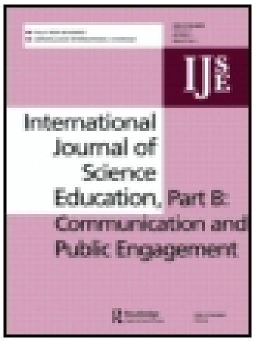

Routledge
Taylor & Francis Group

International Journal of Science Education, Part B
Communication and Public Engagement

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/rsed20

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INTERNATIONAL JOURNAL OF SCIENCE EDUCATION, PART B
https://doi.org/10.1080/21548455.2021.1946619

Promoting interest, positive emotions, and knowledge using augmented reality in a museum setting

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ABSTRACT

Informal learning environments, such as museums, provide unique opportunities for science learning. They are deliberately designed to impact public understanding of science and shape visitors' attitudes and behaviors. As a developing technology, augmented reality (AR) offers the transformative potential to support museums' educational missions by enhancing visitors' experience, thereby creating effective conditions for learning and personalized interactions with science. We implemented an AR-enhanced exhibit at the La Brea Tar Pits (LBTP) to reduce scientific misconceptions and explore the role of interest and emotions around science and AR technology as it related to learning and knowledge revision. Using a pretest-posttest design, 62 adults completed an AR experience that addressed two scientific misconceptions related to the consistency of tar and frequency of large animal entrapment. We found that participants had significantly fewer misconceptions at posttest than at pretest. Participants also reported higher levels of interest in science content than AR technology and discriminated between emotions they experienced with regard to science content and AR technology. Feelings of curiosity predicted knowledge revision and interest in both science content and AR technology. These findings may be useful for museums and other science communicators seeking to create AR interventions that support learning and conceptual change.

ARTICLE HISTORY
Received 24 November 2020
Accepted 18 June 2021

KEYWORDS
Science education; museum education; technology

The importance of public understanding of science amidst the current climate of misinformation is crucial as citizens increasingly encounter complex and oftentimes conflicting information on a daily basis (Sinatra & Hofer, 2016). As an important source for scientific information, museums play a vital role in the collection, preservation, research, and interpretation of historical, scientific, and cultural artifacts for public learning and enjoyment (Schwan et al., 2014). By exposing visitors to novel and striking experiences that fill them with curiosity and awe, museum guests generally feel amenable to learning – thus, museums are ideal settings for fostering learning and engagement, and for countering scientific misconceptions. Given visitors' varying prior knowledge, interests, backgrounds, and ages, museums must consider effective and appropriate ways to disseminate information, support knowledge generation and revision, and promote

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Supplemental data for this article can be accessed https://doi.org/10.1080/21548455.2021.1946619.

interactivity to encourage interest and engagement. Although augmented reality (AR) technology is increasingly being used to facilitate engagement in STEM settings, students have often been the main audience of focus (Goff et al., 2018). Moreover, studies that incorporated AR technology into a museum setting often emphasize gains in accessibility and engagement rather than development of content knowledge, reduction of misconceptions, or interest and emotions (see Damala et al., 2008; Szymanski et al., 2008).

This study makes two key contributions. First, we explored the role of AR in increasing knowledge gains and reducing scientific misconceptions among adult museum visitors. Second, we examined interest and emotions related to scientific information as well as interest and emotions related to AR technology. By investigating interest and emotions in AR separately from interest and emotions in science content, we were able to develop a clearer understanding of the role that AR technology played in reducing scientific misconceptions – whether it was a means to initially engage learners in an exhibit because of novel technology or if it deepened an already existing intrinsic interest in science.

Technology usage in museum settings

Defining augmented reality (AR)

Augmented reality (AR) is a technology that overlays virtual objects onto the real-world (Chien et al., 2019). AR environments have three distinct properties: (1) the combination of real and virtual objects into a single environment, (2) real-time interactions with real and virtual objects, and (3) an alignment of real and virtual objects (Azuma et al., 2001). Milgram and Colquhoun's (1999) Reality-Virtuality (RV) continuum identifies a spectrum of 'mixed reality' with real-world environments and modeled, virtual environments placed at opposite ends of the continuum. The middle portion of the RV continuum represents worlds that are partially modeled – that is, some degree of technology and modeling are present in the environment (Milgram & Colquhoun, 1999). Within the RV continuum, AR lies closer to the real-world environment given that virtual content is overlaid on to a physical space (Goff et al., 2018).

AR techniques for aligning real and virtual objects can be further classified as image-based (e.g. markered) or location-based (e.g. marker-less; Cheng & Tsai, 2013; Matuk, 2016). With markered AR, a physical object is tagged (e.g. QR code) such that when the object is viewed through an AR application, digital content (e.g. objects, video, sound) is presented and positioned in relation to the physical object (Matuk, 2016). Marker-less AR, in contrast, relies on a location tracking system (e.g. GPS, Wi-Fi) to integrate the virtual content with the real-world environment (Koutromanos et al., 2015).

Initial research suggests that AR can enhance the learning environment and enable learners to observe, explore, and deepen their understanding of the world around them due to the heightened richness of instructional content (Chien et al., 2019). By overlaying virtual objects on to physical objects, hidden worlds become visible (Dieck et al., 2018; Salmi et al., 2017; Wu et al., 2013), information about historical events and artifacts from different times and places become observable, and experiences that occur in particular environments are evoked (Harrington et al., 2019). In this way, AR is uniquely positioned to improve knowledge outcomes and resolve persistent science misconceptions by enhancing engagement experiences and personalized interactions with science (Koutromanos et al., 2015; Yoon et al., 2012).

