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Exploring mouse necropsy through augmented reality: developing a web application for enhanced learning and visualization

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Abstract
Necropsy, the examination of animal carcasses to determine the cause of death, is an essential skill for many professionals. Traditional training methods, however, are costly and time-consuming. The article suggests that Web-based Augmented Reality (WebAR) can offer an immersive and cost-effective training experience for laboratory animal necropsy. It describes using photogrammetry techniques to create a virtual necropsy environment consisting of 10 necropsy steps. A questionnaire was used to evaluate the usability, educational value, and drawbacks of the designed application by students who tested it. The paper outlines best practices for developing WebAR simulations, including high-fidelity 3D models and interactive elements. Additionally, it presents methods for creating new WebAR applications using specific programs or scripts. This paper highlights the potential benefits of WebAR for laboratory animal necropsy training, emphasizing its accessibility, cost-effectiveness, and scalability.

Keywords Mouse · Veterinary · Laboratory animal · Necropsy · Augmented reality · Pathology · Education · Virtual reality

1 Introduction

Necropsy, the post-mortem examination of an animal's body, is an essential component of veterinary medicine and experimental research. This procedure is conducted to study the animal's anatomy and physiology, identify any abnormalities or diseases, and collect tissue samples for further analysis [1, 2].

Laboratory animal necropsy education is important for researchers, students, and professionals who work with animals in scientific research and testing [3]. Understanding the anatomy and physiology of the animal species being studied is critical for performing an accurate and thorough necropsy. This education covers the basics of animal anatomy and physiology, including the major organ systems and their functions, as well as the techniques for performing a necropsy, such as proper dissection methods, tissue collection, and preservation [4, 5].

In necropsy education, it is crucial to teach ethical considerations and regulations governing the use of animals in research, including humane treatment, proper care, and the appropriate disposal of animal tissues [6, 7]. Trainees should also learn how to properly document and report their findings from the necropsy, using standardized terminology and preparing detailed reports [4].

According to the EU Directive 2010/63, Article 23(2), individuals responsible for handling and taking care of animals used for scientific purposes must have sufficient education and training before performing any procedures. The education and training should include knowledge about the 3Rs (refinement, reduction, and replacement) and alternative

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methods. To achieve this goal, the concept of "Virtual Reality (VR) in Biomedical Education" has been developed, effectively integrating VR elements with traditional learning content [8, 9].

Laboratory animal necropsy education can be provided through a variety of methods, including lectures, demonstrations, hands-on training, and online resources. It is important for institutions that use animals in research to provide comprehensive and ongoing education to ensure that all personnel involved in animal experimentation perform their duties in a responsible and ethical manner [10].

However, learning and teaching necropsy can be challenging due to the need for cadaveric specimens and limited access to training resources. Fortunately, advancements in technology have paved the way for innovative approaches to necropsy education. Such an approach has supported the creation of a new tool for education using 3D WebAR technology, which enables interactive and immersive learning experiences using web browsers and mobile devices.

Augmented reality (AR) is a technology that overlaps computer-generated images, videos, or other digital content, for example, 3D models, onto the real world, usually through a mobile device [11, 12].

WebAR is a type of augmented reality that can be accessed through web browsers on mobile devices and computers, without the need for a dedicated app or software. WebAR uses the camera and sensors of the device to overlay virtual 3D objects, which are modeled with software or created with photogrammetry with real textures, onto the real world, creating an interactive and immersive experience for the user. This technology has numerous applications in education, marketing, and entertainment, among others [13, 14].

Photogrammetry is the process of using photographs to generate accurate measurements of objects and the environment. This is achieved through the analysis of the relationships between the captured images, which allows the creation of 3D models or maps of the photographed subject [15–17].

In the context of laboratory animal necropsy, AR can be used to enhance the process by providing additional information and guidance to the pathologist or researcher performing the procedure. For example, AR can be used to overlay images of the animal’s internal organs onto the physical body, making it easier to identify and locate specific tissues or structures. AR can also be used to display detailed instructions or annotations on how to perform certain tasks during the necropsy, such as how to properly collect tissue samples or examine specific organs.

Using AR in laboratory animal necropsy education could improve the accuracy and efficiency of the procedure, providing a more engaging and interactive experience for researchers and students. Additionally, it could help reduce the number of animals needed for education by allowing for a more precise and thorough analysis of each individual animal.

In this paper, the benefits of 3D WebAR technology, including photogrammetry, for necropsy education are explored, highlighting how it can enhance the learning outcomes for veterinary students and professionals who use laboratory animals in their studies. The primary goal of using the app in teaching is to provide an engaging and interactive learning environment. The app aims to make learning more accessible and enjoyable through multimedia content, interactive exercises, and personalized learning paths. Another important goal is to gather feedback on the app’s user-friendliness. Understanding how students and teachers interact with the app helps identify areas for improvement, ensuring the app is intuitive and easy to use for all users. To the best of our knowledge, there have been no published studies evaluating the educational benefits of virtual WebAR-based mouse necropsy. Additionally, this article provides guidance for professionals interested in creating new AR applications, explaining how to implement this process in their own designs.

