Anatomy Builder VR: Embodied VR Anatomy Learning Program to Promote Constructionist Learning

Jinsil Hwaryoung Seo
Brian Michael Smith
Margaret E. Cook
Soft Interaction Lab
Department of Visualization
Texas A&M University
College Station, TX 77843, USA
hwaryoung@tamu.edu
brimism@gmail.com
atmgirl@email.tamu.edu

Erica R. Malone
Michelle Pine
Department of Veterinary
Integrative Biosciences
Texas A&M University
sassa-fras27@tamu.edu
mpine@cvm.tamu.edu

Steven Leal
Soft Interaction Lab
Department of Computer
Science
Texas A&M University
steven2gleal@tamu.edu

Zhikun Bai
College of Veterinary Medicine
Northeast Agricultural University
Harbin, 150030, China
252711172@qq.com

Jinkyo Suh
532 Southwest Parkway
College Station, TX 77840, USA
loveelegans@gmail.com

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CHI'17 Extended Abstracts, May 06-11, 2017, Denver, CO, USA
ACM 978-1-4503-4656-6/17/05.
http://dx.doi.org/10.1145/3027063.3053148

Abstract
We present Anatomy Builder VR, a program that examines how a virtual reality (VR) system can support embodied learning in anatomy education. The backbone of the project is to pursue an alternative constructivist pedagogical model for learning canine anatomy. The main focus of the study was to identify and assemble bones in the live-animal orientation, using real thoracic limb bones in a bone box and digital pelvic limb bones in the Anatomy Builder VR. Eleven college students participated in the study. The pilot study showed that participants most enjoyed interacting with anatomical contents within the VR program. Participants spent less time assembling bones in the VR, and instead spent a longer time tuning the orientation of each VR bone in the 3D space. This study showed how a constructivist method could support anatomy education while using virtual reality technology in an active and experiential way.

Author Keywords
Anatomy education; virtual reality; constructive method; canine anatomy.

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

Introduction

Anatomy education is fundamental in life science, health education, dance, and visual arts. In anatomy education, it has been traditionally believed that cadaver dissection is the optimal teaching and learning method [1]. Cadaver dissection definitely does provide tangible knowledge of the shape and size of the organs, bones, and muscles. However, dissection offers only a subtractive and deconstructive perspective (i.e. skin to bone) of the body structure. When students start with the complexity of a complete anatomical specimen, it becomes visually confusing and students may have a hard time grasping the underlying basic aspects of the anatomical form [2]. Consequently, many students have difficulties when mentally visualizing the three-dimensional (3D) body from the inside out (i.e. bone to skin), as well as how individual body parts are positioned relative to the entire body. Recently, new visualization techniques including virtual and augmented reality have shown great potential in learning and training. However, most of them still only provide simple navigations of the structure, and do not support students' active manipulation of anatomical contents to promote 3D spatial understanding [3].

We investigated how virtual reality environments with hand controllers may benefit students' learning in canine anatomy. This paper presents Anatomy Builder VR, a program that allows users to put bones together in the layout that they would be in a live animal. A pilot study was performed with 11 undergraduate students, to explore how students can learn canine limb skeletal models using a traditional bone box, as well as a virtual reality system.

Learning Materials in Anatomy Education

Current students spend most of their study time memorizing anatomical terms shown in two dimensional (2D) graphics in a textbook [10]. These graphics are useful for structure identification via rote memorization, but students are rarely able to use them to accurately demonstrate a movement that results from specific muscle contraction [11, 12] or to understand the spatial relationships between structures. Unfortunately, even with the availability of 3D interactive tools, mentally visualizing movement remains problematic for many students. They are expected to mentally manipulate 3D objects using information learned from 2D representations [13]. Individuals pursuing careers in areas such as orthopedic surgery, physical therapy, choreography, or animation require a deeper understanding of structure/function relationships. They need to know the muscle's normal action at a joint, its interaction with other muscles, and finally the motor deficits that result from injury to said muscle. This level of complexity is not easily conveyed via 2D static representations. Therefore, further exploration into effective anatomical pedagogy is definitely warranted [14].

