Interacting with Augmented Reality: how does location-based AR enhance learning?

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Abstract. Augmented Reality (AR) can provide additional information about mediated events, but can it enhance our learning and comprehension? We performed a user study of a location-based AR application in order to answer this question. A 2-condition (AR modality vs. non-AR digital book modality) between-subjects experiment with 36 dyads of secondary school students in Singapore was conducted to examine how the use of AR modality in an educational context impacts students' learning performance. Data from the experiment showed that location-based AR improved students' learning performance by catching their attention and enhancing their ability to elaboratively process the information they encountered. Theoretical and practical implications are discussed.

Keywords: Location-based AR, modality, learning, transportation.

1 Introduction

Augmented Reality (AR) development is booming today, providing a contextual layer of extra information (e.g., images, locations, sound, etc.) to add on to user perceptions of the physical environment. Numerous applications have adopted the AR technology into their design, such as in the fields of gaming, entertainment, tourism, marketing, and social networking. However, as the industry is busy developing new apps to improve their design, little is known about the psychological effects of AR, and related user-experience outcomes. For example, AR is being touted as a promising tool for enhancing education, but we do not know how the use of an AR app compared with other digital educational tools can impact students' learning performance. Therefore, our study investigates the impact of an AR game, "the Jackson Plan," on students' learning performance, and attempts to explore the psychological factors that may mediate the relationship.

1.1 Augmented Reality

Augmented Reality (AR) is a new modality of presenting information, whereby a contextual layer of computer-generated virtual content is superimposed on a mediated representation of the real physical world. AR blends the real and virtual worlds seamlessly, constantly changing the ways we experience and interact with the physical environment. With the arrival of mobile media, this technology is on the verge of being adopted ubiquitously in our daily lives to enhance what we see and feel. In 2010 alone, AR mobile applications were downloaded more than eleven million times. By 2015, the number of downloads is estimated to exceed one billion per year [1]. Among these applications, for example, AR has been designed as a tourist guide on mobile devices [2], a shopping assistant in e-commerce websites [3], and a way to promote learning in an educational environment. According to the 2011 Horizon Report, AR technology will be widely employed in US universities in the next two to three years, as a way to assist teaching inside or even outside the classroom [4]. These educational AR applications include AR books, AR gaming, object modeling, skill training, etc., which aim to enhance students' learning.

1.2 Psychological Effects of AR

Due to its unique characteristics, AR may have a psychological effect on users in various ways. The most representative and appealing feature of AR is its ability to superimpose extra information into the real world based on sophisticated display technologies, which, on the one hand, increases the viewability of the interface and contextualizes the information, but, on the other hand, runs the risk of demanding too much user attention to encode the supplemental information. Limited Capacity Theory [5] would argue that cognitive resources directed towards encoding the message come at the cost of storing the contents of the message for later retrieval, thereby resulting in poorer memory, and therefore inferior learning outcomes. While AR certainly runs this risk of privileging encoding over storage, many AR games and apps are tied to real-world locations, allowing users to view the world through a web camera on their devices with additional information superimposed by the app, which may provide users a sense of presence, or physically being in the environment [6], thus leveraging their engagement with the content (i.e., mental "transportation" into the narrative [7]), eventually enhancing users' cognitive information processing and memory. Under this alternative view, AR will serve to enhance the user's "perceptual bandwidth" [8] such that the user is able to process more information more efficiently and thereby achieve an enhanced mental representation of mediated reality. Given these potential psychological paths to user outcomes, how AR can influence users' learning performance is unclear. Therefore, we experimentally examine how the use of AR modality in an educational context impacts students' learning performance as well as their user experience.

2 Method

2.1 Design and Participants

A 2-condition, between-subjects (location-based AR modality vs. non-AR digital book modality) experiment was conducted to answer the research questions. Participants were recruited from 3 Secondary One history classes in a public school in Singapore. The students were selected by a teacher to ensure social and cognitive homogeneity. In all, we had 72 students participating in the study. Since the procedure required students to work in groups of two, we had a total of 36 dyads for random assignment to the two experimental conditions. None of the students had learned about the historical event described in the application, which was a history class chapter for their grade, before the study, and all of them had some experience of playing games on handheld devices.

