity Asset Store	https://assetstore.Unity.com/packages/2d/textures-materials/gridbox-prototype-materials-129127
Menu Chalk Board	LunarCats Studio	Unity Asset Store	https://assetstore.Unity.com/packages/3d/characters/menu-chalk-board-101989
Morgue Room PBR	Rokay3D	Unity Asset Store	https://assetstore.Unity.com/packages/3d/environments/morgue-room-pbr-65817
FREE Rigged Skeleton and Bone Collection	Ferocious Industries	Unity Asset Store	https://assetstore.Unity.com/packages/3d/props/free-rigged-skeleton-and-bone-collection-166829
Clipboard	cookiepopworks.com	Unity Asset Store	https://assetstore.Unity.com/packages/3d/props/clipboard-137662
writing-chalk-short-01.wav	newagesoup	Freesound	https://freesound.org/people/newagesoup/sounds/377842/
Calming/Relaxing Ambience Music Loop	freelncr	Freesound	https://freesound.org/people/freelncr/sounds/553417/

JetBrains Rider Editor	1.2.1	Unity Package Manager	N/A
Oculus XR Plugin	Oculus, Facebook, version 1.9.1	Unity Package Manager	N/A
TextMeshPro	2.1.6	Unity Package Manager	N/A
Timeline	1.2.18	Unity Package Manager	N/A
Unity Collaborate	Unity, version 1.2.16	Unity Package Manager	N/A
Unity UI	Unity, version 1.0.0	Unity Package Manager	N/A
Visual Studio Code Editor	Microsoft, version 1.2.3	Unity Package Manager	N/A
XR Interaction Toolkit (Samples – Default Input Actions)	Unity, version 0.10.0-preview.7	Unity Package Manager	N/A
XR Plugin Management	Unity, version 4.0.7	Unity Package Manager	N/A

3.2 Methods

There were two key elements in creating the VR application, see Fig. 1. The first being the application design which could be divided into three key steps: the initial concept, workflow, and the storyboard. The second element was the development of the graphical assets which can be broken down into Segmentation, Retopology, and their implementation within the application.

3.2.1 Initial Concept

Initially this research aimed to create a fun and interactive VR application designed to aid the education of veterinary students on the entire canine skeleton. This was to be accomplished by using auditory and visual learning accompanied by an instant feedback quiz. These key aspects of the application would allow the user to navigate the canine skeleton learning each bone as they went and to assess their learned knowledge. The MoSCoW design method was used to prioritise the various aspects of the application allowing a clear understanding of the tasks needed to produce a functional game that met the requirements of the project. The MoSCoW design method allows for the different elements of the application to be organised into must have, should have, could have, and will not have. The prioritised aspects were then placed into a Kanban to allow for each task to be easily organised into each individual category, see Fig 2. A Kanban is a method used for workflow management which allows for the visualisation of work and to maximise the efficiency of the workload (Kanbanize, 2021).

3.2.2 Workflow

The workflows were created for the segmentation, retopology, and application creation steps which are detailed in Figs 3-5.

3.2.3 Storyboard

Start Scene The application loads into an empty space apart from a blackboard in front of the user. On the blackboard will be the menu on it allowing the user to start the game, quit the application, or learn more about the application itself. The user will be unable to move about this scene, only look around and interact with the black board. The basic layout for the start menu is shown in Fig. 6.

Game Scene After the start button is pressed it will load the user into an interactive laboratory room which will have some tables and a blackboard. The blackboard will be like the one in the start scene, see Fig. 6, where the user will be able to exit the application and read information about the application. However, there will also be a help button with instructions on how to navigate the application. These three buttons will be found after clicking on the menu button on the blackboard, see Fig. 7. Next to the menu button will be the button that will start the quiz. Each question will be a multiple-choice question with the choice of four answers. Upon moving onto the next question, the quiz will show if the correct answer and if the user got it right or wrong.

The user will be able to move about the environment and interact with various objects in the room. Individual bones will be on the tables with their name on a label next to them and a little audio control pad where the user can play, pause, and stop an audio recording giving information on its corresponding bone. The basic layout for the bone models can be seen in Fig. 7.

