

Gesture's Role in Collaborative Problem Solving With Augmented Reality

James Planey, Robin Jephthah Rajarathinam, Emma Mercier, Robb Lindgren, Rachel Zhou
planey@illinois.edu, rjrthnm2@illinois.edu, mercier@illinois.edu, robblind@illinois.edu, yiqiuz3@illinois.edu
University of Illinois Urbana-Champaign

Abstract: Headset-based augmented reality (AR) unlocks unique opportunities to integrate gestures into collaborative problem-solving activities. This paper documents a collaborative astronomy sky simulation across AR and tablet technologies. Two groups of students were identified from a larger data corpus based on the amount of interactions within the AR headset. These groups were coded for episodes of on-task problem solving and instances of collaboration involving gestures. Gesture interaction analysis assisted in identifying collections of interactions facilitating exploration, orientation, perspective-sharing and communication of mental models. These patterns of interactions suggest productive use of AR technologies to collaborate and problem solve through the use of gestures.

Introduction and theoretical background

Undergraduate science education has increasingly adopted instructional approaches that focus on interactive, exploratory, and collaborative learning (Freeman et al., 2014). Students beginning their undergraduate education in the United States are also increasingly arriving with learning experiences shaped by the Next Generation Science Standards (NGSS) which emphasizes the adoption of science and engineering practices including collaborative inquiry (NGSS Lead States, 2013). Students engaging in collaboration have shown positive learning outcomes such as comprehension, knowledge retention, enhanced reasoning, and improved knowledge transfer (Menekse & Chi, 2019). The gains in learning outcomes from collaboration have been shown to be strongly correlated with the quality of the student interactions within the collaborative groups (Volet et al., 2009), and thus much of the focus of educational reforms in undergraduate education has been on improving these interactions. It is here that technology can play a significant role in supporting meaningful engagement by facilitating the way that groups interact with each other and the learning domain (Chen et al., 2019). Augmented reality (AR- the merging of digital content with the physical environment) positions itself as a potentially powerful platform for the design of systems supporting collaborative interactions in science learning contexts (Chen et al., 2017).

While the benefits of AR for science learning have been shown across an array of topics (Bork et al., 2021), much of the previous work has been centered on lower-fidelity mobile AR and quantitative analyses (Arici et al., 2019). There is less documentation around the influence of AR headsets (such as the recently released Microsoft HoloLens 2) and the associated spatial and hand tracking capabilities they provide. Headset-based AR provides access to an array of spatial affordances that allow learners to engage in novel perspective-taking and spatial interactions (often at room scale). This opens up exciting possibilities for exploring the role AR can play in facilitating collaborative learning around spatially complex science content. To explore the role gesture plays within technology-mediated collaboration, the following paper describes a qualitative analysis of group interactions within a mixed technology (headset AR and tablet computer) environment as students engage in small groups. The goal of this work is to address the question: What role does gesture play in the facilitation of a shared conceptual space among collaborators in a technology-mediated astronomy problem solving task?

Methods

Environment and task design

The software used in this analysis was the result of iterative pilot testing and educator feedback. Figure 1 shows a group accessing the 3 simulation representations. “Horizon view” (top-right AR view) provides the user with a first-person view of the sky as if standing on Earth. “Star view” (bottom-left tablet view) removes the horizon limitations from the perspective, giving the user access to the full celestial sphere. “Earth view” (bottom-right tablet view) places the user in orbit above the earth with the ability to place location pins with which to change their position on the Earth or confer with other users about potential sky viewing locations. Interaction on the tablets is touch-based, while interacting in AR leverages hand and gesture detection to allow the user to tap interface items, pinch holograms to reposition them, and tap their index and thumb together to select distant objects such as stars. A multi-part problem solving task was created: “Lost at Sea.” In the narrative a crewed space capsule has splashed down at night in an unknown ocean location. Group members are then tasked with

exploring the night sky to determine the location of the crash site. Figure 1 shows all three group members engaging with representations of the constellation Orion across the three main view of the simulation.

Figure 1

Example of a group working in the simulation. horizon view (in AR top-right), star view (tablet bottom-left), and Earth view (tablet bottom-right).



Implementation and participants

Participants were enrolled in an undergraduate introductory Astronomy course, with weekly hour-long small group discussion sections and large group lectures. Groups were video and audio recorded, and screen capture was taken of the tablet interfaces. A composite view of the AR user's experience was streamed to a laptop and also recorded. Each group had access to one Microsoft HoloLens 2 AR headset and two tablets. Week 1 of the implementation was focused on an introduction to AR and the CEASAR technology, week 2 consisted of a seasonal variation lab from the regular curriculum explored with CEASAR, and week 3 was the "Lost at Sea" task. In total, 115 consented participants took part in the 3-week implementation. The following analysis focuses on the "Lost at Sea" enactment, in which 24 groups of 3-4 students participated across 8 discussion sections.

Identifying groups of interest

We extracted interaction logs from the tablet and AR platforms to identify focal groups for in-depth analysis. For the purpose of this study, we focused on groups with relatively higher levels of logged engagement within AR. Two features extracted from logs were compared to help evaluate the level of engagement: (1) number of AR-generated events during the whole session (2) variety of AR-generated events, indicating how users utilized the AR headsets. As a result, group Beta and group Gamma were selected and further explored.

Gesture interaction analysis

To begin identifying gestures that occurred during active collaboration, episodes of on task activity were identified. Within these episodes, occurrences of gesture were documented. Gesture was interpreted as either deictic (pointing or attention-directing), symbolic (representational of phenomena), or beat (rhythmic motions for emphasis) (McNeill, 1998). The resulting gesture instances allowed for the identification of vignettes which were then analyzed for instances of perspective-taking and interaction that arose due to the use of the AR headset. All sessions were co-coded by two members of the research team and differences were reconciled through discussion.