Using AR in museum settings

Although a number of investigations have focused on AR use in classrooms, scientific understanding and engagement can also be fostered within informal science environments (Banks et al., 2007; National Research Council [NRC], 2009). Museums, in particular, have incorporated AR technology since the early 2000s. Today, AR is commonly used with mobile devices to superimpose virtual images over a physical environment, allowing the viewer to see one cohesive image (Marques & Costello, 2018). In addition to videos and graphics, text and audio can be overlaid on real-world artifacts and landscapes, which facilitates access to content that is typically obscured or inaccessible (Yoon & Wang, 2014). This pairing of virtual and physical content can deepen the levels of interaction between visitors and the exhibit content due to increased contextualization. AR, for example, allows visitors to observe and draw comparisons between cultural artifacts that have disappeared with artifacts that are present on site (Chang et al., 2015). This supports museum guidance activities and enhances visitors' presence within a certain space by allowing them to observe changes in that place over time (Chang et al., 2015).

Prior research on AR technology in museum settings examines its role in increasing visitor interest, engagement, and accessibility. For example, Damala and colleagues (2008) found that a mobile museum guide that incorporated AR was linked to increased visitor enjoyment when viewing AR-enhanced paintings at the Museum of Fine Arts in Rennes, France. The AR presentation consisted of textual overlays placed next to paintings as well as pictograms which provided additional content. Findings from interviews, survey data, and focus groups indicated that participants endorsed a moderate to strong positive attitude regarding the ease of the AR-enhanced mobile guide. However, participants who were frequent museum visitors and those who used a computer on a daily basis reported feeling more distracted when using the mobile guide, which suggests that AR may be invasive for visitors if not carefully constructed (Damala et al., 2008).

In addition to supporting interest and engagement, AR technology can also modernize museum spaces that have remained physically unchanged over extended periods of time. In a study conducted by Marques (2017), an AR application called Skin & Bones was used at the Smithsonian's National Museum of Natural History to increase engagement and interactivity. Using the Skin & Bones application downloaded on a touchscreen tablet, visitors used AR to superimpose fully fleshed bodies over mounted skeletons of extinct and extant animals. Increases in exhibition engagement and higher levels of satisfaction were also noted for visitors who used the AR (Marques, 2017).

While much of the literature focuses on engagement, a small, but growing, body of research has explored how AR can support learning and reduce misconceptions in museum settings. Research conducted by Yoon and colleagues (2017) involved the creation of an interactive AR experience to scaffold learning and confront middle-school students' misconceptions about a challenging science concept (Bernoulli's principle). Survey data and interviews with middle school students revealed that learners who engaged in the AR experience had fewer misconceptions at posttest compared to a control group. Similarly, AR experiences supported cognitive gains for middle school students learning about electricity, particularly when scaffolds were included in the experience (Yoon et al., 2012).

A more recent study, conducted by Dieck and colleagues (2018), assessed how a wearable AR application enhanced participants' learning experiences. Forty-four adult participants who attended an art gallery in the United Kingdom were divided into an experiential Google Glass treatment group and a control group. Semi-structured interviews and an analysis of task completion revealed that participants in the control condition, who completed paper-based tasks, recalled more detailed information about the artists and paintings. However, participants in the Google Glass condition, who used wearable AR applications to complete learning tasks, found (a) information easier to recall, (b) the art gallery tour to be more seamless, and (c) the experience to be more engaging and personalized compared to the control group.

In summary, the empirical literature tends to emphasize the ways in which AR can enhance interest, engagement, and accessibility in informal learning environments which are important precursors to learning and knowledge acquisition (Goff et al., 2018). However, more research is needed to understand how AR might facilitate conceptual shifts for deep learning among adult learners in informal settings. To frame our study which examines the role of AR in supporting learning gains, reducing misconceptions, and exploring the roles of interest and engagement, we draw from theory on conceptual change.

Knowledge revision, interest, and emotion

Conceptual change theory can be useful in examining how AR impacted participants' interest, emotions, and shifts in misconceptions about the scientific processes that occur at the La Brea Tar Pits. Conceptual change is defined as a process of restructuring conceptual knowledge that occurs when learners resolve prior knowledge with observations (Vosniadou, 2013) and involves motivational, sociocultural, and affective factors (Pintrich et al., 1993; Sinatra, 2005; Sinatra & Mason, 2013). According to Dole and Sinatra's (1998) Cognitive Reconstruction of Knowledge Model (CRKM), conceptual change occurs when instructional messages are comprehensible, coherent, plausible, and rhetorically compelling. Learner characteristics, such as background knowledge and motivation, also play a critical role in the revision process (Dole & Sinatra, 1998). Learners who possess strong ideas that are conceptually well-developed and linked to other ideas are more likely to have a stable and coherent conceptual understanding, which makes their ideas less likely to change. Learners' motivational factors also impact the possibility for conceptual change such that individuals who experience dissatisfaction and personal relevance (defined as self-efficacy, interest, and emotional involvement) are more likely to experience knowledge revision (Dole & Sinatra, 1998).

