Designing a Multi-user Interactive Simulation Using AR Glasses

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Abstract
In this research, we present the design and formative evaluation of an interactive simulation for informal learning environments. The wearable feature of Augmented Reality(AR) glasses enables full-body movement and embodied interactions in digitally augmented physical environments. The interactive simulation was developed to engage and immerse users to understand an abstract scientific concept about the refraction of light. To design playful and meaningful learning experiences, several design features related to social interaction, multi-user interaction, and embodied interaction were unpacked and integrated in the design process. Through the formative evaluation with participants in the laboratory setting, we found several possibilities and challenges about designing an interactive simulation in informal learning contexts using AR glasses.

Author Keywords
augmented reality; computer-supported collaborative learning; embodied interaction; interactive simulation; AR glasses; optical see-though displays; projected AR.

ACM Classification Keywords
H.5.1 Information interfaces and presentation: Multimedia Information Systems - Artificial, augmented, and virtual realities

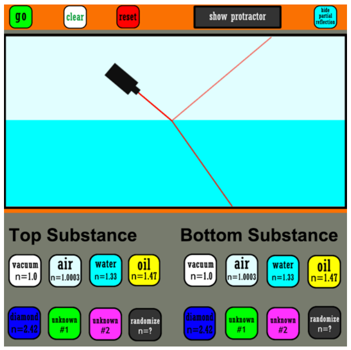

Figure 1: Example of conventional interactive simulation for light refraction [6].

Introduction

The main purpose of this research is to design a multi-user simulation leveraging the affordances of wearable technologies such as Augmented Reality(AR) glasses in a science museum context [7]. For the past decade, there has been growing awareness of the important role of informal spaces for providing playful and creative learning experiences [2,7]. The nature of learning in such informal learning spaces is unique that learning experiences tend to be self-directed, emergent, unstructured, and social [7]. With the overarching goal of designing playful learning through gesture computing, this research particularly focuses on the rich opportunities for experiential and social interaction offered in informal learning spaces and explores how the advances of wearable technologies can mediate playful learning experiences among museum visitors.

This paper entails the design and implementation of a simulation with optical see-through AR glasses. interaction patterns among visitors at science museums indicate several challenges in exhibit design and missed opportunities for learning. Firstly, many of gesture-based learning environments were not designed to support both the subjectivity and multiplicity of visitor experiences [1], hence resulting in superficial and short-term engagement. Moreover, the public nature of exhibits at science museums leaves several design issues regarding how to establish connections among visitors through social interaction [1,4]. In sum, we suggest the need for interactive mechanisms mediating engagement with multiple co-located visitors who are potential learners as well as those directly interacting with an exhibit.

Recognizing the aforementioned need, we have been exploring the possibility of designing a multi-user, gesture-based simulation at digitally augmented physical enviorments using the glasses-type AR. From the theoretical lens of embodied interaction design, which foregrounds the interwoven nature of body, mind, and knowledge, we have designed an interactive simulation where visitors learn about the complex scientific concept through full-body immersion mediated through the AR glasses that enables the engagement of multiple co-located users and the seamless integration of physical and virtual spaces. In this paper, we present our on-going research of the interactive simulation and the results from the formative evaluation of the pilot design.

System Design

ARfract: AR simulation environment

The ARfract is a room sized simulation environment augmented with interactive technologies. Through the simulation, visitors can have learning experiences about an abstract scientific concept that covers the propagation of incident light and refraction at air-water boundary.

The system design of the simulation includes the integration of three main components: optical see-through AR glasses, projected AR on the floor, and physical space in an informal learning context (Figure 2). Specifically, AR glasses play a critical role to provide personalized augmented information in Figure 4c & d (e.g., scaffolding instructions, simulation of scientific phenomenon in ego-centric viewpoint) to each visitor and receive gestural inputs. Compared to the previous AR applications, glasses-type AR sets both hands free from holding a visualization media. In addition, the

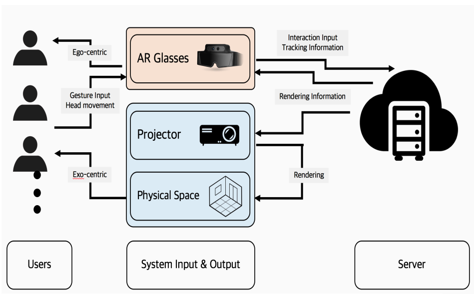

Figure 2: ARfract system infrastructure and data flow.

Figure 3: ARfract in use at the laboratory setting. A user performs grab & release gesture to fire light and the other observes it. White line is velcro for sticky floor; blue line & ball for the light.

transparency of our glasses-type AR provides a novel experience of tightly coupled digital-physical world. The projected AR provides exocentric viewpoints of the simulation to visitors, which affords a global situational awareness that helps visitors comprehend the simulated phenomena easily [3] (Figure 3).