2.2 Stimulus Material

Two applications containing the same interactive game were developed for this study, one of which contained AR features while the other one was a digital book. The content presented by the two different modalities was identical. An Apple iPad 2 was used in both conditions as the primary device via which they experienced the educational content. The content followed a narrative structure. In the story, “The Jackson Plan” map, which was the original city plan map of Singapore, was stolen, and the participants were asked to locate the missing map by talking to different original immigrants (non-player characters or NPCs, see Figure 1) and collecting clues from their conversations. The story was created based on information about the founding of modern Singapore and the life conditions of its original immigrants. As the original immigrants’ trading center, Singapore River was chosen as the physical corresponding location for the location-based application. While students were walking, a map of Singapore River (see Figure 2) would show up on the iPad screen, on which students’ current location and their next destination were indicated. There were 6 destinations in all, representing the starting point, ancient trading spots of British, Chinese, Indians and Malays, and the final destination. Once the student arrived at a spot, the location-based service would automatically trigger a NPC’s appearance on the screen, and then the NPC started to talk to the student. Besides, four mini-games were embedded in the narrative story to help students understand and learn different immigrants’ specific trading activities. Similarly, the mini-games were also triggered by the GPS. AR features were embedded in several steps. For example, when participants arrived at the destination, which was the statue of Raffles, they needed to capture information on the statue using the iPad to trigger a newspaper page on the iPad screen indicating who had stolen the map. While for the digital book application, students just needed to tap the iPad screen to proceed from screen to screen and get the newspaper page at the end, thus featuring no interactions with objects in the real world.

2.3 Procedure

Each dyad of participants was randomly assigned to one of the two conditions. In the experimental condition, students were taken to the Singapore River to complete their session (see Figure 3). A moderator was assigned to accompany each dyad of students. After briefly introducing the game, the moderator started the game and gave each dyad an iPad. The 18 dyads of participants in the control condition completed their session in a classroom in their school. After completing the game, each participant was asked to complete two paper-and-pencil questionnaires. Then, researchers bought each participant a meal, and asked them not to discuss the experiment with others.

Fig. 1. Non-player character

Fig. 2. Real artifact and game maps

Fig. 3. Outdoor AR players vs. indoor non-AR players

2.4 Measurement of Learning and User Experience (UX)

Two questionnaires were used to measure participants' learning and user experience. One questionnaire contained 20 multiple-choice questions testing their ability to recognize factual information and knowledge embedded in the game, such as information about the history of modern Singapore's founding and the trading activities of original immigrants. Another questionnaire contained 40 items which participants rated using a 5-point Likert-scale ranging from 1 (not at all) to 5 (very much). Learning motivation was measured by 11 items, two of which pertained to intrinsic goal orientation (r=0.60, e.g., the most satisfying thing for me in playing "The Jackson Plan" is trying to understand the historical content as thoroughly as possible), 5 referred to task value (α=0.84, e.g., I think learning history in playing "The Jackson Plan" is useful for me to learn), and 4 to self-efficacy (α=0.86, e.g., I'm confident I can understand the most complex materials presented by "The Jackson Plan"). Learning strategy was measured by 7 items, among which elaboration was measured by 4 items (α=0.85, e.g., when playing "The Jackson Plan", I try to relate the material to what I already know) and peer learning was measured by 3 items (α=0.75, e.g., when studying for history, I will try to explain the material to a classmate or a friend). In addition, game engagement was measured by 7 items (α=0.80, e.g., I feel my mind wandering when I am playing "The Jackson Plan"). Telepresence was measured by 3 items (α=0.80, e.g., when I am playing "The Jackson Plan", I have a sense of "being there"). Perceived novelty of the application was measured by 5 items (α=0.77, e.g., the way in which "The Jackson Plan" was presented is novel). Transportation was measured by 7 items (α=0.84, e.g., I was mentally involved in the story while playing "The Jackson Plan"). Aside from these self-report measures, the applications in both conditions automatically recorded the time that participants spent on the application.

