Cognitive Assessment of *VR Anatomy* Learning Intervention

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Learning Goal

VR Anatomy is an educational intervention that seeks to take advantage of the specific affordances of virtual reality (VR) technology for human anatomy learning. It aims to be a "fully-featured virtual reality anatomy atlas" (3D Organon, 2016b), providing a 3D model of the different systems in human anatomy. In great detail, almost every bone, muscle, blood vessel, and organ is labeled and manipulable (3D Organon, 2016a). Users can focus on specific systems of the body (i.e. digestive, musculoskeletal, etc.) or view a complete life-size human model. The 3D model is normally static; however, there is a mode where users can view animations of joints and bones in motion. By allowing users the ability to see 3D models of individual organs, manipulate the smallest structures of the body, and reference anatomical definitions, the intervention presents a multimodal learning experience. Most notably, as with real-life physical models of the human body, *VR Anatomy* focuses on the visual appearances, spatial relationships, and dynamic movements of individual parts of the body and the systems they comprise. Its goal is for users to identify and understand the location, function, and terminology of anatomical structures in the human body.

VR Anatomy is also an immersive experience, allowing the user to stand in a classroom-like environment, bordered by hospital surgical and radiological rooms for context. When wearing a high-end commercial VR product (HTC Vive or Oculus Rift), the fidelity is high enough to be a convincing realistic simulation of a medical learning environment. It attempts to replicate a medical school classroom that would contain a highly detailed physical model of a human body. In the virtual experience, the user's hand controllers can grab and manipulate any part of the body. This mimics the real-life ability to physically interact with a human medical model. Sensors also track the headset so that when users physically move their head in orientation or x-y-z position, the software program detects the movement and updates the view. This system allows for a learning experience that parallels the feedback that students receive when examining a real-life physical model. However, one significant difference is that that by leaning or walking “into” the model, the user is presented with a view of the interior of whatever organ or tissue intersects virtually with the current headset position.

This app’s download page on the STEAM store is the most detailed available public statement of the intended audience for this app: “The app is designed to suit a range of users, from medical and allied-health students to educators, healthcare professionals, patients, artists, and curious minds. It is helping students grasp the challenging subject of anatomy, but also is easily understood by individuals without a medical background” (3D Organon, 2016b). Both the classroom environment, which evokes a medical school experience, and the provided materials make it clear that the primary intended audiences are those listed earlier in the description’s “range of users.” While someone of nearly any age or level of life sciences expertise can likely learn to navigate the menus and manipulate the model, the written materials do indeed seem to have been “written by professors of anatomy and medical professionals” (3D Organon, 2016b) in order to teach peers-in-training about “clinical, topographic, and systems-based anatomy” (3D Organon, 2016a). The emphasis is on technical precision and accuracy, not non-expert interpretation or explanation. This is not to say that lay people won’t learn from and enjoy the tool, only that the developer’s design decisions show a preference for being useful to the more expert audience.

Core Learning Theory

By designing an immersive environment and an ability to connect physical motions with virtual interactions, the core learning theory of 3D Organon’s *VR Anatomy* is a primary reliance on two theories of cognition, embodied and situated. Embodied cognition can be broadly understood as the idea that all forms of cognition are embedded in some type of physical or bodily interaction with the world (Wilson, 2002; Soylu et al., 2017; Shapiro, 2010). As Shapiro (2010) describes it, there are three prominent themes of embodied cognition: conceptualization, replacement, and constitution. Conceptualization is the notion that “an organism’s understanding of the world … is determined in some sense by the properties of its body and sensory organs” (p. 68). In other words, each organism’s unique sensorimotor organs and physical attributes enable it to perceive and understand the world uniquely. Replacement, a possible departure from mainstream schools of thought in cognitive science, states that “a body in interaction with the environment replaces the need for representational processes” (p. 4). This theme controversially claims that the mechanisms of embodied cognition are incompatible with the symbol-centric paradigm of the cognitivist school of thought. Finally, the theme of constitution purports that “the body or world plays a constitutive rather than merely causal role in cognitive processing” (p. 4). This tenet projects the body or world into an integrated and critical role in cognition, rather than simply being an object to be interpreted for cognitive processes.