ARfract is digitally augmented with both first person view (egocentric) and top down view (exocentric) controlled by head tracking and hand gesture inputs (ego-referenced control). This configuration (like the ego-referenced handle control of driving experience with both car navigation and driving scene) is expected to provide more presence and immersion with global situation awareness [3] compared to a desktop interactive simulation for top down view (exocentric) only in Figure 1. Through the use of the projected floor and the transparent AR glasses, it is possible to combine individually augmented space and shared public space, thereby extending learning experiences in physical and virtual realms. As the system architecture of the AR simulation shows in Figure 2, the system I/O control information is transmitted and distributed by the system server. In sum, through the use of the AR technologies, the simulation can a) accommodate multimodal playful learning, b) provide opportunities for more interaction possibilities with visitor's free body and hand movements (e.g., embodied interaction with a digitally augmented space and social interaction among multiple co-located visitors), and c) provide an intuitive and straightforward presentation of abstract concepts.

Learning goals

From learning perspectives, our research goal is to design an interactive simulation at informal learning contexts where learning processes takes place in more self-directed, vicarious and collaborative ways. Through the simulation, visitors do not passively receive and accommodate information from the learning environment. Instead, we expect them to actively speculate and reflect on outcomes from the interactive simulation. To help visitors have more time and opportunities to explore and reflect on the digital interactive environment, interactions should be designed to effectively scaffold less structured learning compared to formal learning environments. Therefore, we designed our digitally augmented informal learning environment: 1) to encourage in-depth observations and discussion among learners and even watchers in an informal learning space, 2) to accept natural body movement as an input based on a perspective of embodied cognition, and 3) to naturally guide learners to transfer their learning experiences to more sophisticated understanding.

Interaction Design

We have explored the possibility of designing a multi-user, gesture-based simulation leveraging the affordances of wearable technologies such as AR glasses (Figure 3). A physical space is digitally augmented with the AR glasses worn by any individual visitors. Our design supports and focuses on the case of two participants because the group of two visitors was the most common among visitor group distributions in informal learning environments. The simulation can encompass a wide range of visitor groups. Single users can play the simulation alone, and adding the glasses to the system allows multiple users to perform the simulation simultaneously. Further, we used a top down projection on the floor for interactive mechanisms mediating engagement with multiple watchers and

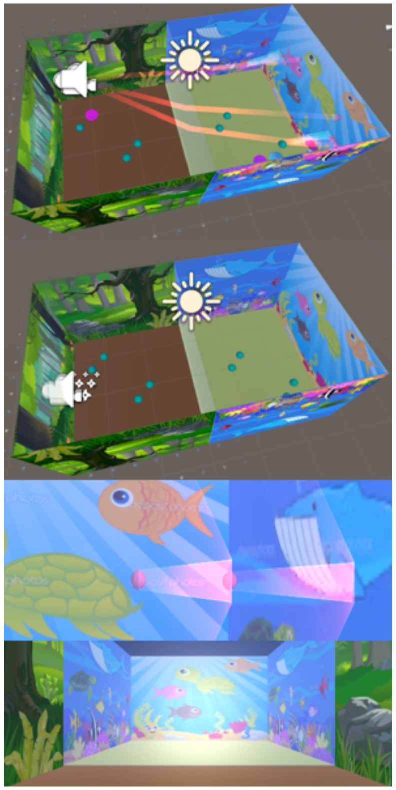

Figure 4: Screenshots of ARfract. a) traces of lights, light trail history, active position of users in red sphere and deactivated position in green; b) 8 user positions; c) ball and light trail presented; d) virtual background and boundary.

passer-by visitors who are potential learners as well as those directly interacting with an exhibit (Figure 3). Through this system design, we expect active and comprehensive social interaction among multiple co-located visitors.

On the basis of embodied cognition, we expect that individual interactions at our simulation, together with actions of learners and feedback from the system, can give visitors strong motivation for learning. Therefore, designing the physical actions at digitally augmented physical space requires us to consider how digital augmentation and physical space is coupled to encourage body movements that facilitate learning at our simulation [5]. Externalized cognition of learners should be visualized as feedback from our simulation, which allows the learners to reflect on and explore their interaction with the simulation. We suggest that coherent connection between the body movements and simulation output is essential for embodied learning experience to be successful. Based on these design considerations, more detailed descriptions about the simulation, ARfract, and its design features are as follows:

- Position & Turn-taking: Total of 8 positions at green sphere in Figure 4a & b. 2 distance from the imaginary boundary (close or far); 2 shooting direction (from water or from air); 2 interaction status (shooting or observation). For knowledge transfer to Snell's law, effective multi-user interaction, and social interaction.
- Grab and release gesture: grab the light, move arm to aim, release to fire controls the direction of light (Figure 3). For embodied interaction.
- Light at AR glasses: Egocentric viewpoint (Figure 4c). Ball (leading gaze and emphasis on travel of light path); Real-time rendering of light trail (emphasis on refraction of light). For transfer to Snell's law.
- Light on the floor: Exocentric viewpoint (Figure 4a). Recent three trails (reflection, memory, and self-directed learning). Learning aid for both active participants and watcher. For transfer to both total reflection and Snell's law.
- Become a light: Walking on the light trail and walk back while looking at the most recent light trails & Sticky velcro floor at water side (congruency between bodily action and learning concepts). For transfer to Snell's law and embodied interaction.
- Virtual boundary at the center: AR environment design in Figure 4d (water in the sea background & air in the forest background). For intuitive mapping and coherency between digital and physical space.