3.2.4 Segmentation

The models needed for this application had to be anatomically accurate, therefore segmentation was conducted on the CT dataset of the canine. The software used to conduct this process was 3D Slicer which is used to process medical data. The data set required processing before segmentation could take place as the images had noise in them which would have affected the quality of the segmentation, see Fig. 9A. Each series used had the Median Image Filter applied to it using a 1:1:1 ratio to smooth the images reducing the noise, see Fig. 9B. Unfortunately, this filter left the data series blurry, so a filter called the Laplacian Sharpening Image Filter was used with image spacing enabled to sharpen the images, see Fig. 9C.

Once each series had been edited, they underwent segmentation. This was done by using the paint tool in the segment editor with the intensity range set to 400 – 3017. Manual segmentation was chosen to ensure the segmentations were anatomically correct, see Fig. 10. The completed segmentations were then exported as models and saved as .stl files ready to be used in 3DS Max.

3.2.5 Retopology

Retopologising the models was required as the models produced in 3D Slicer had high polygon counts and some even had holes in the meshes. This makes the models unfit for use in the application development stage, see Fig. 11. To begin the retopology of the polygonal surfaces of the 3D Slicer models the .stl files were imported into 3DS Max.

3DS Max has a freeform tool which is what was used to conduct the retopology, reducing the polygon count, removing any holes, and neatening the mesh of each model. To begin, the “Draw On: Surface” tool was used selecting the imported model as the surface being used. The offset variable was set to 0.100 and a new object was created making the new mesh separate from the original one making it easier to export later down the line. The "Strip" tool was then selected with the minimum distance set to 50 to draw a strip of polygons over the surface of the model, see Fig. 12A. Once the initial strip had been made the "Extend" tool was used to create and manipulate the polygons and vertices over the surface of the model until it was encased in the new mesh, see Fig. 12B + C. To give the models a better finish, all the smoothing groups were removed from the mesh and then auto smoothed which was set at 45.0, see Fig. 13. Before exporting the new models, a basic material was added so that the texturing could be done in Unity.

3.2.6 Application Creation

An HP Intel Core i5 Laptop was used for the design and development of the application and an Oculus Quest 2 was used for the troubleshooting and running of the final application. To begin creating the application all the packages shown in table 4 were installed into the Unity project and the build settings the platform was changed to Android, see Fig. 14, as this is the required settings for the application to run on the Oculus Quest. The font for the text in the application was created in Adobe Photoshop 2020 which was designed to have a chalky look to it as this writing would be found on the blackboard, see Fig. 15. For the text to be used within the UI in Unity the images of the writing were turned into sprites. After this all assets from table 4 were loaded into the project in Unity so that everything needed for the application creation was in one place ready for use.

Using Unity 3D, two scenes were designed: a start menu scene and the game scene. In the start scene there needed to be UI elements that the user could interact with and navigate through the start menu. Examples of such is a start and exit button shown in Fig. 6. To make the application user friendly an audio clip would play when a UI element was interacted with providing instant feedback. A script was designed to contain the coding required for both the start and exit buttons to function as needed, see fig16. For the application to fit the design purposes it required an audio recorded learning element as well as a quiz that would evaluate the learning of the user within the game scene of the application. This meant that the application could be divided into two fundamental areas: the learning of the material and the testing of what had been learned.

Within the learning aspect of the application the main source of information would come from audio recordings. The user would need the capabilities to play, pause and stop each recording as they examine the models. To control the audio small remotes were created in

3DS Max which were then imported into the Unity Project. To make the buttons on the remote interactable a canvas was placed on the surface of the model with three buttons on it and a script outlining the audio control. This was replicated for each remote in the scene. The script worked using a Boolean system which would allow for the playing, pausing, unpausing and stopping of the audio recording, see Fig. 17.