Results

Gesture interaction analysis interpretation

The coding scheme shown in Table 1 was applied to both group Beta and group Gamma. Groups varied in their use of the AR headset and how it helped them complete the task. While both groups engaged with all levels of the Lost at Sea task, neither group fully completed the task. 11 vignettes from the two groups were used to explore their types of gesture interaction and learning opportunities. Four gesture interactions were identified in the Beta group as they rotated the AR headset during the activity across all members. Seven gesture interactions were identified in the Gamma group, with one member acting as a dedicated AR user. These 11 gestural interactions were categorized based on the interaction codes in table 1 and summarized below.

Table 1
Gesture interaction codes

Code	Description
Exploration	The group is interacting with the AR user (making gestures) to help navigate within their augmented 3D space. The interaction involves information pertaining to solving the task by gesturing to each other about what star/constellation to look for and where in the night sky.
Orientation	The group interacts with the AR headset user (making gestures) to locate key constellations and directions within the augmented 3D space to create shared knowledge across the members (requires multiple AR users per group per session).
Synthesizing AR and tablet perspective	The whole group tries to combine their varied perspectives obtained by interacting with augmented 3D room space and the 3D simulation space within the tablet to create a shared knowledge within the group.
Sharing AR perspective	The AR headset user (making gestures) shares their unique perspective gained from interacting with the augmented 3D space to their group members.
Sharing symbolic conception	Group trying to combine their varied mental models between the AR and tablet with the use of symbolic gestures.

Exploration

Exploration gestures occurred across both groups frequently due in part to the ill-structured nature of the tasks. In Beta, student A, a tablet user, asks student B to use the Horizon view and moves his hand to show a flat surface to represent the ground when in Horizon view. B navigates accordingly and A proceeds to describe what B should be doing. He points up asking B to verify the position of the constellation as A looks at their tablet.

Orientation

In Beta, the sharing of the AR headset amongst all group members allowed for orientation interactions. These interactions were critical in facilitating a new group member's entry into the AR simulation by priming them with spatial references in the classroom to engage with the AR content. In Gamma, student A gives the AR device to Student B and asks them to look at the constellation Leo by pointing along the table to the wall. A also talks about the position of the Earth with respect to the constellation (using their hands as if shaping something spherical) and describes where it is with respect to their surroundings by pointing at the center of the table. A also directs B to walk around the table and look for the United States by pointing slightly away from the center of the table.

Synthesizing AR and tablet perspective

While the previous interactions focused on sharing AR experiences with the rest of the group, one vignette from group Beta shows a unique instance of an AR user simultaneously leveraging the tablet perspective (visible to other group members) to communicate simulation view limitations, promoting a collective spatial understanding. Student B who is in AR, talks about their field of view limitation within the horizon view and uses a reference constellation (referred to as trapezoid) to describe the limits. Students A and C who are in Earth view, are looking at the same region in the night sky. B points at the tablet to show them the exact region he can view to Student A, who points at the tablet to confirm what B is saying they can view. A finally confirms that they have found which hemisphere they are in, and Student B prepares to share the information with C.

Sharing AR perspective

With a single AR user for the duration of the discussion session, Gamma's AR user devoted a significant portion of their interactions to broadcasting their simulation perspectives to the group. The AR user gestured multiple times during the discussion session in an attempt to share a portion of their perspective with the rest of the group (see Figure 1 for an occurrence of this gesture). In group Gamma, Student A is describing the rotation of the constellation as he changes time. They describe to student B the directions of north and trace the path the constellation made when he changed time. B is unsure whose path A is tracing, hence tries to confirm if it is Earth. A then Clarifies that they are talking about the constellation Orion.

Sharing Symbolic Conceptions

A vignette from Gamma shows the importance of shared mental models with each participant engaging in symbolic representations of the cardinal directions. While the AR user gestures their compass layout in the horizontal plane, the tablet user uses the vertical plane to respond and clarify. This set up a spatial mismatch that led to confusion for the AR user. Student C is describing to Student B the directions in a compass with reference to the angle it makes. C uses their raised forearm and open palm to show different angles in the vertical plane, perpendicular to the plane (horizontal plane) that B is using to make sense of their directions. Student B is taken aback by the information, but with further explanation from C, B can infer that Orion is north.

Discussion and Conclusion

The interactions documented here show the productive possibilities of AR facilitated collaboration in groups that actively engaged with the technology. Gesture found a frequent role as the mediator for collaborative interactions across the technologies while participants generated and modified knowledge. For the groups analyzed here, we found that the different types of gesture interaction afforded different types of collaborative knowledge building, from introducing new knowledge to the groups' understanding of the task, providing new perspectives to move the group forward and establishing consensus around the solution path. While the use of gesture was productive for the groups analyzed here, the selection of the groups based on their frequency of AR usage to provide a rich source of potential gestural interaction.

With the analysis scheme developed here, examining groups with lower levels of AR device usage will be critical in seeing how (and what) collaborative possibilities identified here are still evident. For example, while the simulation provided multiple avenues for sharing perspectives (annotation, view bookmarking), users in this study often chose gestures outside of the simulation as an alternative. This is evidence of the power of the spatial connections made between the AR and classroom environments, but these naturally occurring gestural collaborations may appear at different frequencies across the rest of the data corpus. The challenge for the design of AR-mediated system such as this one going forward will be to capitalize on the gestures documented here and integrate them into the control of the AR system itself, creating a shared "gesture toolbox" for group collaboration and simulation interaction.

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