3 Results

We first conducted a MANOVA by considering all the dependent variables. The results showed a significant effect for modality, Wilks' Λ=.64, F (10, 61)=3.45, p<.01. Univariate results confirmed a main effect of modality on intrinsic goal orientation, F (1, 70)=7.20, p<.01, task value, F (1, 70)=9.74, p<.01, self-efficacy, F (1, 70)=5.57, p <.05, elaboration, F (1, 70)=11.50, p<.01, telepresence, F (1, 70)=11.00, p<.01, transportation, F (1, 70)= 8.91, p<.01, and learning performance, F (1, 70)=10.76, p< .01. On all variables, participants in the location-based AR condition scored higher than their counterparts in the digital book condition.

Since participants in the location-based AR condition spent much longer time (M=29.51, SD=4.73, counted in minutes) to complete the whole game than their counterparts in the digital book condition (M=9.40, SD=2.78), the analyses were repeated with time as a covariate. In addition, perceived novelty was also controlled to rule out its effect. Results of ANCOVA analyses showed that, with time and perceived novelty controlled, participants in the AR condition still reported higher level of task-value (F (1, 58)=4.06, p<.05), more self-efficacy towards learning history from the application (F (1, 58)=4.66, p<.05), more elaboration (F (1, 58)=3.95, p=.05), more engagement (F (1, 58)=5.03, p<.05) while experiencing the game, and showed better learning performance than those in the non-AR condition (F (1, 58)=3.96, p<.05).

Multivariate regression was performed to test the relationships between measured variables. The results showed that with time and perceived novelty controlled, participants' amount of elaboration during playing the game was significantly correlated with their leaning performance (b=.85, t (51)=2.04, p<.05). Similarly, participants' amount of elaboration (b=-.35, t (52)=-2.00, p<.05), engagement level (b=.24, t (52)=2.52, p<.05), and telepresence (b=.38, t (52)=3.31, p<.01) were significantly correlated with their transportation level.

A series of mediation tests using the PROCESS Macro [9] was conducted to explore the mechanism underlying the effect of AR on students' learning performance and transportation level. The results showed that the modality influenced participants' learning performance through a three-step mediation model. The two modalities led to different levels of engagement, and participants' engagement further influenced their amount of elaboration, which in turn affected their learning performance, *b*=.32, 95% C.I. from .02 to 1.06, *SE*=.24 (see Figure 4). The modalities influenced participants' transportation level through two paths: firstly, engagement level of participants mediated modality's impact on transportation, *b*=.28, 95% C.I. from .01 to .92, *SE*=.21; secondly, modality influenced participants' engagement, and their engagement level influenced telepresence, which then in turn influenced the transportation, *b*=.30, 95% C.I. from .02 to .88, *SE*=.20 (see Figure 5). However, transportation did not predict participants' learning performance. Nor did it mediate modality's effect on learning.

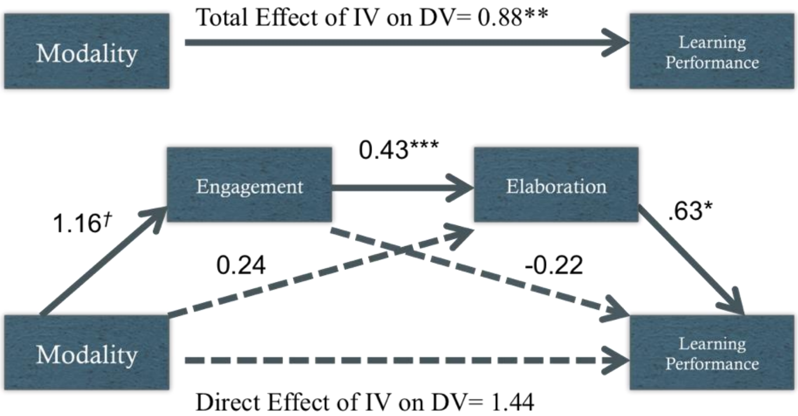

Fig. 4. Regression coefficients (†p < .10, *p < .05, **p < .01, *** p < .001; solid lines indicate a significant indirect path). IV refers to independent variable and DV refers to dependent variable, which are modality and learning performance respectively in this model. The modality variable had two values; with 0 representing digital book condition and 1 representing the location-based AR condition.