In line with motivation, emotions are also important factors involved in the conceptual change and knowledge revision process. Emotions experienced during knowledge reconstruction – called epistemic emotions – arise when incoming information is congruent or incongruent with an individual's beliefs, prior knowledge, or recently processed information (Silvia, 2010), and can play a role in helping or hindering learning. Epistemic emotions generally range from positive (e.g. curious) to negative (e.g. confusion; Pekrun, 2006) and can 'prepare and sustain reactions to important events and states' (Pekrun et al., 2002, p. 96) while also impacting learner motivation (Pekrun & Stephens, 2010). For example, an individual exposed to novel information in an AR intervention may experience the positive emotion of curiosity, and subsequently devote additional attention to relevant details to pursue this curiosity, while individuals who experience negative emotions, such as anger or frustration, may disconnect from the information.

Given this theoretical framing, we expected that presenting museum visitors with targeted information in a novel and engaging manner would reduce misconceptions about specific science topics in a museum setting. More specifically, we designed an AR experience that would immerse visitors in a sensory experience and convey information in a coherent, succinct, and plausible way. We aimed to appeal to visitors with varying levels of background knowledge, such that even visitors with strongly developed ideas about the scientific content would still experience elements of surprise and curiosity while viewing the AR, which would subsequently impact the targeted scientific misconceptions. We predicted that participants would shift their scientific conceptions; that they would find the experience to be engaging and promote positive emotions; and that this engagement would be positively associated with their learning. We also wanted to be sure that visitor engagement (measured in terms of interest and positive emotions), was not driven entirely by novelty of the technology – therefore, we structured our study to distinguish between AR-specific and science-specific engagement.

Research questions

Despite evidence that AR can improve interest and engagement in museum settings, less is known about how AR facilitates learning and reduces misconceptions. Research has not yet discerned whether increased engagement in science settings is the result of having opportunities to engage with science in new, interactive ways, or whether the novelty of the technology is driving the engagement. Furthermore, most studies rely on samples of students in museum settings, even though a large percentage of museum visitors are adults (Bingham, 2019; Farrell & Medvedeva, 2010). Given these gaps in the literature, our study was guided by the following research questions:

1. To what extent does AR technology facilitate knowledge change for this science content?
2. To what extent does AR technology facilitate interest in science as distinguished from interest in AR?
3. To what extent are participants' epistemic emotions about science distinguished from their emotions about AR?
4. To what extent are patterns of epistemic emotions associated with knowledge gain, interest in science, and interest in AR?

Method

Study context

Data for this study were collected as part of a collaboration with University of Southern California and the museum at La Brea Tar Pits (LBTP) to design AR experiences that reduce scientific misconceptions and increase visitor engagement. LBTP is one of three museums of the Natural History Museums of Los Angeles County – which includes the Natural History Museum, one of the largest in the United States, serving more than one million visitors annually. LBTP is situated in an urban public park which contains the still-active tar pits and ongoing paleontological excavations as well as two other museums (the Los Angeles County Museum of Art and the Academy Museum of Motion Pictures). Many park visitors are not even aware that they are on the grounds of a historic museum and world-famous paleontological site.

Sample

Visitors were recruited on-site at LBTP though convenience sampling. A total of $N = 62$ adults were included in the analysis. Most participants were between the ages of 23 and 40 years (53%), had never used AR before (77%), and were visiting LBTP for the first time (63%).

Measures

Knowledge

We created a six-item multiple-choice instrument that measured whether people held two misconceptions specific to LBTP: (1) tar pits acted like quicksand and submerged entrapped animals, and (2) large animals fell into the tar pits on a frequent basis (see Appendix A). For example, we asked participants 'About how often did a big animal die in the tar pit? (a) Once a day, (b) Once a month, (c) Once a year, (d) Once every 10 years, or (e) I don't know.'[1] To establish construct validity (Gehlbach & Brinkworth, 2011; Tourangeau et al., 2000), items were developed in collaboration with LBTP scientists and staff by first identifying common misconceptions held by visitors, then by creating a large pool of items that were revised and narrowed down to the existing six items based on multiple rounds of expert evaluation. The knowledge measure was completed prior to and immediately after the intervention. Each item had five response options, only one of which was counted as correct (scored as 1), while the incorrect responses and 'I don't know' response options were scored as 0. We computed two composite knowledge scores by summing the number of items that participants answered correctly at pretest (Cronbach's $\alpha = .62$) and posttest (Cronbach's $\alpha = .54$) and then created a knowledge gain score by subtracting the average pretest scores from the posttest scores.[2]

Interest

Two interest measures were used to capture participants' situated and individual interest: a six-item measure of interest in science (based on one used in prior research, Polikoff et al., 2018) and a six-item measure of interest in AR technology. To capture participants' interest in science, they were asked 'Are you interested in learning more about how animals are removed from the tar pits?'

To capture interest in AR, participants were asked 'Does using AR make you want to learn more about the tar pit?' Both interest scales used a five-point scale (1 = *No,* 3 = *Neutral,* 5 = *Yes*). The interest in science scale was internally consistent at conventional levels (Cronbach's $\alpha = .85$) as was the interest in AR scale (Cronbach's $\alpha = .91$).

Epistemic emotions

Similar to the interest measure, two emotion scales were implemented: one measured emotions about science content and the other measured emotions about AR technology. For both scales, emotions were measured by adapting the Epistemically-Related Emotion Scales short form (EES; Pekrun et al., 2017), a self-report questionnaire that asked participants to rate seven key emotions (i.e. curious, excited, surprise, confused, anxious, frustrated, bored). To measure participants' emotions about the science content, they were asked, 'How anxious did you feel when you were learning about the tar pits?' In contrast, participants were asked, 'How anxious did you feel when you were using [the] AR?' when evaluating their emotions related to the AR technology. For both sets of measures, participants responded on a five-point scale (e.g. 1 = *Not Anxious,* 5 = *Totally Anxious*).

