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Mini Review

Bridging the Gap: Enhancing Modern Anatomy Education Through Mental Rotation Training and 3D Technological Integration

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Abstract

Mental rotation is a crucial cognitive skill for understanding spatial relationships and three-dimensional aspects, especially in the study of anatomy. However, students with limited mental rotation abilities often face challenges when translating two-dimensional anatomical depictions into three-dimensional mental models. This article explores the impact of mental rotation skills on anatomy learning and proposes strategies to enhance these skills. It discusses the limitations of traditional and digital resources and introduces the concept of Stereoscopic 3D visualization technology (3DVT) and clay-based modeling (CBM) as effective teaching methods. Additionally, the article emphasizes the importance of pre-assessing students' visual-spatial abilities and integrating a variety of teaching tools to create a comprehensive and enriched learning environment in anatomy education.

Keywords: mental rotation, anatomy education, spatial visualization, 3D representations, stereoscopic 3DVT, clay-based modeling

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1. Introduction

Mental rotation is a cognitive skill that enables individuals to mentally manipulate and rotate objects within their mind's eye [1, 2]. This ability is fundamental to understanding spatial relationships, particularly in the context of anatomy. Students with limited mental rotation skills may face challenges comprehending the intricate spatial arrangements and three-dimensional aspects of anatomical structures. Recognizing the diverse spatial abilities among students is crucial for developing adaptable teaching methods that cater to the needs of all learners. While improving mental rotation skills may seem daunting, it is an achievable goal.

Various digital and traditional resources can assist students in honing these skills. Digital platforms that enable students to interact with three-dimensional representations of anatomical figures offer a significant advantage by providing visual perspectives from multiple angles, reducing the reliance on mental rotation alone.

2. Context Analysis

Anatomy inherently demands a robust capacity for spatial visualization. Beyond grasping the form and function of anatomical structures, students must grasp their spatial interrelationships. While anatomy textbooks and atlases provide two-dimensional (2D) images, they do not fully capture the dynamic three-dimensional (3D) nature of body parts [3]. This limitation often challenges learners in translating 2D depictions into a comprehensive 3D mental model, making it difficult to understand certain functional aspects of anatomy. For example, discerning structures associated with the caudate lobe as the liver shifts across planes can be intricate [3]. In the study of anatomy, students frequently need to mentally manipulate and view structures from various angles to identify specific anatomical features. Visual-spatial skills, involving mentally adjusting and rotating objects in a three-dimensional space, are fundamental not only for medical students' anatomical comprehension but also for surgical trainees and practicing surgeons. Therefore, the ability to mentally configure and accurately pinpoint 3D structures and their associated parts is imperative for medical and dental students, especially when anatomy is presented from diverse angles and planes.

3. Target Issues

Students with limited mental rotation abilities often encounter difficulties when navigating the multifaceted spatial and volumetric intricacies of anatomy [1, 2]. The need to understand three-dimensional anatomical structures means these students may struggle to project these forms mentally from different perspectives. When faced with 2D illustrations of 3D structures in textbooks or PowerPoint presentations, equating the 2D representation with its 3D reality becomes more challenging [1–3]. Deciphering spatial relationships and understanding how structures relate and interact with each other, a critical aspect of anatomy, becomes notably strenuous for students with limited mental rotation skills.

While 3D visual aids can bridge some understanding gaps related to spatial orientations, mastering 3D visualization is not an instantaneous process [3]. It is important to note that the brain processes 2D and 3D information differently, which adds to the challenge of transitioning between the two [3, 4]. Most students find 3D atlas applications beneficial for anatomical comprehension and user-friendly. However, slightly less than half believe that 3D atlases could fully replace 2D versions in the coming decade [4]. This suggests that while 3D atlases can expedite anatomical identification, they do not surpass 2D atlases in imparting profound anatomical knowledge or enhancing memory retention. Consequently, while 3D atlases can effectively complement 2D resources in anatomy teaching, they may not be the ultimate solution for individuals with reduced mental rotation abilities [4].

Translating 2D images into 3D mental constructs requires significant cognitive processing [3, 4]. This can increase cognitive load, especially when observing unfamiliar 3D objects monoscopically in a 2D environment (desktop) as opposed to stereoscopically in a 3D platform (3D environment app) [5]. Consequently, digital 3D representations on 2D media, such as the 3D Complete Anatomy or Sectra Table's Education portal, may not cater optimally to students with lower visual-spatial capabilities. As the cognitive load theory suggests, excess cognitive burden can hinder learning, particularly for those with weaker visual-spatial skills, often leading to subpar academic outcomes [5].

4. Desired Future Teaching Scenario

Stereoscopic 3D visualization technology (3DVT), such as virtual reality (VR) and augmented reality (AR), holds a distinct advantage over monoscopic 3DVT (e.g., sectra table and 3D complete anatomy) for students with limited visual-spatial skills, aligning with the compensatory hypothesis [5]. Stereoscopic 3DVT's intrinsic 3D representation eliminates the need for additional cognitive efforts to construct a mental 3D image, preserving cognitive resources for learning [5]. Such stereoscopic perspectives can be especially beneficial for students with limited visual-spatial abilities. Engaging with 3D structures through direct manipulation can facilitate stronger connections between motor and visual processes, ultimately enhancing learning. This approach aligns with the embodied cognition theory, suggesting that interacting directly with structures in a virtual space can foster a tangible sense of these 3D forms. Navigating around a 3D model as a reference can further enhance depth perception [5].