2 Materials and methods

2.1 Study design

Support was obtained from the experimental animal care and production center to carry out the study. All mice used were acquired and used according to the Balikesir University Experimental Animal Breeding Research Center’s own Institutional Animal Care and Use Regulation and conducted according to their guidelines. Deceased mice were obtained from this center for this study. These were Swiss albino male and female mice between 5–6 weeks old. Standardized necropsy procedures were performed, and a total of 10 scenes were scanned for AR. These 10 scenes formed the basis for the WebAR application.

2.2 Necropsy steps

The mice were brought to the necropsy room immediately for necropsy and the photogrammetric scanning process to avoid postmortem changes. Throughout the entire necropsy process, scissors, forceps, and scalpels of varied formats and sizes were used.

The first step involved fixing the mice to lie in dorsal recumbency. To do so, the paws were stretched outwards and secured onto the necropsy table with the help of a pin. The mice were placed on a styrofoam board, and a blue paperboard was used to facilitate photogrammetry (Fig. 1).

The second step involved making a shallow incision, opening the skins of the mouse to examine the subcutaneous tissues, lymph nodes, and breast tissue in females. At this stage, the peeled skin ends were pinned to the board.

The third step involved opening the abdominal cavity of the mice. The abdominal cavity is opened by performing a midline incision of the abdominal wall from the pubic symphysis to the xiphoid, through the linea alba to examining the abdominal organs. The abdominal wall was then retracted and fixed to the styrofoam board, providing a suitable environment for photogrammetry.

The fourth and fifth steps involved examining the abdominal viscera and performing the photogrammetry process. The digestive tract, with the liver and spleen, were removed from the abdominal cavity and combined into a 3D scene using photogrammetry. Additionally, the kidneys and urinary bladder were visualized. In females, the genital apparatus, including the uterus, the ovaries, the oviducts, and the vagina were also clearly visible at this stage.

In the sixth step, the thoracic cavity was examined by removing the ribs on both sides of the sternum, dorsal to the chondrocostal junction, and from the last rib to the first rib with scissors, and photogrammetry was performed to image the lung and heart tissue.

The seventh step involved examining the testicles of a male mouse for photogrammetry purposes. When the abdominal cavity is opened, the testes are often found in the pelvic cavity, close to the internal inguinal rings and at the sides of the bladder, they were removed, cutting the excretory ducts close to their opening into the urethra.

In the eighth step, the mouse was turned over and secured with the help of pins. Prior to opening the skull, the skin covering the skull was removed. To do so, the skin from the nose to the back of the head was completely peeled off, and the skin was stretched and fixed to the styrofoam board before starting the photogrammetry process.

In the ninth step, the calvarium was removed by separating the skull bones with a transversal section at the level of the eyes, followed by sections extending from both sides to the occipital bones to make the brain visible. Subsequently, photogrammetric processing was conducted.

In the tenth step, after removing the brain, an examination of the pituitary gland was conducted, followed by photogrammetry.

2.3 Photogrammetry

Photogrammetry is the process of using photographs to create 3D models or maps of objects or environments. The steps involved in photogrammetry are as follows:

The first was to take minimum 40 pictures using an iPhone 14 camera (any high-resolution digital camera can be used) from different angles around the cadaver during the necropsy stages of mice. The cadaver was rotated (Fig. 1) and photographed every 10 degrees approximately. During the photography process, meticulous attention was devoted to ensure comprehensive illumination of all anatomical regions of the cadaver. Meticulous care was exercised to ensure

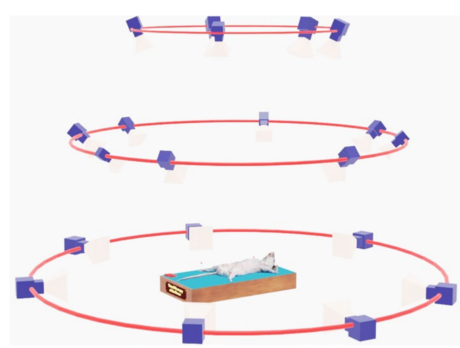

Fig. 1 A schematic image showing a series of overlapping photographs of a mouse in the first step of a necropsy. The result is a three-dimensional rendering of the mouse in various stages of necropsy

that the cadaver was properly focused on all photographs. Approximately 40 photographs were deemed sufficient to establish the context (Fig. 2). While aiming to minimize processing time, exceeding this quantity may prolong processing durations. The approach involves capturing multiple images of identical areas, aiming to maintain consistent angles. In instances where the initial 3D model exhibited deficiencies in accuracy, this was rectified through the acquisition of supplementary photographs.