The AR experience

Data collection commenced by asking museum visitors if they wanted to participate in a 'technology enhanced experience of the La Brea Tar Pits.' Participants first completed a consent form and an online pretest of their science knowledge on a tablet device. Participants then engaged in an immersive outdoor AR experience installed near the entrance of the LBTP museum where they were provided with a smart phone outfitted with a Google cardboard headset and a pair of headphones. Before beginning the AR experience, a member of the research team informed participants that information would be conveyed visually and auditorily and that the AR would be projected on the lawn area. Participants remained stationary while using the headset – however, they could rotate their body from left-to-right to get a full view of the visual content. No more than three participants completed the AR experience at any one time to ensure adequate spacing between visitors. Once participants began the AR experience, a member of the research team remained nearby to collect and sterilize the equipment after each use and cue the AR experience for the next user.

At the start of the 6-minute AR experience, participants saw a large puddle of asphalt ('tar') projected on to the lawn area which was accompanied by a narration that explained how asphalt has continuously seeped from the earth on the LBTP grounds for tens of thousands of years, resulting in millions of fossils becoming trapped and preserved in the tar pits. The narration described how temperature affects the consistency of the tar whereby tar can be hard enough to walk on during a cold night but have a texture similar to glue on a hot day. Using the headset, participants viewed a virtual young mammoth approaching the superimposed tar pit, getting entrapped in the sticky tar, and then struggling, and ultimately failing, to escape (see Figure 1).

Participants then saw and heard about how predators, such as dire wolves, could be drawn to entrapped prey, often becoming entrapped themselves. An adult-sized mammoth, the young mammoth's mother, appeared to the right of the participant and made a sound of distress, causing the participant to crane their neck upwards to view the full size of a long-extinct adult mammoth. The prey and the predators visually faded from the tar pit and became replaced by images of bones, symbolizing the decomposition and fossilization process. The AR experience concluded by explaining the frequency of large animal entrapment and displayed a timeline to represent the thousands of years over which entrapment occurred. The closing scene had participants pan across a timeline, with the leftmost portion of the timeline representing prehistoric time and the rightmost portion of the timeline representing modern-day, leading to the front entrance of the LBTP museum. The narration ended by asking the participant to consider what the tar pits might reveal about the past and the future with the final phrase, 'Science happens here' displayed over the museum entrance.

In summary, the AR experience addressed two target scientific misconceptions – (1) tar pits acted like quicksand and submerged entrapped animals and (2) large animals were trapped in

Figure 1. A screenshot taken from the AR-enhanced experience mock-up depicting a virtual baby mammoth entrapped in a tar pit.

the tar pits frequently. To address the first misconception, participants learned through the animation and narrative about how the viscous tar led to the fossilization of large mammals such as mammoths and dire wolves, as well as microfossils like pollen. The second misconception was addressed by presenting visitors with information about the frequency of large animal entrapment which, on average, occurred only once every decade. In total, the AR experience lasted approximately six minutes which was largely determined by the amount of time required to present the relevant content that addressed the two scientific misconceptions of interest for this study. While this 6-minute timespan was longer than some prior studies that used AR technology (e.g. 1:04 min per AR experience in Marques' (2017) Skin & Bones application), it was significantly shorter than others (e.g. 20-30 min in Dieck and colleagues' (2018) study with Google Glass in an art gallery).

Upon completion of the AR experience, participants completed a posttest that was identical to the knowledge pretest as well as measures for interest in science, interest in AR, emotions about science, emotions about AR, and demographic information. An experimental design was not possible because there was no alternative experience to use as a control condition. As a result, we used a pretest-posttest design (e.g. Campbell & Stanley, 1963).

Analytical approach

To answer our first research question, we used paired t-tests to compare mean knowledge scores between posttest and pretest. To address the second research question, we used paired t-tests to assess whether interest in science was different from interest in the AR technology. To address our third research question, correlations and principal component analyses were conducted to examine the relationships between epistemic emotions related to science and AR technology, respectively. To address our fourth research question, a series of regression analyses were run using conceptual change, interest in science, and interest in AR as outcome variables.

Results

Table 1 presents descriptive statistics for the scales and items used in this study as well as for participant characteristics.

Knowledge

To answer our first research question – *To what extent does AR technology facilitate knowledge change for this science content?* – we examined the pretest and posttest knowledge items to determine whether adults overcame misconceptions and increased knowledge through their engagement with the AR intervention. A t-test comparing raw pre- and posttest scores (ranging from 0 to 6) revealed significant gains from pretest ($M = 2.05$, $SD = 1.41$) to posttest ($M = 4.37$, $SD = 1.39$; $t(61) = 10.5$, $p < .001$), with the difference being more than one and a half standard deviations increase (Cohen's $d = 1.66$).

Interest

To answer the second research question – *To what extent does AR technology facilitate interest in science as distinguished from interest in AR?* – a paired t-test was conducted to compare interest in science versus interest in AR. While interest was high in both, participants reported being more interested in the associated science content ($M = 4.6$, $SD = 0.59$) than the AR ($M = 4.3$, $SD = 0.76$; $t(61) = 3.97$; $p < .001$; Cohen's $d = 0.44$).

Table 1. Descriptive statistics for participants ($N = 62$).