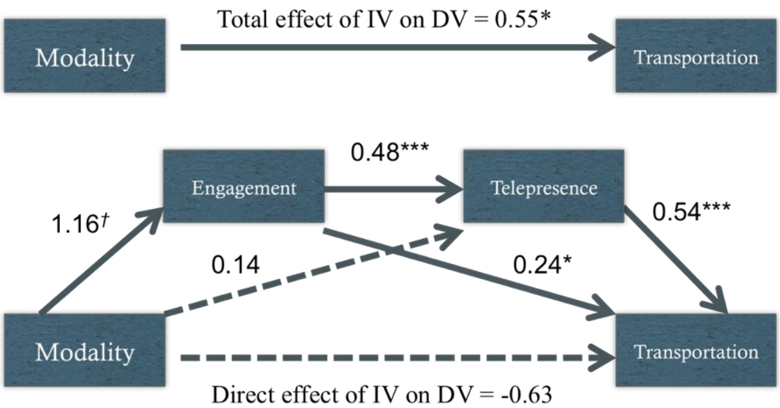

Fig. 5. Regression coefficients (†p < .10, *p < .05, *** p < .001; solid lines indicate a significant indirect path). IV and DV are modality and transportation respectively in this model.

In summary, this study found that location-based modality could enhance students' learning performance by making them engaged in the task and facilitating them to elaborate on the information they encountered. Similarly, location-based modality was also more likely to transport users away from the physical world and make them immersed in the virtual narrative world. Users' enhanced engagement and telepresence mediated this process.

4 Discussion

Our findings show that location-based AR modality improves users' learning performance by enhancing their engagement and ability to elaboratively learn information from the application. The elaboration variable mainly referred to students' ability to put together information from different sources (e.g., narrative, mini games) and make connections between new information and their prior knowledge, history and the game event, virtual event and real world activities. The present study provides practical evidence that location-based AR modality, by enabling users to augment the real world environment with virtual features, generates greater engagement with the content, thereby improving learning performance. Therefore, AR holds promise a potentially useful avenue for educators to fully engage students and achieve desirable learning outcomes.

Our study also found that location-based AR modality had an effect on users' transportation level by leveraging their level of engagement and strengthening their feeling of presence in the virtual world. Since transportation is an important determinant of narrative's persuasive effect on audience, AR can serve a persuasive function [10]. Digital content designers who want users to be immersed in their content should try to use location-based AR modality to present the content, so as to provide users a feeling of actually being in the narrative world. This can be particularly useful for digital story-telling and other forms of informational, as well as entertainment, narratives delivered via devices that can support AR. It can also help marketers persuade users about their products and services by affording greater transportation into the narratives constructed.

A common concern with any new technology is that the technology's effect may be caused by the novelty effect, which will fade away as the technology becomes common. However, in our study, participants in the digital book condition reported slightly higher perceived novelty (*M*=3.54, *SD*=.76) of the application than their counterparts in the location-based AR condition (*M*=3.51, *SD*=.61). Therefore, we can rule out this alternative explanation in this study.

A limitation of this study is that although students worked in pairs, their data were collected and analyzed individually, without controlling for their dyad membership. Due to a technical failure in the study protocol, information about which two participants worked together was not captured by study administrators. Another, more important, limitation of this study is that while participants in the experimental condition completed their session in the outdoor environment, those in the control condition completed all the procedures in a classroom. Therefore, one may argue that it was the actual historical site, but not the AR technology that made the experimental stimulus outperform the stimulus of control condition. However, based on several factors, we believe this alternative explanation is unlikely. First, the Singapore River is totally different from what it looked like 200 years ago. The area used to be a trading center, but now all the old buildings were replaced or used as modern restaurants, so study participants were not able to get any relevant information about the history of Singapore or the immigrants' trading activities by simply being in the environment. Therefore, it is safe to argue that the real-world environment is not likely to influence students' learning performance. Besides, in terms of the transportation level, the real world environment is actually more likely to distract students from concentrating on and immersed in the narrative. Students had to walk for several minutes before they could continue to get new information from the application, so the whole story was not continuous for them. In addition, while they were walking along the river, a lot of students were attracted by lobsters and crabs in some restaurants' aquariums. Each of these two situations could decrease outdoor students' transportation compared to a classroom, but they still reported much higher level of transportation. Therefore, the location-based AR modality appears to be quite powerful in inducing transportation into the narrative despite the presence of formidable environmental distractions. This bodes well for the future of AR apps in the domain of education, especially in distracting out-of-school environments, because the technology itself appears to be quite involving and therefore conducive to learning.

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