

Exploring Joint Attention around Shared Referential Anchors during Physical, Virtual and Mixed Reality Laboratory Activities

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Abstract: This study explores student collaboration in three types of laboratory environments in middle school inquiry science classrooms: a physical laboratory environment, a virtual laboratory environment, and a mixed reality environment. Based on video of student collaboration across the three types of environments and supplemented with interview data, we analyzed joint attention of students around shared referential anchors across the three environments. Our results indicate that the mixed reality and virtual environments provided several opportunities for joint attention not available in the physical environment, namely opportunities pertaining to the availability and persistence of representations that could act as shared referential anchors. The mixed reality environment also provided advantages over the virtual environment in terms of the visibility of referential anchors to all group members. The implications of these findings and directions for future work are discussed.

Introduction

Within inquiry science classrooms, the two dominant representational forms for student-led inquiry have typically been physical laboratories and computer simulations. Teachers often decide between one or the other representational form based on tradeoffs such as the cost and amount time required for each (Hofstein & Lunetta, 2004). However, research shows that it may be beneficial for students to perform inquiry with both forms, as physical laboratories and computer simulations may have different affordances for learning (Jaakkola & Nurmi, 2008; Smith, Gnesdilow & Puntambekar, 2010).

Since groups of students often use physical laboratories and computer simulations collaboratively, (van Joolingen, de Jong, & Dimitrakopoulou, 2007), it is important to understand the affordances of these representational forms for students' collaboration. Different representations may have different affordances for collaboration (Suthers & Hundhausen, 2003), for example in supporting joint attention. Representations and other material resources may help students sustain joint attention and mutual engagement during collaboration by providing a publicly accessible referential anchor for the co-construction of knowledge (Crook, 1995), and joint attention itself is critical for collaborative learning (Barron, 2000).

There has been growing interest in the use of mixed reality technologies, such as augmented reality and tangible interfaces, for supporting learning and collaboration (e.g., Marshall, 2007; Jermann et al., 2009). In this paper, we describe a mixed reality laboratory environment that combines elements of a physical laboratory and a computer simulation. We then explore student collaboration across the physical, virtual and mixed reality laboratory environments, focusing on students' joint attention around shared referential anchors.

Methods

We performed an exploratory study examining students' face-to-face collaboration around three types of laboratory environments in science classrooms: a physical laboratory environment, a virtual laboratory environment, and a mixed reality physical/virtual environment (see Figure 1). Students in small groups of 3-4 used all three environments to explore physics concepts related to inclined planes. Students engaged with the physical and virtual laboratory environments, within the classroom as part of the CoMPASS simple machines curriculum (Puntambekar, Stylianou & Goldstein, 2007). This curriculum integrates a digital hypertext environment, physical and virtual science experiments, and design challenges within cycles of inquiry. The students engaged with the mixed reality environment after the completion of the curriculum; this was designed to pilot a prototype of the mixed reality environment. For this study, we observed and videotaped one group of four 8th grade students as they engaged with the three environments (see Figure 1). We also interviewed this group as well as five additional groups of 6th grade students (3-4 students per group) about their experiences with all three environments. This study is a step within a larger design-based research program to help students link multiple representations within middle school science inquiry classrooms. For this particular step, we are exploring how blending elements of physical and virtual laboratory environments may support students' learning of science concepts.