Other learning elements within the application were the user's ability to view the models in three dimensions and to compare the models to diagrams that were in the game scene. As the application was created for a VR platform it allowed the user to view the models from different angles allowing for a better understanding of the dimensions of the models. The diagrams in the game scene were added onto clipboards that the user could look at while examining the 3D bone structure allowing for an instant 2D to 3D comparison. Each diagram was taken from various websites (The Art of Medicine, 2015; SpineUniverse.com, 2019; MSR Blog, 2021; Halihanafiah, n.d.).

Within the application the consolidation of information was to come from the quiz which was designed to give instant feedback to the user. This was done by confirming the correct answer before the user moved onto the next question. The information needed to answer each question could be found within the virtual environment. The type of buttons used for the four multiple choice answers were toggles, see Fig. 18. This meant that toggle groups could be used to confirm if the answer chosen was correct or not. The coding for this was much simpler for creating the quiz, see Fig. 19. For the user to take the quiz multiple times as they wanted without having to exit the application a simple reload function was added to the same script that had the coding for the start and exit buttons. This allowed for the game scene to be reloaded once the user clicked on the exit quiz button which would reset everything in the room including the quiz, see Fig. 16.

4 Results

4.1 Medical Dataset

Eleven data series were obtained however only three of these series were used for the models. Fig. 20 shows which data series were used for segmentation. Each of the three data series used were filtered with the "Median Image Filter" and then the "Laplacian Sharpening Image Filter", see Fig. 9. Both filters could be found in the simple filter's module in 3D Slicer.

4.2 Segmentation Outcomes

The canine skeleton consists of approximately 320 bones however only fifteen bones were segmented. The bones segmented were the C1-4, the T1-10 and the L1 vertebrae. The C1 vertebrae was segmented from the filtered data series 6: Neck 1.0 Bone + Paws, see Fig. 21. C1-4 were segmented but only the C1 and C2 vertebrae were exported as .stl models. Out of the thoracic vertebrae, ten out of thirteen bones were segmented, see Fig. 22. The T1 vertebrae was the only thoracic vertebrae to be exported from 3D slicer to be retopologised. The L1 was the only lumbar vertebrae to be segmented and exported from 3D Slicer, see Fig. 23.

4.3 Retopology

The polygon count for each model before and after retopologising the mesh of the models is shown in table 5. The first model to be retopologised was the T1 vertebrae which originally had 20,264 polygons however after being retopologised the model only had 1,457 polygons, see Fig. 24A. The C1 vertebrae was the next model to undergo retopology taking the original polygon count of 20,763 to 2,479 polys, see Fig. 24B. Next was the C2 vertebrae which had a polygon count of 19,916 however after the retopology took place its polygon count dropped to 2,468, see Fig. 24C. The last model to undergo retopology was the L1 vertebrae which started with 33,360 polygons but finished with 1,961 polygons, see Fig. 24D.

Table 5 Polygon count of both the original model produced in 3D Slicer and the retopologised model made in 3DS Max.

Model	Original Polygon Count	Retopologised Polygon Count
T1	20,264	1,457
C1	20,763	2,479
C2	19,916	2,468
L1	33,360	1,961

4.4 Application Design

The MoSCoW Kanban had changed from the initial design as items needed to be moved around to narrow the scope of the project. These changes can be seen in Fig. 25.

Within the start scene the UI elements consisted of a title, a start button, an exit button and an about button, see Fig. 26. The user could navigate the UI with ease as the buttons when clicked made a scribble noise as though someone was writing on the chalkboard, which let the user know when the button had been pressed.

Once the start button has been clicked the game scene is loaded up, see Fig. 27. To minimise motion sickness the user could snap turn the camera with the right-hand joystick or they could move their head to look around. To move around the environment the user could use the joystick on the left-hand remote. The blackboard provides the menu and quiz options. The menu provides the user with information on the application, help if the user gets stuck using the application, and a way to exit the application once the user is finished. The knowledge consolidation aspect of the application comes from the quiz where the user can answer multiple choice questions with four answers to choose from. These questions will be drawn from a database of questions to randomise the quiz each time. For demonstration purposed the quiz was designed to have four questions drawn from a database of five questions.