Photos were collected into a folder on a MacOS computer. The "HelloPhotogrammetry" macOS app from "Creating a Photogrammetry Command-Line App" was used [18], and the folder of necropsy images added. The app transformed the images into a 3D model (Fig. 3). This model contained the texture of the cadaver, making it more realistic. After completing this step, the program exported the model in USDZ file format, ready for opening in AR on MacOS or iOS devices (Fig. 4). Subsequently, the USDZ format was converted to GLB, ensuring compatibility for use on Android devices and web browsers.

2.4 Preparing for augmented reality

The 3D model obtained through the photogrammetry process was initially generated using the "hellophotogrammetry" program on MacOS, optimized for functionality within the iOS and MacOS environments. However, to ensure compatibility with the Android platform, conversion to the GLB format is necessary. This conversion was facilitated using the open-source Blender [19] application (Fig. 5a), recognized globally for its capabilities in 3D modeling and animation. In Blender, the previously exported USDZ format of the 3D model was imported and subsequently exported in GLB format. Consequently, 3D models depicting necropsy scenes are now available in both GLB and USDZ formats, ready for integration into augmented reality applications.

2.5 WebAR design

A script known as the model viewer, developed by Google, facilitates the display of 3D models derived from photogrammetry and converted to GLB format. This script enables the presentation of these necropsy stage scene models in both computer browser-based 3D environments and augmented reality formats on mobile devices. The model viewer script serves as software designed specifically to showcase 3D models within websites or web applications optimized for mobile platforms.

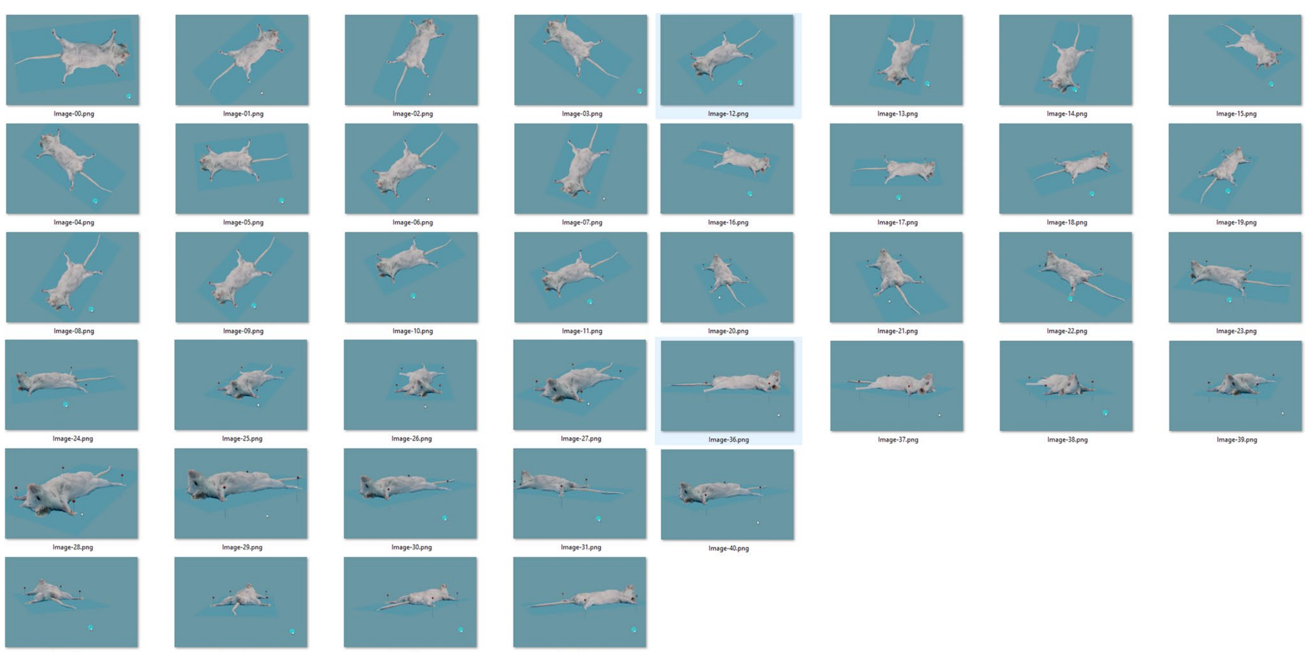

Fig. 2 Approximately 40 photos taken from different angles around the mouse cadaver during the first necropsy stage