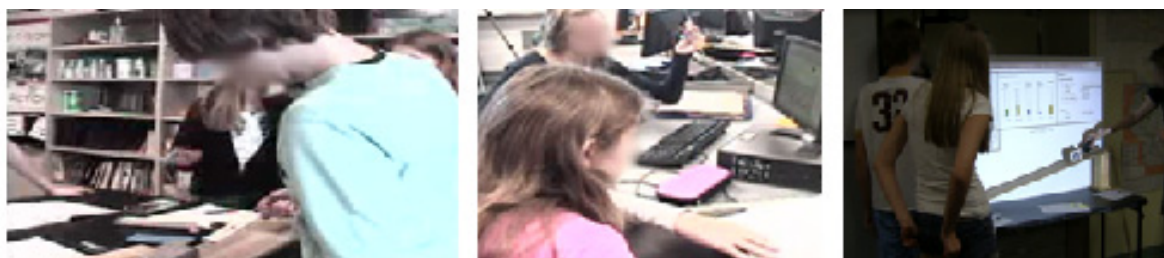


Figure 1. A Student Pulling a Block Up a Ramp in the Physical (Left), Virtual (Center), and Mixed Reality (Right) Environment.

Learning Environments

Across the three environments, students performed an experiment to determine the amount of force and work required to pull an object up different inclined planes. For the physical experiments, students used three different ramps, a support upon which the ramps would rest, a brick to pull up the ramps, and a spring scale to measure the amount of applied force. Students also recorded values of other variables involved in pulling the brick up the ramp.

For the virtual laboratory environment, students used a computer simulation of this inclined plane experiment. Students could change the properties of the inclined planes by inputting numerical values or by controlling sliders. They would then increase the amount of applied force using the slider until there was enough force for the brick to move up the ramp. An animation of the brick moving up the ramp would be displayed, along with numeric values and graphical representations of the amount of force applied and other physics concepts.

The mixed reality environment combined elements of the physical and virtual laboratory environments. Students performed the physical inclined plane experiment while real-time data of the experiment was projected onto the screen. Students also ran the inclined plane simulation in the same space to explore what would happen in situations that would be impractical or impossible to set up with the physical materials (e.g., a frictionless environment). This mixed reality environment utilized an electronic force sensor to measure the force applied in moving the brick up the inclined plane, a webcam and fiducial markers to detect the position and orientation of the brick, and an infrared pen and two Nintendo Wii remotes to allow students to use the screen as an interactive whiteboard (Lee, 2008). For all three environments, students recorded their results in a table provided in a workbook.

Data Sources and Analysis

We videotaped one group of four 8th grade students as they completed the physical and virtual inclined plane experiments in the classroom setting and engaged with the mixed reality environment in a laboratory setting. The videos consisted of 16 minutes for the physical environment, 14 minutes for the virtual environment, and 13 minutes for the mixed reality environment, for a total of 43 minutes of video. For the physical and mixed reality environments, the four students worked as a whole group; for the virtual environment, students worked in pairs with each pair at a separate computer. We also conducted open-ended interviews with six groups of 3 to 4 students (including the videotaped group) after they used the mixed reality inclined plane environment, to ask students about their preferences for using these environments.

We analyzed video data through a combination of an inductive and deductive approach (Patton, 1990). The overall focus on shared referential anchors during collaboration was derived from previous literature, and the specific subcategories of the use of referential anchors were developed inductively from both the student interviews and video data. For the video data, we first coded instances of joint attention around shared referential anchors. We defined an instance of joint attention around a shared referential anchor as one or more members of the group talking about a material resource or representation in the environment (e.g. spring scale, notebook or digital representation) with at least one other member viewing the same reference. We further divided the overall instances of talk around shared referential anchors into several subcategories. The first subcategory was whether each instance of talk constituted only the reporting of data to other group members or whether the talk consisted of more extended conversations about these shared referential anchors. The second subcategory was the specific representations that served as referential anchors. These could include measurement equipment in the physical laboratory environment (e.g. spring scale or meter stick), inscriptions within the student notebooks, or digital representations (e.g. graphs, vectors or numerical values) in the virtual or mixed reality environments. Additionally, a second part of this subcategory was which specific science concepts were represented by the referential anchors. The third subcategory was the timing of these instances: either during a trial in the experiment (i.e., during the process of pulling the brick up the ramp) or after a trial. The final subcategory was the number of students in the group viewed the representation at the time that the talk

occurred. To establish inter-rater reliability, the first two authors independently coded the entire corpus of video data. Inter-rater agreement was 88% for coding total instances of talk around shared referential anchors and 91% for coding the subcategories. All discrepancies in coding were resolved through discussion. We then used the interview data to shed light on our understanding of the video data.