Item	%	Mean	SD	Min	Median	Max
Learner characteristic						
Have used AR	23%					
Have previously visited tar pits	37%					
19–22 years old	5%					
23–40 years old	53%					
41–60 years old	36%					
60+ years old	6%					
Interest, Emotion, and Knowledge Composites						
Interest in Science		4.58	0.59	2.67	4.83	5.00
Interest in Augmented Reality		4.30	0.76	2.00	4.58	5.00
Prior Knowledge		2.05	1.41	0.00	2.00	5.00
Final Knowledge		4.37	1.39	1.00	5.00	6.00
Knowledge Gain		2.32	1.74	−2.00	2.00	6.00
Discrete Emotions						
Surprise (science-specific)		3.02	1.32	1.00	3.00	5.00
Curious (science-specific)		4.21	0.99	1.00	4.50	5.00
Excitement (science-specific)		3.68	1.10	1.00	4.00	5.00
Confused (science-specific)		1.53	0.78	1.00	1.00	4.00
Anxious (science-specific)		1.31	0.80	1.00	1.00	5.00
Frustrated (science-specific)		1.21	0.48	1.00	1.00	3.00
Bored (science-specific)		1.27	0.52	1.00	1.00	3.00
Surprise (AR-specific)		2.69	1.29	1.00	3.00	5.00
Curious (AR-specific)		3.61	1.14	1.00	4.00	5.00
Excitement (AR-specific)		3.31	1.26	1.00	3.00	5.00
Confused (AR-specific)		1.44	0.59	1.00	1.00	3.00
Anxious (AR-specific)		1.23	0.61	1.00	1.00	4.00
Frustrated (AR-specific)		1.39	0.69	1.00	1.00	4.00
Bored (AR-specific)		1.39	0.64	1.00	1.00	3.00

Note: Descriptive statistics for the learner characteristics (e.g. prior experience with AR, returning visitor to LBTP, age) were computed. Ratings for interest in science content and AR, as well as composite pretest scores, posttest scores, and knowledge gain scores are presented. Descriptive statistics for seven epistemic emotions as it related to scientific content and AR technology were also computed.

Epistemic emotions

To answer our third research question – *To what extent are visitors' epistemic emotions about science distinguished from their emotions about AR?* – we examined both pairwise correlations and conducted a factor analysis on emotion items. The results of the pairwise correlations for distinct emotions (see Table 2) showed that while some emotions were strongly related for science and AR (e.g. anxious), others were weakly correlated (e.g. confused). In this analysis, we considered correlations less than .4 to be weak, .4–.6 to be moderate, and over .6 to be strong (aligned to the rule-of-thumb for Dancey & Reidy, 2007). Using this criteria, strong correlations between self-reported feelings about science and AR were observed for anxious emotion items ($r = .66$, $p < .001$) and curious emotion items ($r = .65$, $p < .001$). In contrast, confusion ($r = .34$, $p < .01$) and surprise ($r = .27$, $p < .05$) each had a weak correlation between visitors' feelings about science compared to AR, indicating that these emotions were not as strongly coupled. For all other emotions, moderate correlations between feelings about science and AR were found with most tending toward the higher end moderate correlations.

As seen in Figure 2, not all science/AR pairs of emotion items were correlated uniquely or even most-strongly with each other. Moreover, groups of emotions were also evident. For example, anxious showed a dominant correlation between the science and AR item prompts, as evidenced by the size of the circle. However, excited (science) and curious (science) had a higher correlation with one another compared to their respective AR item prompts. Frustration (AR) showed a different pattern and had moderate correlations with several emotions. These patterns indicated that a component analysis was appropriate given that some emotions paired strongly based on their emotion cue (e.g. anxious) while others correlated with other emotions about the same prompt (i.e. science, AR).

Since emotion items were likely to correlate with multiple factors, a principal component analysis was performed using an oblique rotation (R *psych* library *principal* with 'oblimin' rotation). To determine the number of factors, a scree plot was generated (Figure 3). This plot showed elbows

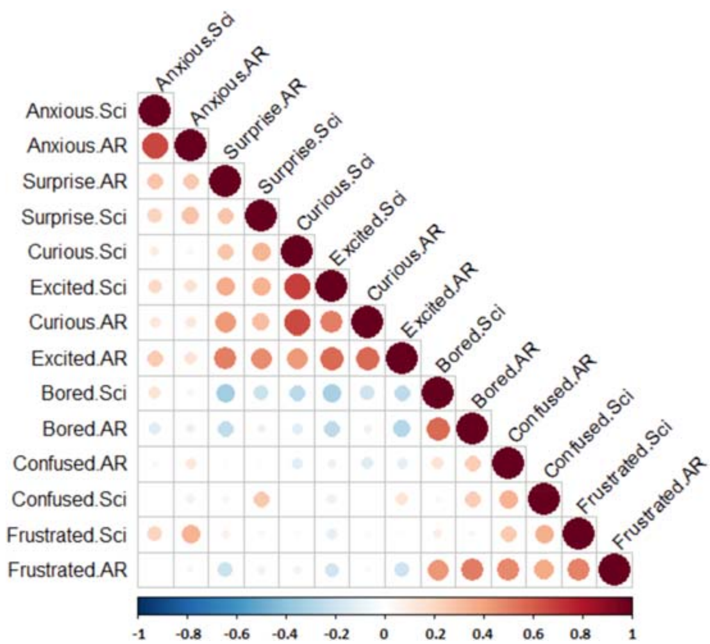

Figure 2. Emotion Correlation Visualization.

Note: The strength of the correlation coefficient is represented by the circle size, with a larger circle indicating a correlation coefficient that is close to 1. Negative correlations are depicted in blue and positive correlations are depicted in red.

