Augmented Reality in Collaborative Problem Solving: A Qualitative Study of Challenges and Solutions

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Abstract: Augmented reality (AR) can help learners solve problems more effectively during collaborative problem solving (CPS) experiences. In this study we investigate what kinds of difficulties and challenges were encountered by pairs of collaborators as they interacted with a tangible learning activity, with and without AR visualizations; and we suggest AR features to address those difficulties. We qualitatively analyze the behaviors of 8 groups, selected from a larger study in which participants interacted with an augmented speaker. We identify episodes where collaborators show struggles during CPS, discuss types of difficulties encountered, and use existing literature to suggest AR features that address the identified issues.

Introduction and Related Work

Collaborative problem solving (CPS), defined as the capacity of individuals to solve problems by joining their knowledge, skills, and efforts with others, is a fundamental competency to modern workspace and societal needs (OECD, 2017). Appropriate design of CPS learning experiences allows learners to develop the skills needed to successfully build knowledge and solve problems in collaborative settings. Existing research on CPS has been focused on measuring specific constructs to predict collaboration quality, by measuring interpersonal competencies (Oliveri et al., 2017). Augmented Reality (AR), which is the mixing and incorporation of virtual and real content (Milgram et al. 1995), has the potential to help collaborators during CPS activities. When investigating how new technologies such as augmented reality can be designed to improve collaborative learning, educational designers need to understand the specific difficulties that learners encounter in traditional CPS activities and what new technological features could be designed to address them. In this research we study how this can be achieved when designing augmented reality to improve CPS learning experiences.

Augmented reality has been shown to improve learning processes by reducing cognitive load, connecting intangible phenomena to observable graphic representations, or improve learning by making abstract concepts more intuitive, thus improving the retention of the learned materials (Radu, 2014). The use of AR media has been shown to impact dyads' behavior and communication when compared to non-AR groups (Unahalekhaka et al., 2019; Hung-Yuan, 2014), and research in higher education settings shows that the use of AR during CPS activities influences the time spent at different points in the CPS process such as organizing and interpreting data (Hung-Yuan, 2014). In this work, we contribute to research by comparing what difficulties are encountered as collaborators engage with an existing learning experience under AR and Non-AR conditions, with the goal of identifying new AR features that can be implemented to improve the CPS experience. We apply a granular analysis of learner behaviors to answer the following research questions: RQ1: What difficulties are encountered during the collaborative problem-solving learning activity, and how do they differ between AR vs. non-AR contexts? RQ2: What AR features can be used to reduce or prevent these difficulties from arising?

Methods

We use data collected from a previous study (Radu & Schneider, 2019) where 60 dyad pairs interacted with a loudspeaker system (Figure 1) designed for encouraging learner explorations of how sound, electric current and magnetic fields are related. Participants could interact with the system by playing music through a headphone connection from a smartphone, pushing buttons to change the amplification and direction of electricity, and moving the speaker membrane (a cup) to explore its effects on sound output. Study participants were split into two groups, either seeing augmented reality educational visualizations ("AR" group), or not ("Non-AR" group). Participants in the AR group received the same system, physical tools, and printed poster information as Non-AR group, but also could see the poster information as represented in augmented reality visualizations (Figure 1) shown as component labels, and visualizations of audio sound waves, electric currents, and magnetic fields. These representations were provided in static form for the Non-AR condition. For this paper we qualitatively analyzed a subset of 8 groups, where half saw educational AR (AR group) and half did not (Non-AR groups). Half the groups were selected having strong collaboration scores and half low scores, using the rubric from (Meier et al., 2007), done to ensure variety of collaborations and balance within conditions, and was not analyzed separately.

