Tar AR: Connecting the Past with the Present in Informal Science Learning

Abstract: Informal science learning spaces such as museums have been exploring the potential of augmented reality (AR) as a means to connect visitors to places, times, or types of content that are otherwise inaccessible. This design-based research engaged the La Brea Tar Pits Museum and university partners in a research practice partnership to enhance place-based science learning through potential AR exhibits. Results from implementation of four design iterations show that AR technology is a promising tool to help learners interact with content that dates back thousands of years and overcome their scientific misconceptions. Furthermore, incorporating AR technology into museum exhibits can update them with 21st learning tools to support visitor enjoyment in science learning.

Purpose

A key mission for science museums and science centers is to engage a large and diverse public audience in science learning (Macdonald, 1997). To that end science museums attempt to present information in entertaining, socially-oriented, and innovative ways. For instance, recent work makes use of immersive technologies into the museum experience (Radu, 2014). An example is the use of augmented reality (AR), defined as technology that overlays virtual objects on to the real-world (Azuma et al., 2001). This technology allows learners the unique ability to interact with content that is both situated in the context of the exhibit and virtually generated in a way that can allow for hidden worlds to become visible (Salmi, Thuneberg, & Vainikainen, 2017; Wu, Lee, Chang, & Liang, 2013). AR can also be leveraged to allow interactivity with public exhibits that might otherwise be passive (e.g., outdoor features prior to entry).

Theoretical Framework

An advantage of using AR in informal learning spaces, like museums, is the ability to bring physical places alive with virtual additions to their setting. Researchers studying AR have combined GPS location awareness technology as a way to to engage learners in the rich content places can offer (Dunleavy & Dede, 2014). This is an example of place-based education (Sobel, 2004) a pedagogy where curriculum or learning experiences are rooted in the communities and places that learners populate daily. More broadly, place-based learning strives to deepen learners meaning-making through the design of activities that are within and about their communities (Smith, 2002; Sobel, 2004; Smith & Sobel, 2010). The combination of AR technology and place-based learning can be employed by museums as a way to connect visitors to their community. It can also offer transformative potential to resolve persistent science misconceptions, by creating effective conditions for both engagement and personalized interactions with science (Sinatra & Chinn, 2012; Sinatra, Heddy, & Lombardi, 2015). The transformative potential of AR not only supports visitors' understanding of abstract science concepts but also long-term knowledge retention, group collaboration, and motivation (Radu, 2014).

Given the potential of AR technology in informal learning environments, the purpose of this study was to explore the utility of AR as an emerging vehicle for informal science learning and engagement. This project is situated at the La Brea Tar Pits and Museum (LBTP), a centrally located field site and museum in one of the largest and most diverse cities in the United States (Los Angeles). The LBTP is a unique place where history, ongoing active science, and community merge on the grounds of a public park. Families gather for celebrations, dogs are walked by their owners, and other normal park activities occur daily alongside paleontologists who are actively excavating and processing fossils dating back thousands of years. On the same grounds resides a museum where those fossils are curated and transformed into exhibits about the history of LBTP. These factors make the LBTP an excellent place for an exploration into how place-based science pedagogy and AR technology can increase public understanding of science.

Methods and Data Sources

This NSF Funded collaborative project investigates two high-level design factors for mobile AR through a Design Based Research (DBR) approach. To date, there have been four design cycles for the AR technology and science learning content. In the first design iteration, AR was used to both extend and emphasize aspects of La Brea as a unique place for the purposes of learning (e.g., Zimmerman & Land, 2014). A convenience sample of adult museum visitors (n=62) was recruited to interact with the five-minute AR experience following a virtual mammoth through an initial encounter with a tar pit to its exhibit in the museum, while they listened to a narration about the scientific inquiry process (see Figure 1). We created a six-item multiple-choice instrument that measured two misconceptions specific to the LBTP: (1) animals fell into the tar, and (2) large animals fell into the tar pits on a regular basis. Along with content knowledge, we collected data on participants' interest and emotions. Two interest measures were used: a six-item Likert scale measure of interest in science, and a six-item Likert scale measure of interest in the AR. Similar to the interest measure, two emotion scales were used: one measured emotions regarding the science at LBTP and the other measured emotions about the AR. For both scales, emotions were measured by adapting the Epistemically Related Emotions Scales short form (EES; Pekrun, Vogl, Muis, & Sinatra, 2017), a self-report Likert scale questionnaire consisting of seven items.