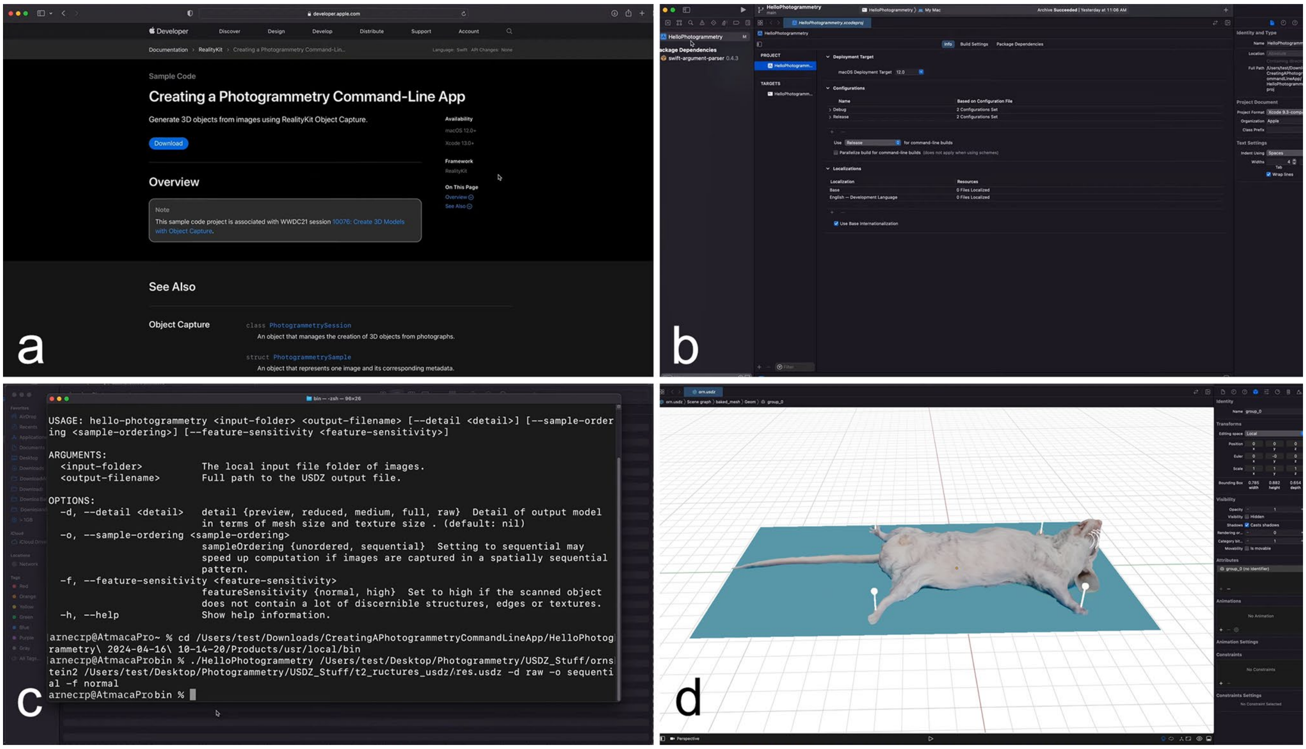

Fig. 3 Steps to render photographs into a 3D model. **a** Screen of the web page interface where the computer code was employed. **b** Folder arrangements visible upon launching the application. **c** Commands necessary for utilizing the code. **d** The resulting 3D model generated after implementing the code

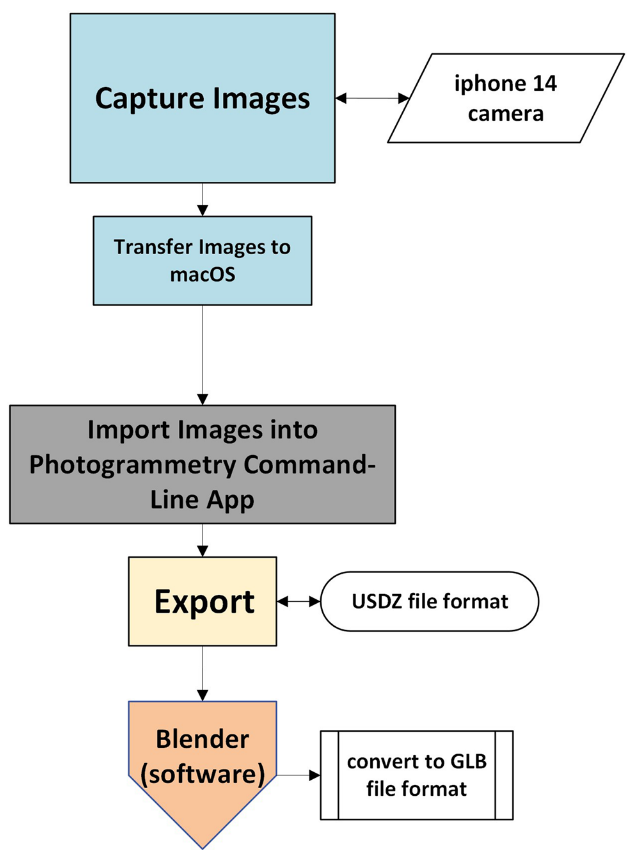

Fig. 4 The schematic image of workflow for Photogrammetry in MacOS computer, with steps on how to convert for use on multiple platforms

