Using Virtual Reality & Ontologies to Teach System Structure & Function: The Case of Introduction to Anatomy

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Abstract

This paper explores the use of virtual reality and ontologies to help learners understand the structure and function of highly complex systems, such as the human body; cars, ships, or airplanes; and buildings. This approach to learning and instruction engages different parts of the learner's mind – visual-spatial processing and conceptual processing – for a total learning experience leading to a comprehensive understanding of the system – the spatial arrangement of its components and the nature and function of each component. This approach has been discussed in several disciplines, including medicine, mechanical engineering, and architecture, using ontologies such as the Foundational Model of Anatomy (FMA) (http://si.washington.edu/projects/fma). The paper presents examples, such as from anatomy: Show a skeleton visible to the learner in 3D just if it was standing there; the learner can take out a bone and examine it more closely. Add muscles, vessels, nerves, organs. Using knowledge from FMA, label and visualize body components, for example: Label each bone with a number that reflects its position in the FMA body part hierarchy. Highlight bones in a region of the body, such as the right foot. Use colors or other means to highlight and visualize components of the body by any of the classifications in the FMA: Concrete body parts (specific structural elements of the body such as the heart, the left lung), Classes of body parts (serous membrane, muscle, nucleated cell, limb), Body substances (fluids and other non-structural physical entities). Spatial concepts (anatomical planes, directions, and patterns, as well as immaterial spatial entities such as surfaces and spaces), High-level body systems based on physiological function (such as the cardiovascular system, endocrine system). These are also concepts students learn about in introductory courses such as Harvard' s Human Anatomy and Physiology I (https://canvas.harvard.edu/courses/4063/assignments/syllabus). In conclusion, the paper presents some general principles identified from the literature across several disciplines, including medicine, mechanical engineering, and architecture.

Keywords: *Learning and instruction, Virtual reality, Ontologies, visual-spatial processing, conceptual processing*

1. Introduction

Using *human anatomy* as an example, we explore the synergistic combination of virtual reality for visual-spatial processing and of ontologies for conceptual processing to help learners form a comprehensive, integrated mental image of the structure and functions of highly complex systems, such as the human body, mechanical devices (cars, airplanes, etc.), and buildings.

Anatomical knowledge is important for practice in all branches of the health sciences. It "supports examination of a patient, forming a diagnosis and communicating the findings to the patient and other medical professionals, performing surgical and other invasive procedures; examining radiological imaging; referring a patient to another doctor; or explaining a procedure to a patient." [1], shortened. Anatomy is also essential for researchers in biomedical sciences, anthropology, and more. Basic anatomy is important in elementary and secondary education to advance medical literacy.

The objectives of anatomy education have expanded from classical training in anatomy, development, and evolution to also providing students with knowledge and skills pertaining to structural variations across individuals and to functional relationships of the anatomical structures, and clinical applications. Given the scope of the content and the importance of learners going beyond rote learning of body parts to an integrated understanding of body structure and functions, developing educational techniques that will advance anatomy education learning outcomes is becoming ever more important.

Virtual reality in education offers opportunities to teach hands-on material in resource-limited environments and to support diverse learning styles. Labeling 3D images with ontology concepts and showing the ontology structure. makes virtual reality an even more powerful tool.

In the remainder of this paper we discuss 2 virtual reality and ontologies in anatomy education and the synergy of visual-spatial processing and conceptual processing in understanding systems, 3 computer imaging to support learning, and 4 learning outcome assessment. Section 5 concludes.

2. Virtual Reality and Ontologies in Anatomy Education

2.1 Virtual Reality (VR). Visual-Spatial Processing, Visualization, Manipulation

There is a considerable literature on using VR in anatomy education and a number of products at various levels of technology. [2-6] True virtual reality using special headsets (not cheap) affords realistic 3-D views. You can see a skeleton in front of you. You can use your hands to take a bone from the skeleton (without the skeleton collapsing) for closer examination. You can add muscles, vessels, nerves, organs. The following images give a weak impression of what is possible

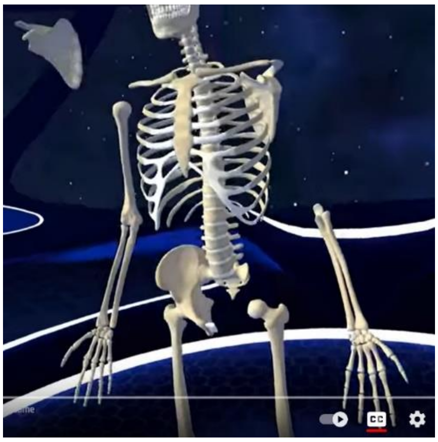


Fig. 1a. VR Skeleton
youtube.com/watch?v=zAtnKZ-i4LY

Fig. 1b. VR Skeleton, part removed for inspection
www.medicinevirtual.com/img/vm-dicom-movie.mp4