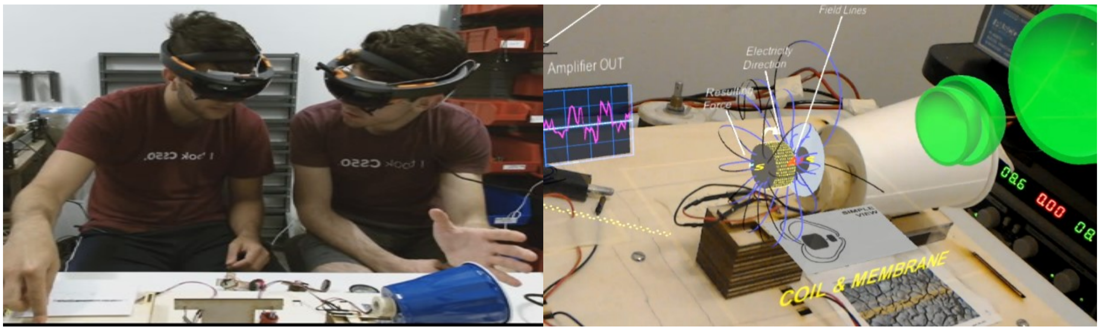

Figure 1. Two users interacting with the system (left). Physical model with educational AR overlays (right) showing electricity (yellow electrons, blue bar charts), magnetic fields (blue lines), audio visualizations (green).

To answer the research questions, we analyzed data using a 2-phase process, which identified types of collaborative problem solving difficulties and determined what AR features may address those difficulties. The first phase involved analyzing videos to detect possible indicators of difficulties in collaboration or problem solving. To detect such moments, we created a coding scheme to identify instances where participants may be having difficulties in the categories of searching for information, communicating information, or leading the activity. The coding scheme was applied to videos from the 8 groups (total 5.36 hours) in 15-second intervals. Each code was tagged if it was present during a 15-second time interval, and multiple codes could be tagged for the same time interval. For inter-rater reliability (IRR), two raters coded 20% of the videos and reached a Cohen-Kappa of .85, which implies substantial agreement. After the IRR test, one researcher coded the remaining 80% of the videos. We then reviewed the tagged time intervals to identify episodes of active collaboration, defined as time periods where at least 3 of the behaviors in the coding scheme were marked during 2 intervals (30 seconds) or more. In the second phase, the video recordings were reviewed by one researcher during those time intervals of active collaboration, to determine the specific difficulties participants encountered during those episodes, and using thematic coding to yield the results presented below. After identifying these categories, we generated augmented reality features that may prevent such problems, by reflecting on existing AR literature.

Results

In this section we discuss the difficulties identified during CPS learning, highlighting differences between AR and Non-AR groups, and we present features that AR systems may provide to address these difficulties. When examining the 8 group videos for this study, we marked a total of 710 time intervals where at least one behavior in the coding scheme was present, yielding 40 episodes of collaboration difficulties. 18 episodes arised in AR groups, and 22 in Non-AR groups. The 40 episodes were organized into the following 5 problem categories:

Lacking Understanding of Representations: This category happened to 7 of the 8 groups (3 AR, 4 Non-AR) and includes moments where participants struggle to reach consensus about how a phenomenon should be defined or represented. This includes situations where reaching consensus is difficult due to imbalanced knowledge, or due to participants misinterpreting the representations from the AR system, or struggling to represent imaginary shapes with available tools. The source of the problem is the difficulty of representing intangible phenomena when the concept has not been understood by both participants. While Non-AR had difficulties discussing the static information accessible to them, the AR groups encountered some issues interpreting 3D dynamic information. AR environments can provide capabilities for participants to generate other representations of invisible phenomena, such as through drawings and gestures. AR features can allow participants to create 3D structures (Kaufmann, 2003) or draw in 3D space to enhance mutual understanding (He et al., 2019).

Lacking Perceptual Information and Causal Relationships: This category happened to 7 of the 8 groups (3 AR, 4 Non-AR), and contains difficulties originated by one or both participants expressing inability to perceive a phenomenon because of perceptual issues such as their vision being blocked, or inability to hear the speaker. Blocked access to sensory information limits participants' capability to understand the problem at hand and to engage in collaborative learning, because participants are unable to discover the connections and ideas necessary to build knowledge and understand the explanations of the studied phenomena. AR features such as show-through techniques can help users to see the objects that are occluded by others (Argelaguet et al., 2010). The users could also be alerted when there is an important change in the system (García et al., 2008), and when in doubt of their decisions, they can use reviewing tools to compare their options (Xia et al., 2018).