It is also worth noting that the design of *VR Anatomy* employs the strategy of *plurality*, a suggestion that Howard Gardner (2011), gives when advising on the use of his theory of Multiple Intelligences. His psychological theory, which has been widely adopted in educational circles, presents human beings “as having a set of relatively autonomous intelligences” (p. xii). In analyzing this particular VR artifact, the spatial and bodily-kinesthetic intelligences seem to be the most heavily targeted. *VR Anatomy*’s 3D model of the human body, able to be viewed from any direction, appeals to those who favor spatial intelligence. Its affordances for seeing the whole body and individual parts within systems aligns easily with the cognitive preferences of those who “perceive the visual world accurately” (Gardner, 2011, p. 182). In addition, *VR Anatomy*’s allowance for users to manually gesture to move individual parts or the entire 3D model, offering the potential for learning through bodily-kinesthetic intelligence. Those users who experience and understand the world best through bodily motions and handling objects will find *VR Anatomy* quite intuitive.

Situated cognition theory also informs the design of *VR Anatomy*. It describes the process of learning as relying less on individual psychology and more on social, cultural, and contextual determinants (Driscoll, 2012). Barsalou (2008) summarizes it as a theory where “the environment plays central roles in shaping cognitive mechanisms” (p. 621). In the artifact, the interactive 3D model is deliberately situated in a learning environment. The immediate surroundings are of a medical classroom, with a conference table, white board, and chairs. Adjacent to the room and visible through a glass wall is a hospital surgery room. Another glass wall looks in on an office with a desk and walls lined with rows of books. Clearly the designers of *VR Anatomy* had a medical education environment in mind when developing this application. The opposite choice, where no environment is presented and the 3D model exists in an empty space, would give an entirely different impression through (lack of) context. Perhaps this alternate environment would be less restrictive and more exploratory than under the social norms that typically apply in a medical classroom. Technically, there is nothing hindering the user from acting in ways that are inappropriate for a classroom; however, the environment design suggests that the desired interactions will be of a formal education nature.

Explanation of Learning Mechanism

Barsalou (2008) provides a schematic account of how learning occurs under embodied/grounded cognition:

> "As [a bodily] experience occurs … the brain captures states across the modalities and integrates them with a multimodal representation stored in memory … Later, when knowledge is needed to represent a category … [the] multimodal representation captured during experiences with its instances are reactivated to simulate how the brain represented perception, action, and introspection associated with it." (618-619)

For example, the assorted sensations of sitting in a chair (Barsalou 2008) get imprinted in memory in a way that informs subsequent experiences of sitting down. Working with a mixed-reality (MR) learning tool, Lindgren and Johnson-Glenberg (2013) build on Barsalou's account to further claim "that when the appropriate sensorimotor systems are engaged, the converging inputs can create stronger and more stable memory traces and knowledge representations" (p. 446). In other words, as a person who has past embodied experience of sitting down in a chair does so, the perceptual signals that person receives converge with the multimodally represented memory of the experience. Each experience of sitting down becomes more natural and coordinated—literally more "practiced."

Squire and Jan (2007) show that using mixed or augmented reality tools (in their case, an AR game) to facilitate student learning is powerful precisely because this technique helps students connect their thinking about a subject to specific elements of the environment in which this learning happens (recall Shapiro's "constitution" above). In moving through a game space "inhabiting" professional roles, players repeatedly experience that "the meaning of a place is perceived from professional perspectives" (Squire and Jan, 2007, p. 10). The "space" and the "moves" become part of the learning, with the multimodal representation of the experience being repeatedly both reinforced and called upon in conjunction with the unfolding gameplay. The key to leveraging the relevant cognitive mechanism is to "combine physical activity with salient and compelling representational supports" (Lindgren and Johnson-Glenberg, 2013, p. 447).

In the case of fully immersive VR tools used in the context of medical education, that physical activity includes (1) the movement of the user's own physical body to adjust visual perspective in the simulation and (2) the virtual movement of selected organs using hand controllers. In the first case, there is a strong connection between the physical experiences of a medical examination and the representational supports provided by the tool. The first time a *VR Anatomy* user approaches a cadaver or living patient, the multimodal representation available in memory and activated by the new physical experience should have a guiding effect on the subsequent action. The "old moves" are relevant to the "new moves" in a direct and physical way. In the second case, the physical movements are less directly analogous in the simulation ("point and click") compared to real life ("reach and touch"). However, it's important to remember that the representation is multimodal; while manipulating an organ with a gloved hand certainly feels different from manipulating a HTC Vive controller, the visual and spatial information the user experiences are still quite similar. Moreover, studies have suggested that tactile manipulation is an aid to mental spatial reasoning (e.g., Ganis, Keenan, Kosslyn, and Pascual-Leone, 2000). Indeed, this account above seems to have been born out in recent research by Jang, Vitale, Jyung, and Black, who found that users engaged in 3D anatomy learning performed better on a post-test if they had manipulated the simulation using a joystick rather than passively viewing while someone else performed the manipulation (2017).