Results

In this section, we first describe differences in instances of joint attention around shared referential anchors across the three environments, and then analyze the subcategories of these instances: the extent of the conversation around the referential anchors, the specific referential anchors utilized, the timing of the instances of joint attention, and the visibility of the referential anchors to all group members. For each of these subcategories, we analyze whether there may be potential advantages of one learning environment over the others in supporting joint attention through the availability of shared referential anchors.

Our analysis showed that there were differences in the total number of instances of joint attention around a referential anchor (see Table 1). While students used referential anchors 10 times each in the virtual environment and mixed reality environments, they only did so 6 times in the physical environment. Furthermore, there were differences in the levels of talk around the shared referential anchors. In the physical environment, 5 out of 6 instances of joint attention involved only reporting data (either from the spring scale or from their notebook) to other group members, whereas one instance involved extended discussion beyond reporting of data. For the virtual environment, 8 of 10 instances of joint attention involved only reporting data, whereas 2 instances moved beyond reporting data to more extended discussions around the data. For the mixed reality environment, 6 out of 10 instances involved only reporting data, while 4 instances of joint attention around shared referential anchors included extended talk beyond reporting of data. Below we describe potential advantages of the mixed reality and/or virtual environments (based on subcategories pertaining to group discourse around shared referential anchors as well as interview data) that may shed light on these differences in group discourse.

Table 1: Instances of group discussion around a shared referential anchor by laboratory environment.

Laboratory Environment	Total Instances of Joint Attention around Referential Anchor	Reporting Only or Extended Conversation	Concepts Represented (Representation Types)	When Instances Occurred	Group Members Viewing Referential Anchor
Physical	6	5 reporting, 1 extended	5 applied force (spring scale) 1 other concept (notebook)	5 during trial, 1 between trials	2-3
Virtual	10	8 reporting, 2 extended	4 applied force (numeric, vector) 5 other concepts (numeric)	1 during trial, 8 between trials	2
Mixed Reality	10	6 reporting, 4 extended	1 applied force (numeric) 9 other concepts (numeric, graph)	4 during trial, 5 between trials, 1 both	3-4

One potential advantage of both the mixed reality and virtual environments over the physical environment was the availability of additional representations that could serve as referential anchors. The virtual and mixed reality environments offered both representations of variables (e.g. work and potential energy) and types of representations (e.g., graphs, numerical values) that were not immediately present in the physical environment. In the virtual and mixed reality environments, students used numeric as well as other representations for joint attention, while in the physical environment, students used the spring scale as a referential anchor on 5 of 6 occasions, and used one student's notebook on one other occasion. In the mixed reality and virtual environments, students also attended to representations of variables (e.g., potential energy, efficiency) that were not immediately available in the physical environment (see Table 1).

A related potential advantage of the mixed reality and virtual environments over the physical environment was the persistence of these representations after each experimental trial was complete (see Figure 2). With physical experiments, students individually wrote down values of applied force from the spring scale, and then could potentially use this inscription in their individual data tables to reason about the data across trials. In contrast, all of the representations provided in the mixed reality and virtual environments during an experimental trial would persist after the trial was complete, providing students with a persistent referential

anchor to publicly make meaning of the data. In the example on the right side of figure 2, one student is pointing toward a graphical representation of work and stating to her group members, “I think work output never changes, because the last time it was [the same].” While in the physical experiment there was only one instance of joint attention around shared referential anchors after a trial (via a student notebook), 8 of the instances in the virtual environment and 5 of the instances in the mixed reality environment occurred between trials (see Table 1).



Figure 2. Students Recording Data after Running a Trial in the Physical (Left) and Mixed Reality (Right) Environments.