In the second design iteration, the AR exhibit moved to a new site, a physical tar pit which is centrally located in the park and currently under excavation. A convenience sample of adult visitors (n=28) were recruited to participate in usability testing. In this 10-minute version, visitors take a moment to observe the actual tar pit dig site and then utilize the AR to virtually dig, discover and identify fossils. Prior to virtually digging, visitors were asked to make a hypothesis about what the environment of Los Angeles looked like during the Ice Age. As they discovered different fossils, they were asked if they wanted to revise their hypothesis based upon the new evidence (see Figure 2). A 10-item post-survey was given to participants that probed their ease of use with the technology, their learning expectancy, and their reactions to the experience (Venkatesh et al., 2003). A semi-structured interview was also conducted with each participant to explore any frustrations, enjoyment, or learning that may have occurred during their participation.

In the third design iteration, many features relating to the ease of use were modified but the core experience remained the same as Design #2. This improved version of the 10-minute experience was tested with a convenience sample of museum employees (n=40) who were recruited to participate. The focus of this iteration was to pilot an eleven-item multiple-choice instrument designed to assess two misconceptions pre and post the AR experience: (1) ice age Los Angeles was very different from the present day LA ecosystem, and (2) tar pits capture everything.

The fourth design iteration was tested in a randomized controlled trial (RCT) where the knowledge instrument was modified, along with aspects of the AR technology, based on the feedback from Design #3. The focus of this RCT was to test 5 conditions which compared manipulation (selection with physical tool versus phone touchscreen) and delivery (headset versus handheld phone) against a control condition (a typical museum informational poster). A random sample (n=135) of adults were recruited and randomly assigned to one of the five conditions; control, AR headset, AR headset with tool, AR phone, AR phone with tool. A 10-item pre and post knowledge instrument and knowledge-based interview questions were given to participants to probe their scientific understandings.

Findings

Design #1 revealed that participants (n = 62) were able to overcome misconceptions as shown by growth in knowledge from pre to post experience. A t-test comparing raw scores (ranging from 0 to 6) revealed significant learning gains from pretest (M = 1.1, SD = 1.6) to posttest (M = 3.87, SD = 2.1; $t(61) = 8.9$, $p < .001$). We also found that while interest was high for both science content and the AR, participants reported greater interest in the science content (M = 4.6, SD = 0.59) than the AR (M = 4.3, SD = .76; $t(61) = 3.97$; $p < .001$). Participants also reported more positive emotions related to the science content (M = 3.6, SD = .9) compared to the AR (M = 2.0, SD = .52; $t(61) = 4.177$, $p < .001$). The aggregate of these findings informed the collaborative team that greater interactivity could be valuable, which was prioritized after the first design iteration. These findings drove the second design of the AR to include more about the science that happens at LBTP and to place participants in the role of the scientist instead of an observer.

The second design iteration indicated that participants (n = 28) experienced some frustrations and reported only mildly positive ease of use (M= 4.0, SD = 1.1). Specific aspects of these frustrations were identified during the post interviews with participants and were refined for future iterations. The learning expectancy results indicated an overall positive perception of participants' ability to learn with the technology (M= 4.8, SD= 0.8). Finally, emotion data indicated overall positive emotions while using the technology (M=5.2, SD=0.7).

Design #3 testing indicated that participants (n=40) experienced a few bugs with the technology and were able to overcome misconceptions about the science at LBTP. This finding was demonstrated through conversations with participants and pretest and posttest knowledge items. A t-test comparing knowledge scores (ranging from 0-100) revealed significant learning gains from (M= 70, SD=25.9) to post (M=88, SD=12.1, $t(39)= 5.5$, $p < .001$). Interview data was transcribed, and then open and axial coding revealed broader themes about the science at LBTP: (a) surprise as an initiator for hypothesis revision, and (b) deeper understanding of fossil evidence (Saldaña, 2013; see Table 1). This iteration demonstrated that a few of the knowledge items were confusing for participants and some experienced bugs with the software. These items were addressed and modified for future iterations.