Multiple digital anatomy resources, including 3D virtual reality [4, 5], have been developed to supplement dissection. They mainly focus on identification of anatomical components and passive user navigation. In addition, they don't provide a flexible learning environment that allows a student to make a mistake and then learn from it. The following alternative learning materials with constructivist approaches have been introduced in anatomy education: 3D printing [6, 7] and other physical simulation techniques [8, 9]. However, these alternative methods also have

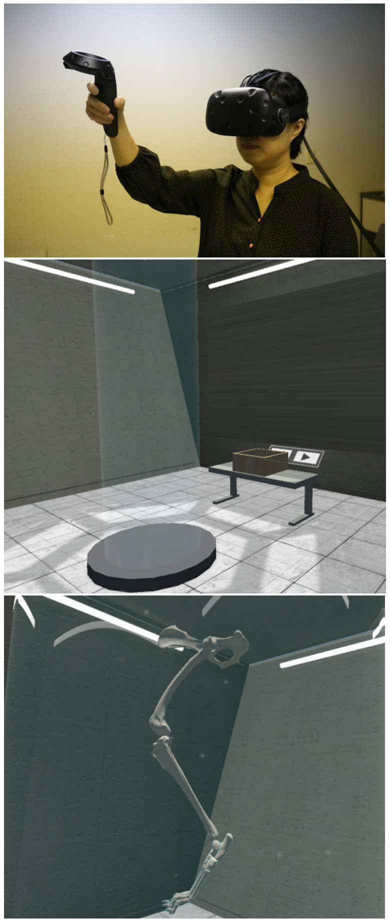

Figure 1. (top) HTC Vive, (middle) Anatomy Builder VR environment, (bottom) Assembled pelvic limb

limitations: it is difficult to create an anatomical model that creates movement, interactions are limited, and a single model can only present limited information.

Constructionist Learning Materials in Anatomy Education

According to the constructivist learning theories, learning is a personal construction resulting from an experiential process. It is a dynamic process, a personal experience that leads to the construction of knowledge that has personal meaning [9]. With the advancement of new technologies, virtual reality systems enable users to interact directly with anatomical structures in a 3D environment. This raises a new question: does manipulating the anatomical components in a virtual space support the users' embodied learning and ability to visualize the structure mentally?

Rapid prototyping including 3D imaging, 3D printing and other physical simulation techniques have been recently highlighted in anatomy education [6, 7]. In the last two decades, 3D printing has been successfully utilized in different medical fields, including education. In anatomy, high-quality 3D printed relicas of cadaveric material were recently produced for teaching purpose. Clay modeling provides an interesting approach to learning anatomy and is a technique that has also been examined in recent studies. Studies [8, 9] have suggested that clay modeling can provide an effective supplement to traditional lecture-based teaching and may be more engaging for students than preserved specimen dissection.

Our goal is to develop a virtual reality learning environment that supports a constructivist learning approach and a flexible learning environment. This environment allows a student to make/manipulate a skeletal system using a digital bone box, as well as learn from any mistakes made throughout that process. The recent development of hand movement tracking ability in virtual reality has allowed us to implement this idea.

Anatomy Builder VR

Anatomy Builder VR (Figure 1) is an ongoing project that examines how a virtual reality system can support embodied learning in anatomy education. The backbone of the project is to pursue an alternative constructionist pedagogic model for learning canine anatomy. Direct manipulations in the program allow learners to interact with either individual bones or groups of bones, to determine their viewing orientation and to control the pace of the content manipulation.

System Description

The Anatomy Builder VR program utilizes the HTC Vive virtual reality platform. The platform comes with a high definition head-mounted display (HMD), two motion controllers, and two infrared tracking stations. The project has been developed in Unity3D. All scripting is done in C#. Unity's development environment allows for easy integration of the Vive with pre-built scripts and API. This allowed us to rapidly develop a functioning prototype and begin design on the user specific interactions. Interaction with the virtual environment is primarily done with the Vive controllers. The controllers have several buttons that are available to be programmed for various interactions.