Table 2. Intercorrelations between discrete emotions for science and AR technology ($N = 62$).

	Anx.Sci	Anx.AR	Bor.Sci	Bor.AR	Cur.Sci	Cur.AR	Con.Sci	Con.AR	Exc.Sci	Exc.AR	Fru.Sci	Fru.AR	Sur.Sci	Kn.gain	Int.Sci	Int.AR
Anxious.Sci														−.26*	.07	.13
Anxious.AR	.66***													−.10	.05	.13
Bored.Sci	.15	.06												−.06	−.48***	−.49***
Bored.AR	−.14	−.10	.57***											.18	−.36**	−.57***
Curious.Sci	.10	.06	−.27*	−.13										.24∼	.64***	.49***
Curious.AR	.13	.13	−.21	−.08	.65***									.16	.47***	.49***
Confused.Sci	.00	.09	.04	.24∼	.00	.01								.26*	−.12	−.06
Confused.AR	−.04	.13	.14	.24∼	−.13	−.14	.34**							.15	−.13	−.32*
Excited.Sci	.19	.16	−.33**	−.26*	.68***	.50***	−.10	−.08						.08	.48***	.44***
Excited.AR	.25∼	.14	−.26*	−.29*	.42***	.56***	.15	−.12	.57***					.10	.46***	.60***
Frustrated.Sci	.21∼	.34**	.09	.05	−.02	.03	.35**	.25∼	−.12	.03				−.04	.00	−.15
Frustrated.AR	.02	.06	.43***	.51***	−.07	−.04	.37**	.47***	−.20	−.21∼	.49***			.11	−.16	−.48***
Surprise.Sci	.21∼	.28*	−.22∼	−.09	.33**	.30*	.26*	−.03	.34**	.46***	.05	−.08		.15	.24∼	.26*
Surprise.AR	.27*	.26*	−.34**	−.25*	.27*	.42***	.05	.03	.36**	.50***	.08	−.22∼	.27*	−.12	.38**	.37**

Note: Pairwise correlations for the seven epistemic emotions as it related to science content or AR technology were run. Correlations between each of the epistemic emotions and the outcome variables of interest (i.e. knowledge gain, interest in science, interest in AR) were also run.

∼ $p < .1$; *$p < .05$; **$p < .01$; ***$p < .001$.

(changes in slope) for eigenvalues at 3 and at 5. Given that Figure 3 indicated more than three groups, a 5-factor analysis was conducted. This analysis fit the data (empirical $\chi 2 = 52.36$, $p < .0096$; 72% variance explained), with factor loadings in Table 3. Due to the limited size of the data set, a cut-off for a strong loading was applied for inclusion to the factor (0.6 or greater) and selected factors are bold. The first factor (F1_Curious) loads strongest on curiosity (both science and AR) and excitement (science only). The second factor (F2_Bored) pairs the science and AR Bored items. The third item (F3_Anxious) similarly pairs the two Anxious items. The fourth factor (F4_ARFrustrated) loads onto Frustration about science, Confusion about AR, and Frustration about AR. The fifth factor (F5_SciSurpriseConf) loads onto Surprise and Confusion about science. These factors indicate that visitors have relatively nuanced epistemic emotions about science versus AR, which fall into two patterns. First, some emotions are strongly coupled and are clearly distinguished from other emotions (F2_Bored, F3_Anxious). Second, some emotions are strongly coupled but also connect strongly to other emotions about either science (F1_Curious, F5_SciSurpriseConf) or AR (F4_ARFrustrated).

Knowledge, interest, and emotion

To investigate the fourth research question – *To what extent are patterns of epistemic emotions associated with knowledge gain, interest in science, and interest in AR?* – a set of linear regressions was performed to estimate each outcome based on a visitor's pretest score and their emotion factors. For each regression, factors were calculated as an unweighted average of items above the cut-off value. The weights and fit for these three regressions are shown in Table 4. The fit to knowledge gain is modest ($R^2 = .11$) and not significant ($p = .26$), although curiosity about science was a significant predictor (F1_Curious; $b = 0.59$, $t = 2.33$; $p = .02$). A follow-up regression with only F1 as a predictor yielded a significant model ($gain = 0.55^{*}F1 - 1.11$; $F = 5.86$, $p = .02$). No other factors, including the intercept, were significant and their weights (and even direction of weights) should be ignored for this sample size.

Self-reported interest in science and AR were highly related to the emotion factors on the same survey ($R^2 = .48$ and $R^2 = .58$, respectively). However, each type of interest was related to different emotion factors. Science interest was related to curiosity (F1; $b = 0.35$, $t = 5.20$, $p < .001$) and negatively

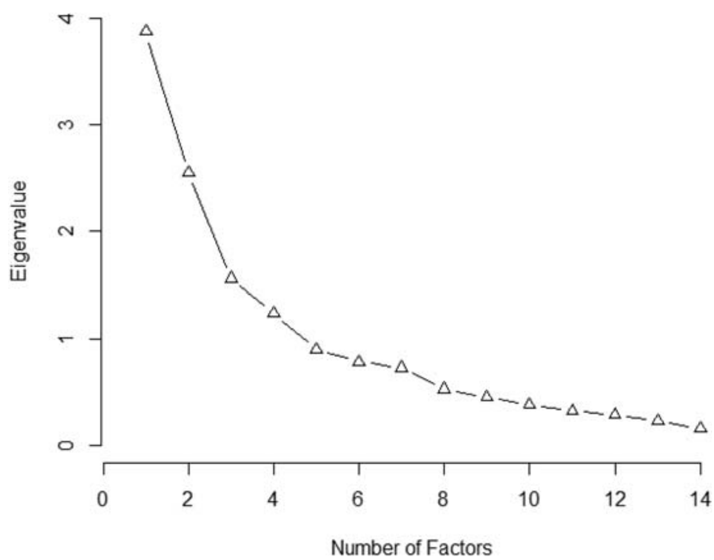

Figure 3. Scree Plot for Emotion Factors.