2.2 Ontologies. Conceptual Processing, Mental Structures

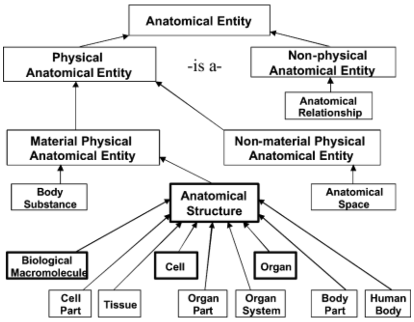
There is not as much literature on using ontologies to convey the conceptual structure of anatomy. [3-4], [7]. Our example is the widely used *Foundational Model of Anatomy* (FMA) [8-10]. Fig. 2 gives a sense of the overall structure of FMA. The conceptual space laid out in the FMA helps students to form a mental image of the structure of the body relating several perspectives. While the conceptual structure of the FMA is very well thought out, the terminology could be made more learner-friendly and the concepts in the hierarchy could presented in a meaningful hierarchy and given hierarchically expressive numbers (as found, for example, in the Medical Subject Headings) to produce a l*earner's version* of the FMA.

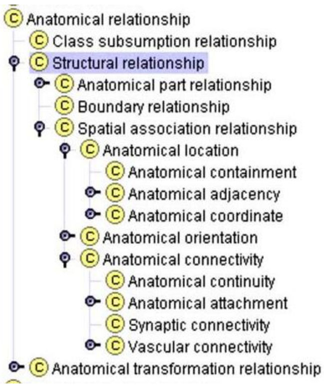
2.3 Anatomy Course Learning Objectives and Topics mapped to FMA [11-12]

The example mappings in Fig. 3 illustrate how FMA concepts correspond to topics covered in anatomy courses.

2.4 Synergistic Conceptual and Visual-Spatial Processing

This approach to learning and instruction engages different parts of learner's mind ─ visual-spatial processing and conceptual processing ─ for a total learning experience leading to a comprehensive understanding of the system ─ the spatial arrangement of its components and the nature and function of each component. The combination of virtual reality (VR) and ontologies uniquely affords learners a synergistic application of conceptual and visual-spatial processing to achieve learning outcomes beyond what each can accomplish on its own. Conceptual processing is incorporated into the learning process by showing conceptual structures alongside the VR images that embody these structures: The immersive nature of VR enables learners' cognition to move from representational to conceptual learning, characterized by a process of structural modifications to the learner's conceptual framework as a result of new experiences and information [13]. The immersive, interactive environment provided by VR promotes the construction of deep conceptual knowledge. A learning environment that offers learners control of virtual objects maximizes learning potential through the autonomy granted to learners by means of physical interactivity, a unique benefit when compared to a non-immersive, decontextualized learning activity. When learners using VR interact with objects in virtual space, deeper learning through visual-spatial processing can occur: motion-produced information caused by interacting with objects in VR provides valuable insights regarding objects' spatial orientation and relation to one another in the virtual environment [14]. Interactive VR learning environments incorporate conceptual and visual-spatial processing synergistically to support deep learning through grounding knowledge through learners' physical participation and interaction with their environment [15].

<table>
<tr><th>Entity types</th><th>Relationship types</th></tr>
<tr><td>


Schematic representation of the principal classes of the FMA taxonomy.
[8], left: Fig. 4, p. 486), right: ([8] Fig. 8, p. 491)
</td><td>


"describe the transformation of anatomical entities during the ontogeny of an organism".(p. 481)
</td></tr>
<tr><td colspan="2">Fig. 2 The overall structure of FMA</td></tr>
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FMA concept (examples)	**Course objective or topic [11-12]**
organ system	List the organ systems of the human body and their major components.
Organ systems are arranged in order of increasing complexity and integrative function	
. musculoskeletal system	. Identify the individual bones and their location within the body. . Identify skeletal, cardiac and smooth muscle. . Describe the structure, location in the body and function of skeletal, cardiac and smooth muscle.
. integumentary system	. Describe the general functions of the skin.
. cardiovascular system	Describe the interaction of the cardiovascular system with other body systems
. respiratory system	List the major functions of the respiratory system
. alimentary system	List and describe the functional anatomy of the organs and accessory organs of the digestive system
. urinary system	Characterize the roles of each of the parts of the urinary system
. genital system	Describe the anatomy of the male and female reproductive systems, including their accessory structures
. immune system	
. lymphatic system	Identify the components and anatomy of the lymphatic system
. endocrine system	Identify the major organs and tissues of the endocrine system
. nervous system (NS)	. Describe the major functions of the nervous system . List the parts of the peripheral NS (PNS) and the central NS (CNS).
. . brain	Describe the orientation of the brain relative to bones of the skull.
Cell	Identify the three main parts of a cell, and list the functions of each.
Anatomical cavity	Describe the location of the body cavities and the organs found in each
Anatomical plane	Identify the various planes in which a body might be dissected.