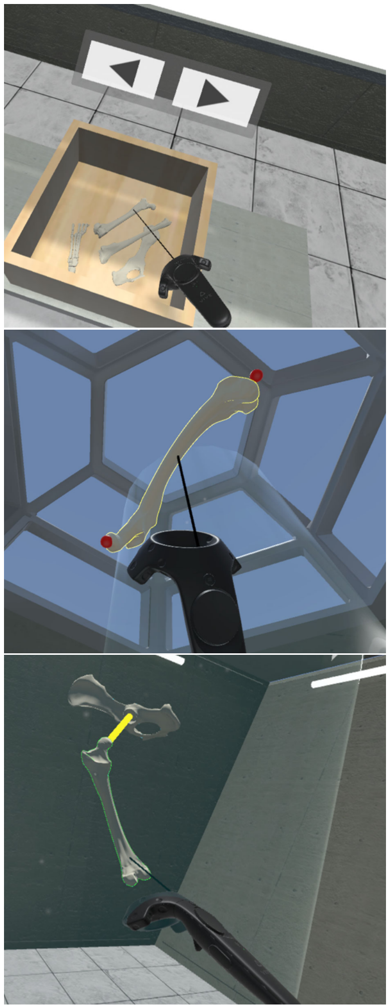

Figure 2. (top) picking a bone using a Vive controller, (middle) transforming of a bone, (bottom) Snapping bones

Interaction Tasks in Anatomy Builder VR

In the current version of the program, a student can assemble a canine pelvic limb. Within the Anatomy Builder VR environment, there is an "anti-gravity" field where the user can assemble the skeleton. Interaction tasks for Anatomy Builder VR includes:

- *Recognition of bones*: Providing all viewing angles is crucial for the identification of objects. Therefore, natural head movement is required to be able to inspect individual objects (Figure 2 top).
- *Selection of bones*: The selection of virtual bones is the prerequisite for 3D interaction. Placing a bone in the anti-gravity field suspends it in place (Figure 2 top).
- *Transformation of bones*: The transformation task includes translating and rotating 3D objects. Since this is the tasks the student is required to spend most of the time on, the success of learning the spatial relations highly depends on the selected interaction techniques (Figure 2 middle).
- Snapping of bones: Selecting and transforming a set of 3D bones is a process to assemble bones at the right positions. Picking up another bone and placing its joint near a connection on the already field-bound bone will make a yellow line appear. When the user let go of the controller trigger, the two joints snap together. The user repeats this action until the skeleton is assembled to satisfaction (Figure 2 bottom).
- *Locating Reference materials*: Appropriate reference material (2D, 3D, or text) to complete the articulation of the limb are presented where the user wants using a non-dominant controller (Figure 3).

Pilot Study

In the pilot study, we investigated how a virtual reality system with direct manipulation may affect learning anatomy in comparison with a traditional bone box method. The main focus of the study was to identify and assemble bones in the same orientation as they would be in a live dog, using real thoracic limb bones in a bone box and digital pelvic limb bones in the Anatomy Builder VR program. For the purpose of the study, we recruited 11 undergraduate students aged 19 to 26. Their majors were from departments across the university and they had never taken a college level anatomy class before. The order was counterbalanced such that 6 of the students started with the bone box first and then virtual reality, and 5 of them started with virtual reality and the bone box later. The students were surveyed for responses before the study began, after each activity, and at the end of the study period.

During the bone box activity, the participant was given a set of directions, and a box containing the bones of the canine thoracic limb. In the other activity of the study, the participants were given a brief introduction to how a VR system worked, and then fitted with the Vive helmet and controller. Upon entering the VR anatomy program, the student was given time to become comfortable with the controls before beginning the tasks. Within the VR space was a screen with slides for directions, an "anti-gravity field", and a box containing the bones of the canine pelvic limb.