Testing of Design #4 indicated that participants in the RCT (n=135) were able to overcome misconceptions about the science at LBTP. A one-way ANCOVA was conducted to compare the effectiveness of each AR condition, controlling for participants' pretest knowledge scores. Levene's test and normality checks were carried out and the assumptions were met. Participants did show significant learning gains in knowledge scores (ranging from 0 to 9) from pre (M= 5.97, SD=1.19) to post (M=7.15, SD=1.2, $F(1,129)= 27.3$, $p < .001$). However, there was no significant difference found in mean knowledge gains among conditions [$F(4,129)= 0.51$, $p > 0.05$]. Open-ended responses to interview questions were analyzed using LIWC (Linguistic Inquiry and Word Count) to tally frequencies of words associated with correct or incorrect descriptions of the environment of Los Angeles during the Ice Age. A t-test comparing pre and post open-ended responses saw an increase in the frequency of correct descriptions of the environment (ranging from 0 to 100) which revealed significant learning gains from pre (M=0.77 SD=2.05) to post

(M=4.2, SD=6.5, $t(132)= 5.7$, $p < .001$). A t-test comparing pre and post open-ended responses showed a decrease in the frequency of incorrect descriptions of the environment (ranging from 0 to 100) from pre (M=5.6 SD=10.4) to post (M=2.6, SD=2.9, $t(132)= -3.4$, $p < .001$). A finer grained analysis using t-tests comparing each condition to the control showed no statistically significant differences in knowledge by condition. However, the qualitative data revealed significant differences advantage of the AR phone with tool condition $t(18)= -2.2$, $p < .05$) when comparing the decrease of incorrect description of the environment of Los Angeles during the Ice Age in comparision to the control condition.

In general, our results at this stage highlight the promise of combining place-based science pedagogy with AR technology for supporting public understanding of science and deeper engagement with the places communities inhabit. While quantitative differences were not found among conditions in knowledge gained, significant learning gains were seen from pre to post, including enhanced quality of understanding illustrating the potential for place-based informal science learning. Furthermore, incorporating AR technology into museum exhibits can update them with 21st learning tools to support visitor enjoyment in the learning experience.

Significance

The strategic impact of this project is the potential to empirically compare how AR design choices for immersion and interactivity impact visitors' engagement and understanding of science. The result of this study could serve as a model for similar public exhibits, as well as design principles that generalize to AR experiences for a larger range of informal learning environments. This research contributes to understanding of usability and logistical issues for different AR designs for a public, outdoor informal setting.

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Figure 1. Pilot Study of AR experience (Design 1)

Figure 2. Participant Engages with AR Experience (Design 2)

Table 1: Evidence of learning about making hypotheses about the past environment of La Brea

	Interview Excerpts
Surprise as an initiator for hypothesis revision	*I guess I expected it to have a look and feel more like a stereotypical ice age, but the fact that it was a lot wetter and had trees and fish was kind of a little surprising for me. I'm not a history buff. I should have known that going in.*
	I mean, what surprised me is that initially where it said this was the Ice Age and I thought, well duh, then it must be that this happened in the Ice Age and I pick Ice, and so I really learned something from this. I mean, it really had not occurred to me that during the Ice Age, the whole country wasn't covered with ice. I actually didn't know that. To find out that LA was wetter and colder, but a lot like it is now, was just fascinating to me. I don't know that just being told that would be meaningful, so I like it in the sense that it led me through that, through the process. I actually found out a very interesting way to learn, to think I've been here, I have Ice Age as an image in my head, but I honestly hadn't thought the fact that Ice Age differentiated across the U.S.
Deepening understanding of fossil evidence	*I think the idea that I started to learn more about how a fossil, discovering a fossil can influence my understanding of the environment. So I found out that, Oh, there's a fish, okay. So in the environment may not be so icy as I thought it was. There might've been some flowing water present. So I was able to reevaluate my hypothesis and choose something else that was more maybe more accurate to that time.*
	Yeah, so when I thought about ice age, I just thought about frozen things and cold and icy mountains. But then one of the fossils that I got was a fish, and then I learned if there was a fish fossil then there were streams and rivers. So that was really surprising, and it was cool to see how one bone really changed my thinking, and then see the change through the VR.