One potential advantage of the mixed reality environment over the other two environments was the visibility of the representations to all group members (see Figure 2). By projecting the data onto a larger space, the mixed reality environment allowed the representations to be visible to all students. During the interviews, one group reported difficulty in viewing the spring scale (in the physical experiment?): “I like [the mixed reality environment] cause you don’t have to [try to see the] spring scale.” The video analysis showed that, in the physical environment, only 2 or 3 students could view the value of the spring scale each time the brick was being pulled up the ramp. In contrast, in the mixed reality environment, all students in the group could view the representations presented. Since the videotaped group worked in dyads during the virtual experiment, all group members could see the virtual experiment on one of the two computers, though this restricted instances of joint attention to two of the four group members. In most of our classroom implementations, however, students use laptops in groups of 3 or 4 due to the number of computers available. Of the groups that had performed the virtual experiments in groups of 3 or 4, several students mentioned that they were better able to see everything in the mixed reality environment than in the virtual environment: “It’s a big screen so everybody can see it;” “I like doing it up here cause you can see it better.”

Discussion

Our findings indicate that the mixed reality and virtual environments may offer more opportunities for joint attention among group members than the physical laboratory environment, and that the mixed reality environment may offer more opportunities for extended discussion around a shared referential anchor than either the physical or virtual environments. As with the virtual laboratory environment, the mixed reality environment provides a referential anchor for the applied force that is more visible to all group members than the spring scale in the physical environment. Both the mixed reality and virtual laboratory environments also provide additional types of representations (i.e. numeric, graphical) as well as representations of additional variables (e.g. work, energy) that can serve as referential anchors and that are not available in the physical environment. These representations persist after a trial is completed, which may allow students to use these representations as referential anchors and to co-construct their understanding of the variables even after the trial is complete. Furthermore, the mixed reality environment improves on the virtual environment in that the representations are on a larger screen and are thus more easily visible for all group members and potentially more likely to serve as referential anchors for all members of the group. The availability of these referential anchors in the mixed reality environment may promote mutual engagement and joint attention (Crook, 1995), which are important for students’ collaboration (Barron, 2000). In this study, the greater number of instances of joint attention in the virtual and mixed reality environments may potentially be attributed to the availability of additional representations as well as their persistence after the completion of experimental trials. The greater frequency of extended discourse surrounding the referential anchors in the mixed reality environment may be attributed to the visibility of the representations to all group members; having only a few members able to view referential anchors within the physical and virtual environments may have led to the greater proportion of only reporting data within these environments.

There are additional opportunities for collaboration that could be incorporated into the mixed reality environment. According to Crook (1995), when designing environments for joint activity, we should allow students to perform publicly visible, concrete manipulations with the referential anchors. With this in mind, the mixed reality environment could be designed to further support manipulations of the available representations.

In digitizing the data from students' physical experiments, the mixed reality environments could provide even more flexible and persistent representations, for example allowing students to view and manipulate graphs and tables of their data across many trials. Having these representations available through the system could provide additional referential anchors that could be more easily shared across group members than their current hand-written data tables in their workbooks. Such publicly available representations that persist across time may allow students to utilize their prior activity as a learning resource (Suthers, 2006).

Overall, this study shows that a mixed reality laboratory environment may provide opportunities for collaboration through the availability of shared referential anchors that go beyond what is available in traditional physical and virtual experiments. It also describes several dimensions of the availability of referential anchors (including their persistence and visibility to all group members) that may be important to consider when designing such environments for collaborative learning. Though in this paper we described opportunities for collaboration across three different learning environments, we did not assess students' understanding as it relates to these opportunities. Additionally, with a small sample and without counterbalancing the sequence in which the three environments were presented, it is unclear whether our results are due largely to the learning environments or to the sequence of these environments. In future work, in classrooms with a larger sample, we will investigate how the opportunities for joint attention identified here contribute to students' learning.

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