Title: Change of Heart: Clinically Oriented Learning Outcomes from Virtual Embryonic 3D Heart Model

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ABSTRACT
Teaching and learning embryology pose challenges due to rapid and complex developmental processes occurring in four-dimensions especially without effective visual aids. Previous investigations have shown that virtual and 3D printed embryo models increase learning outcomes and interest in embryology. One of the most challenging and clinically relevant concepts in embryology is the heart outflow tract septation involving 180-degree spatial rotation and precise alignment of the growing septa that can often go awry, resulting in various congenital cardiac septal defects. Unfortunately, there are no visual aids that effectively demonstrate this complex process in 3D. To that end, a 3D embryonic virtual heart development model (EVH) with interchangeable conotruncal septa was created and its educational efficacy was tested in a COMIRB exempt (# 20-2124), randomized single-blind study with the first-year medical students completing a flipped-classroom embryology active learning event occurring in a virtual platform due to COVID-19 restriction. As a part of the course requirement, all students first watched a pre-recorded lecture video and completed a quiz on their own before attending the synchronous virtual active learning event. During the active learning event, students were randomized into control or experimental breakout session groups. Experimental breakout session groups (16 groups, n=80) were provided access to the EVH with accompanying prompts designed to reinforce 3D spatial orientation and congenital septal defects demonstrated by the EVH. The control groups (14 groups, n=70) were tasked to complete a similar learning activity but on a different developmental process. All students completed a second quiz and a survey after the active learning event.

A Kruskal-Wallis test comparing normalized pre-quiz versus post-quiz results revealed an insignificant change on the post-quiz performance in the experimental group ($p = 0.4348$, $df = 3$) and not in the control group ($p>0.05$). Descriptive statistics on quantitative survey data revealed that students positively perceived the educational value of the EVH, especially for demonstrating embryonic heart development (4.6 + 0.84 on a 5-point agreement scale). The survey data also showed that students felt the EVH helped in understanding spatial and developmental changes (4.8 + 0.80). Consistently, thematic analysis of the survey comments indicated that the spatial and visual aspects of the EVH demonstrating the congenital defects were perceived as essential. The significantly higher learning outcomes immediately after the resource interaction with EVH and the perceived favorability of the EVH warrant further development and research. A future aim of this project is to enhance the EVH to represent the sequelae of abnormal conotruncal septum formation. Group and virtual classroom effects are other confounds that should be reduced in future studies.