Results

On average, each participant spent 6.3 minutes with the bone box and 7 minutes with the VR system. The participants' experiences with the VR system were very positive. In the surveys, most of participants (90.9%)

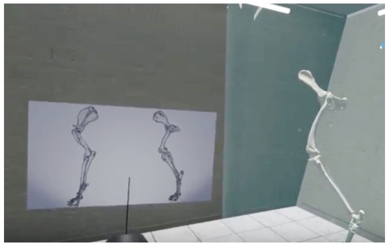

Figure 3. Reference on the non-dominant hand controller

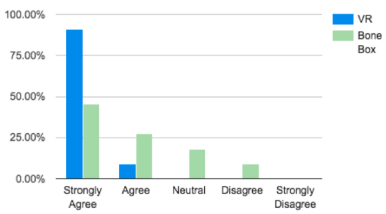

Figure 4. Assessment of overall enjoyment of each learning method

rated as *Strongly agree* for the statement, "I enjoyed using virtual reality to complete the activity." and 9.1% as *Agree*. With the traditional bone box, 45.5% assessed the same question with *Strongly agree*, 27.3% as *Agree*, 18.2% as *Neutral*, and 9.1% *Disagree* (Figure 4).

In terms of identifying bones, participants' ratings were very similar: 45.45% as *Strongly agree*, 45.45% as *Agree*, and 9.1% as *Neutral* for the VR session; 45.45% as *Strongly agree*, 36.35% as *Agree*, and 18.2% *Neutral* for the bone box session. Using this method with a constructivist focus, 63.6% of the participants responded as *Agree* on the statement, "I was able to manipulate bones and put them together with ease in VR", 27.3% responded as *Strongly agree* and 9.1% responded as *Neutral*. However, 36.4% participants responded as *Strongly Agree*, 36.4% as *Agree*, and 27.2% as *Disagree* (Figure 5) for bone box.

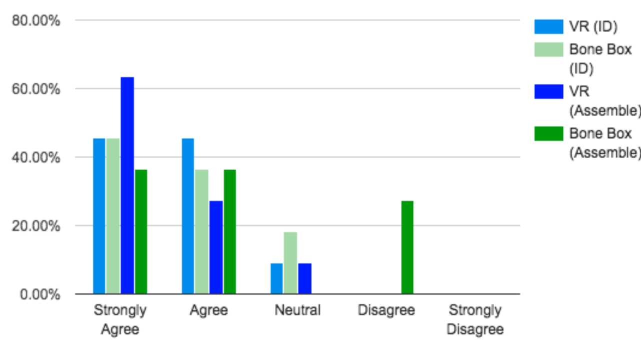

Figure 5. Assessment of identifying bones and assembling bones with each learning method

In the written responses, some participants expressed difficulties in finding details on the bones (ID06), as well as rotating a bone with a controller (ID05). Others expressed positive aspects of using the direct manipulation method in Anatomy Builder VR:

> *"I knew where joints were supposed to fit in the virtual environment since they would snap making it easier for me and making me feel more confident in completing the activity." (ID 09)*

> *"...being able to leave the bones in a specific orientation in VR was a good compromise for me mentally, because I didn't have to continually revisit each bone or use energy holding them in the right place two at a time." (ID 10)*

> *"It actually made it easier because I was able to better manipulate the bones because they were held up "in space." Also, it made more sense when the bones "connected" to each other." (ID 11).*

Discussion and Conclusion

We were interested in investigating how a constructivist learning method in VR can benefit anatomy education, while focusing on direct manipulation of bones. The pilot study showed that participants most enjoyed directly interacting with anatomical contents within the VR program. More particularly, participants enjoyed putting a skeletal system inside of the anti-gravity field because the same setup was not possible with the traditional bone box method. Participants spent much less time assembling bones in the VR but they spent a much longer time tuning the orientation of each bone in the 3D space. During the bone box activity, most of them didn't adjust the model after they finished placing bones on the table. The Anatomy Builder VR program provided a 'sandbox place' to novices so that participants actually enjoyed placing bones into an imaginative skeleton. Even though we were only able to study with a pelvic limb in the VR system, this study showed how a constructivist method could support anatomy education while using virtual reality technology in an active and experiential way. We are extending the understanding of virtual reality design for anatomy education. In the future, Anatomy Builder VR will include muscle systems and an even richer environment for self-evaluate and collaboration.

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