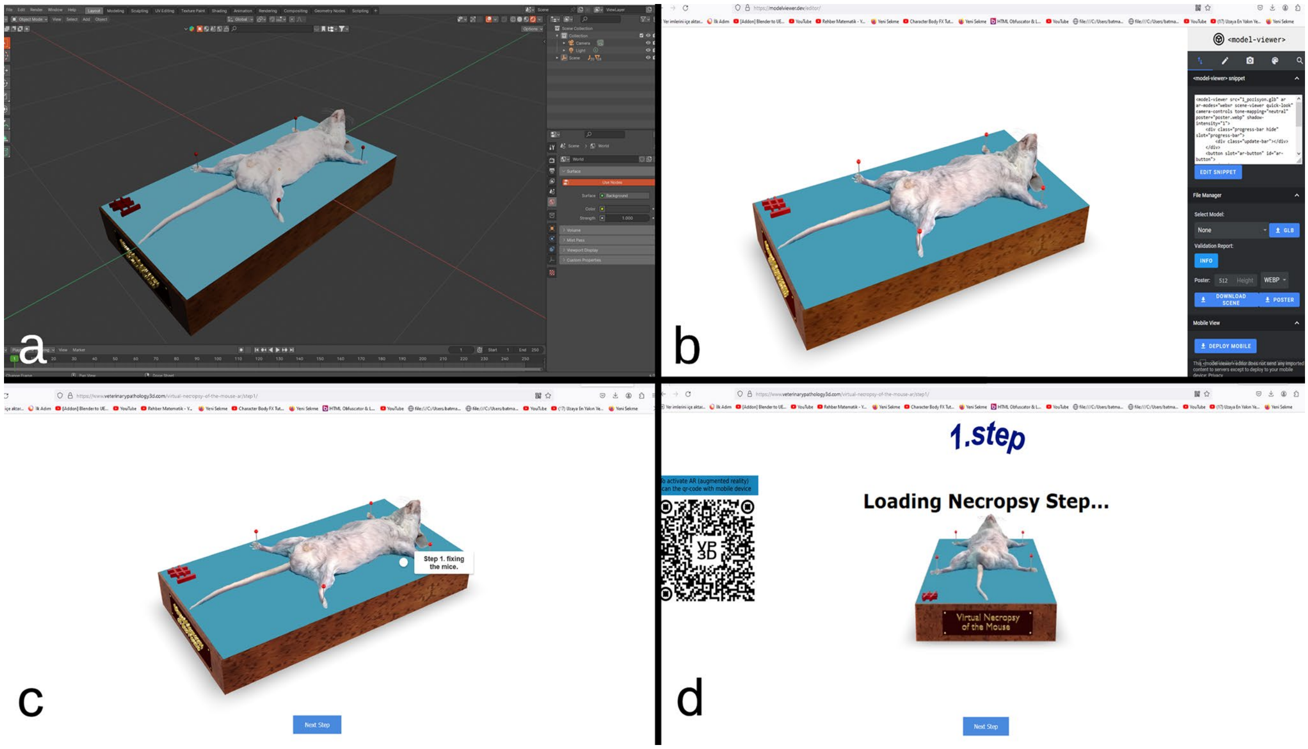

Fig. 5 **a** illustrates user interface of Blender software for convertor edit 3D models after created with photogrammetry tool. **b** displays the Model Viewer editor, to add annotations and deploy the code for AR. **c** running 3D model in web browser **d** QR code added for viewing the 3D model with mobile phones and running it as AR

After accessing the model editor website (https://modelviewer.dev/editor/) [20] and uploading the 3D necropsy scene models (ten steps) individually, the script is exported from the program (Fig. 5b). The exported file comprises an HTML page and corresponding scripts, which collectively constitute a suitable format for deploying the application online.

2.6 Publishing on web

The files generated from the model editor, which include HTML, CSS codes, and the 3D model obtained through photogrammetry during the mouse necropsy, were uploaded to our server hosted at our domain address (veterinarypathology3d.com) using File Transfer Protocol (FTP). FTP is a widely used standard network protocol for transferring files between a client and a server over a computer network, typically the internet. This process allows users to upload or download files to and from a remote server.

By uploading these files, the WebAR application becomes globally accessible to anyone accessing the internet address (Fig. 5c). In the browser version, the 3D model is visible, while users accessing the domain from their mobile devices can view and interact with the 3D models in augmented reality (AR) (Fig. 5d).

2.7 Designing a survey

In the evaluation conducted, it was posited that the adoption of the tool could serve as a valuable instrument in developing a satisfaction survey tailored to students. This initiative aimed to streamline the collection of comprehensive feedback and illuminate nuanced insights into their academic experiences. The survey objectives were defined, and an online survey platform (Google Forms), was utilized to construct the survey questions.