Note: The generated scree plot demonstrated evidence for a 5-factor analysis to be conducted.

Table 3. Emotion PCA Factor Loadings (5-Factor; $N = 62$).

	F1_Curious	F2_Bored	F3_Anxious	F4_ARFrustrated	F5_SciSurpriseConf	Communality
Anxious(Sci)	.04	.09	**.91**	−.05	.00	.83
Anxious(AR)	−.04	−.04	**.86**	.16	.07	.78
Bored(Sci)	−.11	**.85**	.26	−.05	−.10	.80
Bored(AR)	.05	**.84**	−.16	.07	.15	.78
Curious(Sci)	**.91**	.05	−.08	.02	−.04	.77
Curious(AR)	**.87**	.05	.01	.06	.00	.73
Confused(Sci)	−.15	.06	−.13	.41	**.72**	.77
Confused(AR)	−.07	−.03	−.09	**.72**	.08	.55
Excited(Sci)	**.78**	−.12	.06	−.06	−.02	.70
Excited(AR)	.50	−.19	.13	−.10	.39	.67
Frustrated(Sci)	−.01	−.12	.29	**.77**	−.03	.66
Frustrated(AR)	.11	.48	−.02	**.67**	−.03	.81
Surprise(Sci)	.14	.01	.18	−.24	**.79**	.76
Surprise(AR)	.32	−.45	.23	.16	.14	.51
Cumulative Variance Explained	.2	.34	.48	.62	.72	

Note: Output of factor loadings from the principal component analysis. Five factors (i.e. F1_Curious, F2_Bored, F3_Anxious, F4_ARFrustrated, F5_SciSurpriseConf) were identified. Strong loadings were defined as .6 or higher and are designated in bold.

related to boredom (F2; $b = -0.41$, $t = -3.33$, $p = .002$). AR interest was also related to curiosity (F1; $b = 0.31$, $t = 3.91$, $p < .001$), but was negatively related to both boredom (F2; $b = -0.59$, $t = -4.08$, $p < .001$) and to frustration/confusion related to AR (F4; $b = -0.42$, $t = -2.57$, $p = .013$). Unlike interest in science, interest in AR was affected by frustration and confusion related to AR.

Discussion

AR facilitates conceptual change

Prior studies that incorporated AR technology in a museum have largely focused on increasing interest, engagement, motivation, and accessibility of content to museum visitors (see Damala et al., 2008; Marques, 2017). Whereas a smaller number of studies have examined the impact of AR and learning, these tend to rely on student samples (see Yoon et al., 2012, 2017). Studies that have focused on learning in adults (see Dieck et al., 2018) tend to narrowly examine recall or understanding rather than shifts in conceptual understanding or reduction of misconceptions. Our results show that AR technology can facilitate learning of science content and induce conceptual change as evidenced by the significantly fewer misconceptions at posttest than pretest. Furthermore, the AR experience took only six minutes to complete which suggests that even a brief AR interaction can support learning

Table 4. Regression model fits for emotion factors to estimate post-test knowledge, science interest, and AR interest ($N = 62$).

	Knowledge Gain	Knowledge Gain	Science Interest	AR Interest
F1_Curious	0.59* (0.25)	0.55* (0.23)	0.35*** (0.07)	0.31** (0.08)
F2_Bored	0.16 (0.47)	-	−0.41** (0.12)	−0.59*** (0.15)
F3_Anxious	−0.32 (0.35)	-	−0.032 (0.09)	0.10 (0.11)
F4_ARFrustrated	−0.07 (0.53)	-	0.12 (0.14)	−0.42* (0.16)
F5_SciSurpriseConf	0.083 (0.27)	-	−0.033 (0.07)	0.069 (0.08)
Constant	−1.38 (1.35)	−1.11 (0.89)	3.76** (0.36)	4.19** (0.42)
R^2	0.11	0.089	0.48	0.58
Adjusted R^2	0.026	0.074	0.44	0.54
Residual Std. Error (df = 56)	1.67	1.63 (df=60)	0.44	0.52
F Statistic (df = 5; 56)	1.324	5.86* (df=1)	10.47**	15.33**

Note: We examined the impact of each emotion factor on knowledge gain, interest in science content, and interest in AR, respectively. In Model 1, we entered all five emotion factors to predict knowledge gain. In Model 2, we retained F1 as the only predictor for knowledge gain. In Model 3 and Model 4, we entered the five emotion factors to predict interest in science and interest in AR, respectively.

*$p < .05$; **$p < .01$; ***$p < .001$. Standard errors are included in parentheses.

and resolve misconceptions among museum visitors. Although prior studies have noted that training may be a potential complication associated with the incorporation of AR (Marques & Costello, 2018), our findings indicate that a brief orientation was sufficient for preparing participants, the majority of whom had no prior experience with AR, to become quickly engaged in the AR experience and attend to the audio and visual information being presented.