Benefits and Drawbacks

In considering the effectiveness of this tool, it is helpful to enumerate the more traditional modes of medical anatomical learning. These include: (1) lecture-based, (2) manipulable physical 3D models, and (3) human or animal cadaver dissection (Jang et al., 2017; Preece, Williams, Lam, and Weller, 2013; Kerby, Shukur, & Shalhoub, 2010; Dyer and Thorndike, 2000).

Lecture-based, didactic teaching methods have been found to be less appropriate for teaching anatomy than more interactive styles (Kerby, Shukur, and Shalhoub, 2010). While they do provide an avenue for imparting anatomical information, didactic models do not involve obtaining a 3D appreciation of the body or developing relevant anatomy skills (Kerby, Shukur, and Shalhoub, 2010). *VR Anatomy*'s reliance on embodied and situated cognition utilizes interactivity to strengthen the learning context. In addition to enhancing the learning environment, interactive teaching methods are also proven to be more engaging and satisfying for students (Stuges, Maurer, and Cole, 2009). Thus, this particular intervention shows many advantages over traditional didactic methods.

While *VR Anatomy* holds many advantages over lecture-based, didactic teaching methods, it is quite similar to using manipulable physical 3D models. Both types of 3D models, real and virtual, are a good fit for students to learn anatomical information, to obtain a 3D appreciation for the body, and to develop certain anatomical skills (Kerby, Shukur, and Shalhoub, 2010). 3D models are also excellent at allowing students to focus on specific systems of the body. While a cadaver dissection (generally considered to be the best form of training for anatomy) also allows for a 3D appreciation of the body's organs (Kerby, Shukur, and Shalhoub, 2010), it does not afford the ability to easily isolate and emphasize certain systems of the body. The *VR Anatomy* intervention also holds an advantage over real 3D models in that it efficiently integrates multimodal representations of information. In selecting a particular part of the body, audial and textual information are easily and quickly accessible. Being digital, the intervention also allows for levels of visual magnification that are inaccessible in real life. However, *VR*

Anatomy, as well as physical models, lacks in other areas: providing background for the science, improving medical vocabulary, appreciating anatomical variation, relating structure to pathology, and developing team skills (Kerby, Shukur, and Shalhoub, 2010).

Obviously, dissecting a human cadaver is the most complex, demanding, and embodied of the common modes of anatomical learning. Dyer and Thorndike point out that some of what the medical education establishment has considered to be essential aspects of the learning experience can only be learned through direct engagement with a once-living body: the physicality of the cadaver, the smell, the inevitable ethical reflection on the life of the person who donated their body for this purpose, etc. (2000). Most importantly from our embodied cognition perspective, the multimodal mental representation that will be formed in the physical experience of dissecting a cadaver is much more directly related to future medical interventions like physical examinations and surgeries. Cadaver dissection is the most effective "role playing" for future medical students. The wholesale replacement of cadaver dissection with VR-based learning therefore seems ill-advised.

However, there are significant arguments in favor of at least partial replacement or supplementation of existing pedagogies with VR-based systems. First, McLachlan and Patten have reported a reduction in cadaver donations as well as a greater demand due to the increasing number of medical schools. Fewer cadavers means more students having to share them, decreasing the value to each student of direct manipulation of the anatomy learning (2006). In Finkelstein and Mathers' research points out that many medical students experience a significant emotional challenge after doing cadaver dissection, which strongly resembles post-traumatic stress disorder (PTSD). It is likely inevitable that this emotional challenge also will bring more stress on medical students (1990).

Most relevantly to the specific affordances of *VR Anatomy*, Hu, Wilson, Ladak, Haase, and Fung point out that dissection is an ineffective technique for beginners to examine small and/or delicate systems organ and tissue systems like the larynx (2009). In this case, the magnification that is possible in a VR system and the fact that physical manipulation is *not* required for an up-close examination is decidedly a strength. To put it bluntly, you can't stick your head inside someone's voice box.

Conclusion

In summary, our assessment of *VR Anatomy* is that this intervention and others like it have the potential to significantly improve anatomy learning for the people we deem to be the primary audience for this tool, medical and other life-sciences students. While it does not have all the affordances of the most complex and authentic learning experience, it reproduces many of them at a much lower cost. The incorporation of room-scale VR's visuo-spatial perspective as well as direct organ manipulation both leverage the body's inherent ability to record, reinforce, and coordinate the many modes of perceptual information that contribute to embodied learning. While medical students and educators should not rely on this tool to the exclusion of more traditional laboratory experience, *VR Anatomy* can richly prepare them for embodied interaction with both the dead and the living.

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