The study encompassed 58 interns in veterinary medicine who were nearing graduation and participating in a pathology intern practice course. These students were surveyed to evaluate the efficacy of the WebAR mouse necropsy education application or to provide additional feedback. Each participant accessed the Webapp individually on their personal devices. Upon completing approximately 2 h per week over a span of 2 weeks within the pathology intern practice course, participants were invited to participate in the survey.

The survey design and administration were conducted with careful consideration for students' time and privacy. The survey's purpose was clearly communicated, responses were anonymized, and incentives for participation were provided. The survey questions were structured as follows:

1. Does WebAR facilitate the perception and understanding of necropsy education?
2. Does virtual mouse necropsy save time needed to learn real necropsy?
3. How convenient and user-friendly is the virtual mouse necropsy WebAR application?
4. Do you think this WebAR application has any drawbacks?
5. Would you venture to implement AR in the future education using all the methodology described in this article?

Following the collection of survey responses, data analysis was undertaken qualitatively to identify discernible patterns and trends. These findings are valuable for informing future researchers to develop focused and rigorous assessments of the pedagogical impact associated with these educational models.

3 Results

Ten 3D mouse necropsy step scenes, with a total file size of 227 MB, were created with photogrammetry and used as an asset in a WebAR application.

These scenes in 3D models with AR feature were uploaded to the internet server.

Afterwards, the website was immediately activated and can now be accessed at https://www.veterinarypathology3d.com/virtual-necropsy-of-the-mouse-ar/

Users can view all the necropsy steps, including annotations and information, as an augmented reality ready model on desktop browsers from any computer. Users have the option to view the same model on mobile devices, and they can choose to activate the augmented reality (AR) feature by scanning qr-code on webapp, to project the model onto a real-world surface background. Data is provided at GitHub repository "https://github.com/veterinarypathology3d/webar/tree/gh-pages/necropsy".

Figure 6 shows the survey result in 100% stacked column chart. The survey results depict the responses of 58 students to five different queries.

For Query 1 (Does WebAR facilitate the perception and understanding of necropsy education?): A significant majority, 56 out of 58 students (96.55%), responded "Yes". Only 2 students (3.45%) responded "No".

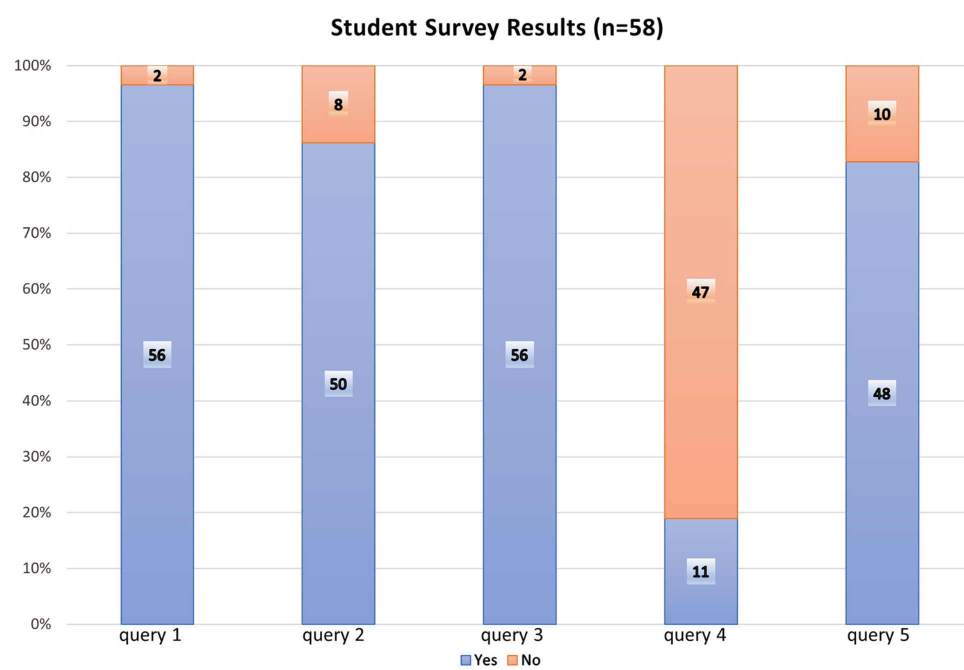

Fig. 6 Student survey result graphic (100% stacked column chart). Total 58 student participated in the survey. Query 1: Does WebAR facilitate the perception and understanding of necropsy education? Query 2: Does virtual Mouse necropsy save time needed to learn real necropsy? Query 3: How convenient and user-friendly is the virtual Mouse necropsy WebAR application? Query 4: Do you think this WebAR application has any drawbacks? Query 5: Would you venture to implement AR in the future using all the methodology described in this article?