Evaluation

We used a see-through AR glasses (Meta One) with 960 x 540 resolution with 23-degree field of view. The AR glasses provide 9-axis Inertial measurement with 360-degree head tracking and 3D time-of-flight depth camera to receive gesture inputs. Projector (Panasonic PT-CW331rea) was set to present to top down projection with a resolution of 1280 x 800 on an area of 3.2 m x 5.44 m. For application development and rendering, Meta One SDK and Unity 3D were used.

We performed formative evaluation with 10 dyads (20 participants) of both gender (14 males and 6 females), aged 12-14 years old. Only two participants had prior experiences with mixed reality. The procedure for the formative evaluation was 1) to practice firing gestures with text guide, 2) experience the simulation with 8 turn-takings, and 3) to participate in a semi-structured interview. During the experience session, dyads with AR glasses were instructed to stand on a shooting position and an observation position, and change the positions when each turn is over. There were 4 shooting and observation positions for each participant. While a participant at the observation position was watching, a participant at the shooting position performed a grab and release gesture to fire light. A ball indicating the forefront of light and trajectory of light was presented to the dyads through AR glasses. The light refracts when crossing the boundary of air and water. Participants were instructed to fire diverse directions until they wanted to close their own turn. Three recent trajectories remained on the floor and the shooting participant walked through one trajectory and walked back. At the water side of the floor, velcro attached on the floor disturbs the walking action of participants. Interaction logs including shooting counts and total reflection phenomena counts, were recorded throughout the session.

In order to observe interaction patterns and user experience at our interactive simulation, we analyzed data from interaction logs and interviews. From the log data, participants had shooting and observation at 27.55 times each (mean) and observed total reflection 4.3 times (mean) accounting for 8.1% of total sessions. Only one pair did not have a chance to observe total reflection. Some participants surprised or asked each other when the light reflects toward them. Participants' comments from the interviews were classified to four categories: strengths and weaknesses of wearable interaction, satisfaction with AR experiences, self-directed and exploratory experiences, and effectiveness of embodied experiences.

Strengths and weaknesses of wearable interaction
Most participants wearing spectacles say "the AR glasses is too bulky and heavy"; however, some reported that following effects of glass-type wearable and head-tracking functions supported learning experiences because they did not have to care much about controlling the augmented visual presentation. Due to the lack of sensor fidelity, the augmented graphics and real world position were sometimes decoupled as time goes.

Satisfaction with AR experiences
For AR features, participants described that the invisible and intangible light seem to really exist and some even reported about the presence that "It seems that I am really present in the virtual world". Most participants were satisfied with the design features to display the light such as the trajectory of light and its refraction.

Self-directed and exploratory experiences
Many subjects describe that the simulation was helpful in learning because they could manipulate the simulation with no restriction by others and could adjust the phase. The simulation experiences afford enough time and opportunities to reflect and explore. One participant described the fact that the augmented contents are private, which makes him relieved and comfortable. These findings stem from the private nature of glass-type AR, which is an important factor to design interactive simulations with AR glasses.

Effectiveness of embodied experiences

Overall, gesture interaction that they control the direction of light and shoot it evokes the satisfaction that they have power to handle originally impossible phenomena and artifacts. Some participants described the reason that they actually moved their body while engaged in the simulation helps better comprehend the scientific concept. The participants commented that "Velcro at the water side disturbs walking, and it is well designed to grasp the fact that speed of light slows down inside the water". Also, some participants said, "Turning their body to follow light trail at the boundary helped me to realize differences between incidental angle and refraction angle". Our design of embodied interaction seems to affects cognition by effectively mapping body movements and scientific phenomena.

Conclusion & Future Work

The contribution of this on-going research lies in that it exemplifies how the affordances of wearable technologies could support meaningful learning to learn about complex science phenomena in informal learning settings. In this paper, we also raise design issues and remaining challenges that relates to how such wearable AR technologies supporting gesture-based interaction with multiple users need to be designed to support the strong congruency between action and conception. In the further study, we will explore the pedagogical and technological design of the mixed reality exhibit, detail the effect of the design features, and unpack how visitors are engaged with this simulation through the in-depth analysis of observed interaction and discourse.

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