The primary learning element of the application was to come from the bones and their individual audio recordings. The layout of the bones, the name tags and their corresponding audio remotes can be seen in Fig. 28A + B. Each audio clip can be controlled independently and can be replayed whenever the user needs. Another learning element in the scene are clipboards with diagrams on them, see Fig. 28C. Each bone has its own corresponding clipboard and the image on it provides labelled information of the bones that can be compared to the 3D models to identify the distinct features of each vertebra.

5 Discussion

This study first investigated the availability of modern technologies such as virtual reality (VR) within the field of veterinary education for undergraduate students. The research then explored developing an interactive, educational VR application that would provide the backbones that other applications could be developed from. From the research it was shown that mixed reality applications have started to be implemented into the education of doctors and students and that the popularity of the applications have led to an ever-growing field of educational applications, simulations, and software's. However, despite the growing popularity these mixed reality applications are lacking in the field of veterinary education (Christ, et al., 2018). Therefore, to bridge this gap in educational resources this research designed and developed an interactive and educational virtual reality application that can be adapted and expanded upon in future applications.

Conducting the literature review allowed the gaining of a body of knowledge on the current resources available to students learning veterinary science and the difficulties surrounding the learning of anatomy. The literature review shows that despite the complexity of animal anatomy and the vast body of knowledge required to understand it, educational resources have not changed greatly over the years (Guevar, 2020). The curriculum for veterinary education has been moving towards focusing more on the clinical aspects of veterinary medicine leaving less time to learn the anatomical knowledge required. It has become clear that the resources available would not be sufficient and that novel resources would be required (Christ, et al., 2018). Although there have been attempts at virtual reality applications being developed for the education of veterinary science, they do not possess the in-depth knowledge required for them to be integrated into the undergraduate student's curriculum (Christ, et al., 2018).

Other studies have shown to improve a student's understanding of the material learned and improved on the student's motivation to study out with class (Uruthiralingam, et al. 2020). This improvement in engagement can be explained by the gamification of educational resources as it makes the material more digestible (Insights, 2018). The use of the Oculus Quest 2, an untethered device, for both in and out of the classroom is ideal as it does not require to be connected to a computer to run applications. It is also more affordable than other models of VR headsets meaning students can use them at home to study in their spare time.

A workflow methodology was a successfully implemented and led to the design and development of an application about the canine anatomy for veterinary. The use of multiple software's allowed for models to be extracted and refined from CT scan data allowing for anatomically correct models that the application would be based around.

The VR application created for this research is a basic example of the initial conceptualisation for the educational resource. Due to the time constraints the quiz was not fully developed however it does demonstrate the functionality of it and has the capacity to be expanded easily. The application is also missing the mini games that were initially thought of which would have aided in the engagement of learning the material. The application produced meets the aims and objectives of the project, however, can be expanded upon greatly to develop a more in- depth learning experience with a greater source of knowledge to learn from. Suggestions on ways to expand and improve upon the application would be to have a more in-depth quiz with a larger question pool, the capability to enlarge and rotate the bone models to fully examine them. Other features that could be added are the ability to highlight the various processes and structures of the bones and to have their names appear when highlighted over. Another way to develop the application would be to add mini games such as organising the different vertebrae into trays or a label placing game. For any future developers, this application provides the framework that will allow for not just the entire canine skeleton to be added but other anatomical structures such as organs, blood vessels and nerves. It can also be used to develop similar applications for the various species of animals that vets need to know about.

The full extent of the usability of this application is still unknown as the time constraints didn't allow for outside parties to test the usability and functionality of the game. Research should also be conducted to assess whether the application improves the learning of the canine anatomy for veterinary students by conducting a study where veterinary students try out the application.

6 Conclusion

The resources currently used in the education and learning of veterinary education have changed little over the years and need to expand to keep up with the vast field of anatomical knowledge that is constantly growing. Advances into using mixed reality in the veterinary education system are slowly happening however need to catch up to the advances being made in medical education. This research provided an application design which can be used as a backbone for other educational applications to be based on. The application requires further developing to expand the functionality of the game and testing to determine the usability of the application.

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