For Query 2 (Does virtual mouse necropsy save time needed to learn real necropsy?): A majority of 50 students (86.21%) responded "Yes". 8 students (13.79%) responded "No".

Query 3 (How convenient and user-friendly is the virtual mouse necropsy WebAR application?): A very high majority, like Query 1, with 56 students (96.55%) responding "Yes". Only 2 students (3.45%) responded "No".

Query 4 (Do you think this WebAR application has any drawbacks?): This query stands out as the only one where the majority of students responded "No". 47 students (81.03%) responded "No". Only 11 students (18.97%) responded "Yes".

Query 5 (Would you venture to implement AR in the future education using all the methodology described in this article?): A strong majority of 48 students (82.76%) responded "Yes". 10 students (17.24%) responded "No".

Two participants answered "no" to query 1 and 3.

The student who answered "no" to the second question stated that doing a real necropsy was more instructive, and that they could not say anything about saving time without doing a real necropsy.

The student who answered "yes" to the 4th question said that the disadvantage of the application was the absence of anatomical annotations on 3D models. As a result, we added annotations on the organs to be displayed on the application. We made these annotations with Model viewer's model editor application.

Ten students who said "no" in question 5 stated that these 3D applications were useful, and they would use it, but they were not enthusiastic enough to develop a new application. Other students (n = 48) stated that they believed that they could also make small-scale applications by applying the methodology written in this article step by step.

4 Discussion

The survey indicates overall high satisfaction with the application, with specific areas requiring attention. Most students responded positively to most queries (Queries 1, 2, 3, and 5), indicating that they find the application useful. High satisfaction rates suggest the application is meeting many students' needs. A sample size of 58 participants could indeed limit the generalizability of findings, particularly if the population being studied is diverse or heterogeneous. Despite efforts to ensure diversity within the sample, the small size may introduce biases and hinder the broader applicability of the results. In future research, increasing the participant size could help address these limitations and enhance the validity and generalizability of the findings.

Various scientists and researchers from various fields use laboratory animals in scientific research. Some of the fields that commonly use laboratory animals including biomedical research, toxicology, genetics, behavioral research, neuroscience, environmental research. Education is very important in the use of experimental animals in this wide field of work. Certification for working and using experimental animals includes necropsy training. Necropsy in experimental animals is a task that requires attention and importance. Formal necropsy of animals allows for accurate examination of tissues and proper collection of tissue samples for further examination [21, 22].

In this study, each necropsy stage in the mouse, the most used animal in biomedical research, was made into a 3D model and converted into an interactive WebAR application for education and training. The workflow methodology has been outlined for the creation of a dual web-based and AR application. This application utilizes widely adopted open-source software and public WebGL codes, ensuring smooth functionality. The interactive WebAR application is designed to serve as an additional educational resource tailored for scientists engaged in experimental studies involving mice.

Laboratory animal necropsy education can be provided through a variety of methods, including lectures, demonstrations, hands-on training, and online resources. It is important for institutions that use animals in research to provide comprehensive and ongoing education to ensure that all personnel involved in animal experimentation perform their duties in a responsible and ethical manner. There are several software programs include Virtual microscopy software, 3D modeling software, Anatomical atlases, Laboratory information management systems (LIMS), Electronic data capture (EDC) systems that can be used in laboratory animal necropsy education to enhance the learning experience for students and professionals. The use of software in laboratory animal necropsy education can help to enhance the learning experience for students and professionals, providing new ways to explore and understand the anatomy and physiology of animals.

Haser et al. [23] aimed to explore the preference and effectiveness of a laboratory animal science (LAS) course blended with video lectures. The course was structured to accommodate a range of student backgrounds, encompassing varying levels of education, and experience related to the utilization of animals. The results showed that most of the participants were satisfied with the blended course, especially the hands-on components. The study concludes that a blended LAS course with video lectures can effectively meet students' needs, providing a sustainable educational experience during both stable and unpredictable times. In this study, it can be concluded that the 3D WebAR necropsy application shares analogous features with those observed in the laboratory animals course, consistent with findings reported by Haser et al. [23].

Lemos et al. [8] conducted a comprehensive study to assess the efficacy of virtual reality (VR) teaching and learning modules as an alternative to traditional live demonstrations, with the objective of better preparing individuals for hands-on training. The study found that VR modules were effective in significantly reducing the number of animals required for hands-on skills training. These modules were highly valued by participants, including those with minimal prior experience with VR technology. Furthermore, individuals with a background in laboratory animal science exhibited greater confidence in the potential of VR to support the 3R principle (Replacement, Reduction, and Refinement) and endorsed its continued use for educational purposes. The study's findings indicate that VR technology holds substantial promise for transforming and diminishing the reliance on animals in experimental animal courses.

The satisfaction survey administered to the students yielded notably positive results. At least 75% of the participants expressed satisfaction with the WebAR application, underscoring the program's popularity and effectiveness among the student cohort. This positive feedback provides crucial insights for the further enhancement of the program.