Clay-based modeling (CBM) is an art-based pedagogical method suitable for teaching gross anatomy [6]. CBM offers a tactile advantage, as described by Hill [7]. Mayer's cognitive multimedia learning model elucidates the connection between clay activities and cognitive learning facets, emphasizing that learners process visual and auditory

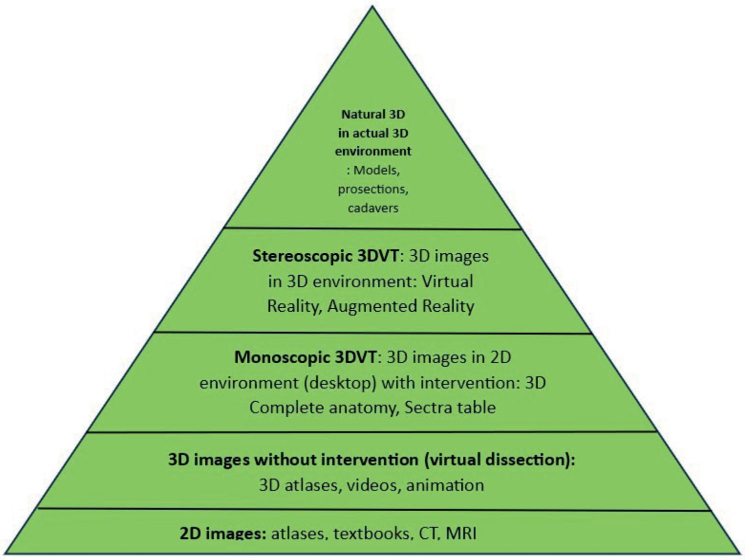

Figure 1: The anatomy learning pyramid: From 2D Illustrations to Real Dissection. This pyramid illustrates the progression of tools used in anatomy education, ranked from basic to advanced based on their effectiveness in aiding student comprehension. At the base, we start with the most rudimentary and least immersive form: 2D images. These provide a foundational, albeit flat, perspective of anatomical structures. Moving up, 3D images add depth, offering a more comprehensive view, although lacking interaction. Monoscopic 3DVT introduces a virtual 3D environment, allowing some interaction but lacking the full-depth perception of real-world observation. Leaping upward, Stereoscopic 3DVT immerses students in a deeper, more detailed virtual 3D environment, closely mimicking real-world vision and enhancing spatial comprehension. However, tangible, hands-on experiences often provide unparalleled learning outcomes, as evident in the hierarchy, with anatomy models coming next, offering tactile interaction that digital methods cannot replicate. At the pinnacle of the pyramid, prosections—actual dissected tissues—stand as the gold standard in anatomy education, providing students with the most authentic, detailed, and holistic understanding of human anatomy. By studying natural tissues, learners gain insights that are often impossible to achieve through models or digital representations, making prosections the most effective tool for mastering anatomy in this hierarchy.

information in parallel but distinct streams. Incorporating haptic feedback during modeling adds another layer of information assimilation [5]. Therefore, stereoscopic 3DVT and CBM offer a deeper understanding of anatomy, making them preferable to monoscopic 3DVT.

Pre-assessing students' inherent visual-spatial abilities can predict their performance in anatomy within medical curricula. Enhancing mental rotation (MR) skills can be achieved through consistent practice, with strong MR capability being a robust predictor of success in anatomy learning [1, 2]. MR training has been shown to improve MR test outcomes and subsequently facilitate anatomy comprehension. The Mental Rotation Test (MRT), consisting of 24 3D object items, assesses MR capability. After practice, both male and female participants exhibited enhanced MR performance, with men typically scoring higher. The anatomy evaluation included a time-restricted multiple-choice test with 239 questions, ranging from basic knowledge assessments to more complex spatial reasoning tasks requiring MR of provided anatomical structures. Post-training, students demonstrated improved accuracy in the MRT, indicating enhanced spatial reasoning [1, 2]. Khot et al. [8] suggested that learning through anatomical models circumvents the need for mental rotations since physical rotations are possible. While Preece and colleagues [9] highlighted the superiority of tangible anatomical models over digital counterparts, they recognized the models' limitation in depicting deeper anatomical details, which is a strength of 3D atlases and virtual dissectors.

In summary, it is advisable to identify students with limited MR skills early on and guide them through MR exercises to enhance their visual-spatial abilities before commencing anatomy courses. Subsequently, the curriculum should incorporate a blend of 2D imagery, pre-recorded videos, tangible models, prosections, and valuable tools like stereoscopic 3DVT and CBM (Figure **1**).

5. Conclusion

Proactively identifying and strengthening the mental rotation abilities of students with limited MR skills through specialized training and exercises can significantly enhance their understanding of anatomy. Interactive technologies that offer 3D manipulation of anatomical structures are invaluable as they enable diverse visual perspectives without relying solely on intrinsic mental rotation capabilities. While cadaveric dissection remains of unparalleled importance, emerging digital tools such as AR and VR undeniably enhance the anatomy learning experience. Integrating 3D digital representations with traditional teaching resources, including 2D and 3D anatomical atlases, tangible models, and wet lab prosections, can provide a holistic and enriched learning environment.

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