Lack of Awareness of Other Person: This category occurred in 4 of 8 groups (1 AR, 3 Non-AR), and includes episodes where a participant is not aware of what their peer is focusing on. This includes cases when participants do not know each other's actions, or they cannot confirm if the peer is aware of a situation, impacting the problem-solving process or slowing the dyad's progress when solving tasks. When participants have poor awareness this limits their engagement with each other and with materials and resources and impairs participant's opportunities to contribute during discussions and reflections (Gutwin & Greenberg, 2002; Mathieu et al., 2000). In our study, groups with AR visualizations, such as the virtual text labels and diagrams, encountered fewer difficulties while remaining aware of each other. We suggest AR features to further increase peer awareness and prevent difficulties in this category. Virtual pointers have been shown to help peers understand what a collaborator is referring to (Bauer, 1999). Field of view indicators can help learners stay aware of what objects are inside their peer's vision, and enhance collaboration (Piumsomboon et al., 2019). Or, participants could see from each other's point of view via a small AR video window, such as presented in (He et al., 2019).

Lacking Easy Access to Information and Resources: This category occurred in 4 of 8 groups (1 AR, 3 Non-AR), and refers to episodes where either a participant lacks access to resources, or the person is left out of participating while the peer controls the tools and system, or participants struggle to link information from the wall poster to the physical system. Previous research of the same AR speaker system found that dominant behaviors are less detrimental to collaboration when participants have AR visualizations, likely because both participants have easier access and improved visibility of information (Radu & Schneider, 2019b). To enhance this ability, AR systems can employ sharing one's viewpoint with peers (Szalavári et al., 1998) or use a snapshot to prevent situations where information may be lost over time (Lee et al., 2020). The system can also be designed to encourage participation by requiring both collaborators to take an action to proceed (Piumsomboon et al., 2019).

Lacking Memory or Background knowledge: This category occurred in 4 of 8 groups (1 AR, 3 Non-AR), and refers to events where participants are confused about the name or function of an object or tool or do not have the vocabulary to describe an object or phenomenon, and situations where participants lack the necessary background knowledge to progress in the task or an inability to remember the past actions during an experimentation process. This limits learners' performance during CPS activities and their ability to progress in the task. Of all groups exhibiting this category of events, indicating that AR representations such as text labels and visualizations helped participants to remember the names and functions of system components. Features such as virtually writing or drawing directly on top of the system objects may help reduce problems related to definitions and memory (Aschenbrenner et al., 2018). AR can also help users track what system components have been interacted with (Benko et al., 2004) and a collaborative session could be recorded and replayed (Greenwald et al., 2019). Users can also explore different steps of an AR pre-recorded tutorial, an approach that has shown to encourage learning and experimentation (Kaufmann, 2003).

Discussion

The results show that difficulties occur in both AR and Non-AR settings, but that augmented reality visualizations mediate the kinds of difficulties encountered during CPS processes. For example, in the case of lacking perceptual information, AR participants had problems related to key information being blocked by their position or their peers, thus increasing the difficulty of solving the task, while in the same category the Non-AR dyads had more problems related to limitations in their perception such as an inability to detect sound or movement. Moreover, problems grouped in the categories of lacking memory or background knowledge, as well as lacking easy access to information resources, were predominantly populated by Non-AR dyads. Thus, while both AR and Non-AR dyads experienced problems related to all categories, the nature of the problems did vary, revealing an effect of AR during CPS learning activities.

Designers working with other educational technologies can benefit from using this process to identify problems and needs. Educators aiming to incorporate AR in their classroom might find it useful to use the listed features in order to prevent the detected problems from happening, thus avoiding the identified problems from impairing student learning. It is important to note the limitation that the problems detected in this study are from a small sample (8 groups) and are heavily influenced by the design of the speaker activity. Future work should observe larger datasets and different activities to find commonalities and expand our understanding of issues that arise during CPS learning activities. Additionally, the method used in this research could be useful for designers working with other technologies to make sure their developments address existing problems and improve the quality of learning activities.

In conclusion, we found that AR and Non-AR participants encounter problems during the CPS learning activities, but the nature of problems change, and the saliency of the problem varies according to the AR and Non-AR conditions. Identifying these problems is useful to ideate AR system features that allow learners to spend less time on difficulties and instead focus on exploration, interpretation, reflection, and learning.

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