Taken together, these findings extend current literature about the use of AR technology in informal learning settings to demonstrate that AR can be used not only to facilitate engagement and interest but can also change previously held conceptions by adult patrons. Offhand exclamations of surprise (e.g. 'Wow!') or observed gestures, such as pointing to the adult-sized mammoth, are speculated to have meaningfully contributed to visitors' learning and overall misconception reduction. Moreover, the ability to view the artifacts and environment in novel ways while being on the grounds of the museum may have supported learning in context (Marques & Costello, 2018). By recreating the entrapment process of large animals using the combination of sound, narration, graphics, and animation superimposed on to an outdoor space, visitors accessed scientific information in ways that a typical museum experience does not ordinarily provide.

More interest toward science content compared to AR technology

Prior research that has explored the role of interest in informal learning spaces has done little to disentangle interest in concrete terms. To distinguish between two areas of potential interest – the novelty component of AR and content about the scientific processes that occur at LBTP, we measured these aspects of interest separately using surveys. Although interest in science content was anticipated given that participants were already visiting LBTP, demographics data showed that the majority of participants (77%) had not used AR previously – therefore, it was of value to explore how attractive the exposure to novel technology was relative to the science content.

Study participants reported greater interest in the science content compared to the AR technology which suggests that participants' engagement in the experience was driven by the science presented rather than by the novel aspects of AR. These findings are noteworthy since prior studies that measured engagement had not considered what made the activity engaging – whether it was some component that was essential to the task or if engagement was boosted due to the novelty of the tool or technology. These findings are promising given that learners may have a continued sense of enthusiasm for science content once the initial novelty of the AR dwindles.

Differences in emotions towards science content compared to AR technology

Similar to interest, we measured participants' emotions related to the science content and AR technology. To date, no studies have disentangled epistemic emotions as they relate to content and medium. Our results indicated visitors' epistemic emotions about science content and AR technology were not always highly correlated with one another. While some emotions were strongly correlated (e.g. anxious, curious), others (e.g. confusion, surprise) were weakly correlated. Although these emotional states may vary based on the exhibit content and design, nature of the AR technology, and individual qualities of the visitor, our findings suggest that participants differentiated between positive and negative epistemic emotions, even during a brief AR-enhanced experience. Given that emotional states can impact the ability to capture and maintain visitor engagement, and thus, can impact conceptual change and learning, this is an important finding that requires further exploration.

Emerging relations between emotions, interest, and learning

When we examined the relationship between specific emotion factors and their relationship to knowledge change, we found that only one factor, curiosity, predicted change. This finding is notable given that prior research has indicated that all seven epistemic emotions are linked to engagement and learning – however, in this study, curiosity was the only emotion construct that was significant. This suggests that efforts to pique museum visitors' curiosity, in particular, should be considered to induce knowledge change. When interest in science and interest in AR are each used as outcomes, we find a significant and positive relationship with both types of interest and curiosity, but a negative relationship to boredom for both interest types. Thus, curiosity has the added benefit of supporting interest in science and in AR technology, while boredom can hinder it. Moreover, negative epistemic emotions such as frustration with AR and science content and confusion about AR (i.e. F4) were negatively related to interest in AR suggesting that these are especially important to consider when incorporating this technology.

Study limitations and future research

Despite some promising findings on the role of AR in addressing scientific misconceptions and facilitating interest in science, study limitations need to be addressed. First, this study did not include a control group which would have offered additional insights into the role that AR played in supporting misconception revision and provided controlled conditions to establish causal evidence of its benefit for learning. Second, findings should be interpreted with caution given the short period of time that elapsed between the knowledge pretest and posttest. Misconceptions were notably reduced once participants completed the brief AR intervention, but it is unclear if the misconceptions were resolved over an extended period of time. Future work should consider incorporating delayed posttest measures to confirm these long-lasting effects. A third limitation is the low internal consistency of the knowledge measures which can be attributed to the small number of items and floor effects. Given that no existing knowledge instruments applied to the content in this study, our research team designed items that addressed the two scientific misconceptions of interest using the content expertize of LBTP staff.

These findings highlight the promise of AR for supporting conceptual change and interest in science in informal learning settings and point to important relationships between interest and learning that might be explored in future research. More research is needed to investigate the drivers of knowledge revision in informal learning environments and how AR might further contribute to conceptual shifts above and beyond existing technologies. In addition, exploration of emotional states and ways to increase positive emotions associated with both science and the technologies that support its delivery should be further investigated. Future research should also explore the implications for conceptual change and engagement with younger museum patrons, especially given the popularity of museums as destinations for school field trips. In the future, researchers might build on these findings by conducting full-scale randomized control trials to explore how learning with AR compares with analog museum exhibits, or what specific aspects of AR impact learning and engagement. Such pursuits may illuminate the mechanisms that explain why people find AR engaging and experience enhanced learning from this emerging technology in museums.

Notes

1. The answer to this question is (d) Once every 10 years.
2. We utilized the full knowledge scale for the main analyses and chose not to investigate specific misconceptions separately due to poor internal consistency. The three-item pretest for misconception 1 had $\alpha = .70$, and a posttest of $\alpha = .30$. For misconception 2, the pretest $\alpha = .58$ and the posttest $\alpha = .70$. Removing items did not improve the internal consistency.

Acknowledgements

Any statements and views expressed in this work are those of the authors and do not reflect the policies or views of any sponsoring organization.

Data availability statement

The data that support the findings of this study are available from the corresponding author, [AK], upon reasonable request.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by University of Southern California Institute for Creative Technologies [UARC Grant number W911NF-14D-0005].

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