Learning Geometry Through Collaborative, Embodied Explorations with Augmented Reality Holograms

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Abstract: Novel forms of technology, like shared Augmented Reality (AR) holograms, can spur the discovery of new hypotheses about cognition and how it is embodied and distributed. These holograms have affordances for exploration, collaboration, and learning that have never been seen before. In the present study, we examine the multimodal ways that high school students interact with shared AR holograms while exploring geometric conjectures. Through multimodal analysis, we find both possibilities and important design considerations.

Introduction

Advances in Augmented Reality (AR) allow 3D holograms to be projected into students' real-world environments, controlled through intuitive hand gestures. Even more significantly, students can engage with these holograms collaboratively, with each student able to manipulate the holograms and see the effects of others' manipulations. These are literally new collaborative objects. We investigate students using AR goggles to explore geometry conjectures and describe the possibilities for collaborative embodiment and access to mathematical ideas.

Theoretical Framework: Collaborative Embodiment

Collaborative embodiment is defined as the ways students co-create actions and embodied ideas that become extended (Clark, 2012) over multiple learners. *Gestures*, spontaneous or purposeful hand and arm movements that often accompany speech, are a powerful way in which mentally-simulated actions can give rise to physical movements (Hostetter & Alibali, 2008). *Collaborative gestures* (Walkington et al., 2019) are gestures that are dependent on the gestures of interactional partners, like echoing or repeating gestures. AR and VR environments also happen at a scale where students engage in whole body movements – students might move around virtual 3D objects to take different perspectives (Walkington et al., 2021). Finally, students engage in collaborative forms of speech, using talk moves like Negotiating, Representing, and Planning (Andrews-Todd et al., 2019). It is through this multi-modal account of communication with speech, gestures, and collaborative embodiment that students generate shared mathematical meaning. We explore these research questions: (1) How do learners use resources like gestures, actions on virtual objects, body movements, and speech to explore conjectures in an AR environment? and (2) What barriers do students encounter to reasoning through collaborative embodiment?

Methods of Inquiry

Participants included 28 high school students enrolled in an enrichment program at a local university intended to support high school students likely to become first-generation college students. Twenty-three of the participants were female and 5 were male; 12 identified as African-American, 14 as Hispanic, 1 as White, and 1 as Other. Participant dyads were asked to reason about 8 geometry conjectures, without AR goggles on. Then they would put on the Microsoft HoloLens 2 goggles and justify 3 to 4 of the conjectures a second time. They used an app developed by GeoGebra for direct mathematical object manipulation (Hohenwater & Fuchs, 2004).

Results

The dynamic, 3D nature of the holograms offered powerful affordances for mathematical reasoning and embodied collaboration. In Figure 1, we see a dyad's second attempt to prove the sphere conjecture in Table 1, this time with the aid of the holograms. Having access to the 3D shape seems to give the students novel insights, and we see them using body movements to change the perspective they have on the sphere and to look at each other. We also seem them using gestures to reference the sphere and collaborative actions to dynamically modify the sphere, all while engaging in collaborative talk. The students exhibited substantial progress of their embodied understanding of 3D figures and how they interact with each other (Lines 1-16). However, students were not always able to use the holograms and their associated embodied resources and motions to reason more effectively. Multimodal analysis revealed that the students encountered issues with mathematical language in many episodes and struggled to decipher the culturally-bound, closed-ended, written medium of mathematical conjectures.

Figure 1
Two participants reasoning about a conjecture about a plane intersecting a sphere at 0, 1, or infinite points. Red arrows were added to the image to show motion or change.

1. S101: I feel like we looked at that all wrong.
2. S102: Yeah, uh uh.
3. S101: Ooh, when I was thinking about –
4. S102: That would be true.
5. S101: When I was thinking about this in my head, I was like, "a plane is just gonna go around and around and around."
6. S102: So, it's true.
7. S101: It's true!
8. Researcher: Why do you think it's true or false?
9. S101: Because, if you really look at the plane – I'm making it bigger.

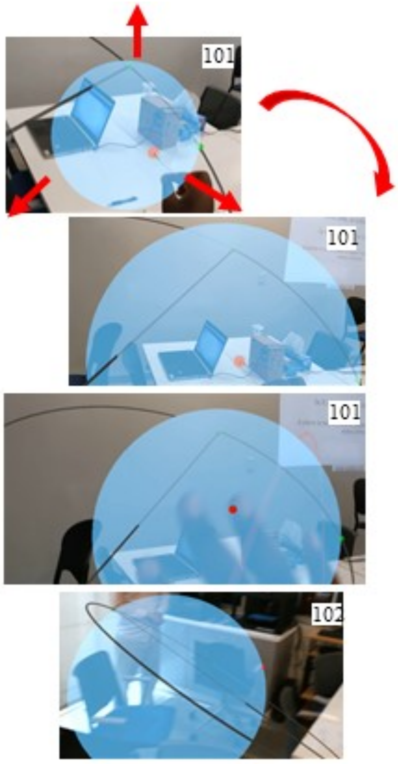
(adjust the sphere so that it is larger)

10. S102: There's many more ways you can intersect it at.
11. S101: It's more ways that it can go in and out!
12. S102: Yeah.
13. S101: Oh wow!
14. S102: There's like, many more ways.
15. S101: Okay, yeah, I was looking at this all wrong in my head. Now that I see it, I can say that it's true.

(gestures to the plane and where it is intersecting the sphere)

16. S102: Okay, yep, many more points that you can –

(steps back to view the plane intersecting the sphere)



Discussion
A variety of rich multi-modal forms of interaction come together in this shared AR environment to support students in creating meaning and constituting students' knowledge. AR holograms may be more powerful and appropriate for concepts that are inherently 3D, as these objects leverage AR's profound affordance for 3 dimensions, like our sphere simulation did. Finally, AR allows students to interact with and explore objects in novel and unconventional ways. However, if you bring traditional "school" tasks into an AR environment, students' reasoning and attempts at meaning-making can be restricted. Tasks in shared AR environments become particularly meaningful if they come from students and their embodied, collaborative experiences.

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