Figure 3. Anatomy Course Learning Objectives and Topics mapped to the FMA. Examples

3. Computer Imaging to Support Learning

3.1 3-D Skeleton View with Examination of Individual Bones

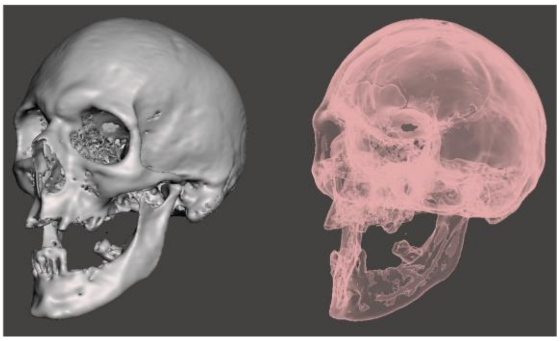

Fig. 4 Skull and transparent skull displaying internal structures (e.g., mandibular canal)

Learners can benefit from studying anatomical structures within the FMA hierarchy. A 3D model of the entire skeleton from which students can examine structures in more detail is beneficial for understanding anatomical relationships and structural orientations. Moreover, this type of 3D modelling permits students to examine the cavities and canals within bones, as well as any associated organs (Fig. 4).

3.2. Cadaver Dissection: VR and Physical

The study of anatomy has traditionally been grounded in cadaver dissection, which offers exceptional learning opportunities. But not all institutions are able to offer this intensive hands-on learning experience. Virtual dissections provide an alternative that makes anatomy learning experiences accessible to more students. Some traditional gross anatomy courses have incorporated VR learning as a supplement that lets students visualize the anatomy in another way. Students can examine computed tomography (CT) data or 3D models to see anatomical structures from different perspectives. Laboratory study and dissection time is highly valued; VR supports learning outside of laboratory hours prior to cadaveric dissections.

3.3. Visualization of Body Components and Functions

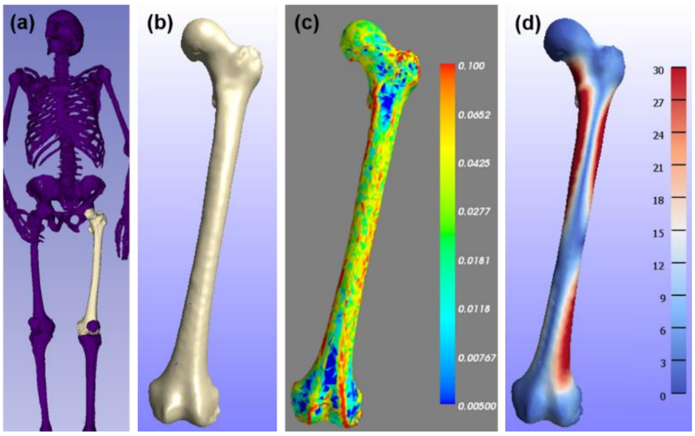

Figure 5: Cadaver-specific 3D models: a) skeleton; b) left femur; c) quantitative morphological data heatmap indicating surface curvature; d) quantitative biomechanical data heatmap showing stress distribution during a walking simulation.

Anatomy education can be further enhanced through detailed examination of specific structures and their unique characteristics. In particular, cadaver-specific 3-D anatomical models can be used to display quantitative data obtained using new computational techniques (Figure 5). These morphological and biomechanical data can help students to more effectively learn about complex structures and how they function.

4. Assessment of Learning Outcomes

In anatomy and physiology, several studies confirm the beneficial aspects of supplementing traditional teaching methods with virtual reality tools [5], [16-18]. Though a difference in test scores was not statistically significant, learning benefits in one study included a quicker time to acquire information and improved retention of information [17]. In a student-reported survey, the majority of students found using virtual reality to be fun and engaging, and the models were useful as study aids [5]. [18] found that "direct manipulation is better than passive viewing for learning anatomy in a three-dimensional virtual reality environment." One concern surfacing in the literature was the initial learning curve when introducing virtual reality into the classroom. Though this concern exists, the enhancement of education through virtual reality is a promising direction to explore going forward.

5. Conclusion

The combination of virtual reality and providing conceptual structures through ontologies is a promising approach to improving learning and instruction in the important subject of anatomy and, by extension, in improving learning of the structure and function of highly complex systems in general.

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