This study explores the integration of augmented reality (AR) technology as an innovative component in the training of laboratory animal necropsy. Although the research focused on mice, the same methodologies would apply if the study were conducted using rats or other laboratory animal species.

Augmented reality (AR) is a technology that superimposes computer-generated images, videos, or other digital content onto the real world, typically through a mobile device or headset [24]. While creating the AR, 3D mouse models were generated at different necropsy steps using the photogrammetry technique to ensure realism. Photogrammetry provides a non-invasive, accurate, and cost-effective way to capture the shape and size of anatomical structures, which can be used in a variety of medical applications [16, 17, 25].

Petriceks et al. [25] suggest that according to their photogrammetry anatomical study, photogrammetry is a reliable and easily accessible method for creating digital 3D models. They suggest that this method can be used to create digital libraries of 3D anatomical specimens, which would be valuable in regions or institutions where cadavers or prosections are unavailable [25]. With this study, 2D quality photos were combined with the 3D model to create a photorealistic 3D model. Both techniques have been combined in a single point as real image and 3D model. In our previous study, pathological lesions were defined only through the 3D model, but even if it was done in good design, it could not be like the 3D model consisting of real photographs as it is now [11]. Photogrammetry shows its advantage at this point using a virtual model made entirely of real images. This feels more realistic to the user [26].

Employing 3D augmented reality to teach mouse necropsy is anticipated to yield several advantages.

Enhanced visualization: Augmented reality can allow users to visualize the mouse anatomy and necropsy procedure in a more interactive and realistic way, which can improve their understanding and retention of the information.

Increased accessibility: With an augmented reality web application, students can access the necropsy tutorial from anywhere with an internet connection, without the need for physical specimens or specialized equipment.

Improved safety: By using augmented reality, students can learn the necropsy procedure without handling real animal specimens, which can reduce the risk of exposure to potentially infectious materials or hazardous chemicals.

Increased engagement: Augmented reality can make the learning experience more engaging and interactive, which can increase student motivation and participation in the learning process. Using AR technology can also help to reduce the need for animal dissection, which can have ethical and safety considerations for both the students and the animals involved.

Regulatory compliance: Many countries and organizations have regulations and guidelines in place that govern the use of animals in research [27]. Proper training in necropsy practices can help to ensure that researchers follow these regulations and can help to prevent legal and ethical issues related to animal experimentation.

Using augmented reality (AR) technology in necropsy education has the potential to revolutionize the way trainees learn and improve a practice skills. Traditionally, necropsy education has relied on textbooks, lectures, and hands-on experience with animals [1, 5]. However, AR technology can provide a more immersive and interactive learning experience that allows users to visualize complex anatomical structures and medical concepts in a way that is not possible with traditional teaching methods [24]. It can enhance the learning experience, improve trainees engagement and retention, and provide a safer and more accessible alternative to traditional methods. AR-based necropsy education can help trainees learn more efficiently and effectively by providing them with a realistic [24, 28] and interactive environment that simulates real-life situations.

Moreover, AR technology can also help trainees better understand the mouse anatomy by allowing them to visualize structures in three dimensions. This can be especially beneficial for trainees who struggle to understand complex concepts through traditional teaching methods. We believe that augmented reality has the potential to enhance necropsy education by providing a more immersive and interactive learning experience that can improve trainees necropsy skills and enhance their understanding of necropsy procedures.

In addition to these practical benefits, AR also has the potential to make learning about animal anatomy and necropsy more engaging and enjoyable for students. Studies have shown that immersive technologies such as AR can increase motivation and engagement in learning [29]. By providing interactive and realistic experiences, AR can help students develop a deeper understanding of animal anatomy and necropsy and can inspire a lifelong interest in these subjects.

In conclusion, augmented reality has the potential to revolutionize the teaching of animal anatomy and necropsy by providing a cost-effective, non-invasive, and engaging learning tool. By allowing students to explore the internal structures of animals and practice necropsy skills in a virtual environment, AR can enhance traditional learning methods and inspire a lifelong interest in all biomedical research field and veterinary medicine.

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Author contribution HTA designed the study including all 3D scans and modeling and making them available on the web and wrote the manuscript.

Data availability Data is provided at GitHub repository "https://github.com/veterinarypathology3d/webar/tree/gh-pages/necropsy". Link is provided within the manuscript Result section.

Declarations

Ethics statement The study did not require ethical approval because no sensitive personal information was collected for survey. And all mice we used were acquired and used according to the Balikesir University Experimental Animal Breeding Research Center's own Institutional Animal Care and Use regulation and conducted according to theirs guidelines. The animals used were already deceased and obtained from a legal source, and no live animals were used in the study. The study was exempt from ethical approval because it involved the use of animal tissues or samples that were obtained post-mortem.

Conflicts of interest The authors declare no competing interests.

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