PROJECT REPORT

Re-Living Paleontology: Studying How Augmented Reality Immersion and Interaction Impact Engagement and Communicating Science to the Public

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Executive Summary

Re-Living Paleontology research conducted systematic usability and comparison studies on how visual immersion and interactivity in augmented reality (AR) affects visitors' engagement and understanding of science. To explore this, two "Tar AR" experiences were designed and studied:
1) Pit 91 Experience: A tabletop AR experience was developed and tested at La Brea Tar Pits, based on fossils found at Pit 91 specifically. This portable AR interaction has learners "dig up" fossils and use them to reconstruct a simulated environment based on fossil evidence. Each fossil cycle supported structured hypothesis testing, where they revise their hypotheses about the climate at La Brea during the Ice Age.
2) Field Experience: A life-sized AR experience was developed (animals and plants "to scale") and tested outdoors at Hancock Park, which is part of La Brea Tar Pits ground. This full-scale experience took visitors "back in time" through AR interaction which overlays a narrative Ice Age scene onto a field in modern-day Los Angeles.

Intellectual Merit:
Research Design. The research involves creating different versions of an AR exhibit to communicate paleontology research from the La Brea Tar Pits to the general public. Each experience used an iterative, design-based research approach beginning with paper prototypes, usability testing and usability studies, and a randomized comparison study with 5 conditions: AR Headset with High Interactivity, AR Headset with Lower Interactivity; Phone-Based AR with High Interactivity, and Phone-Based AR with Lower Interactivity; and an excellent-quality poster that was content-equivalent (Control).

Figure 1: Pit 91 Experience Wearing Headset to Reconstruct an Ecosystem from Fossils

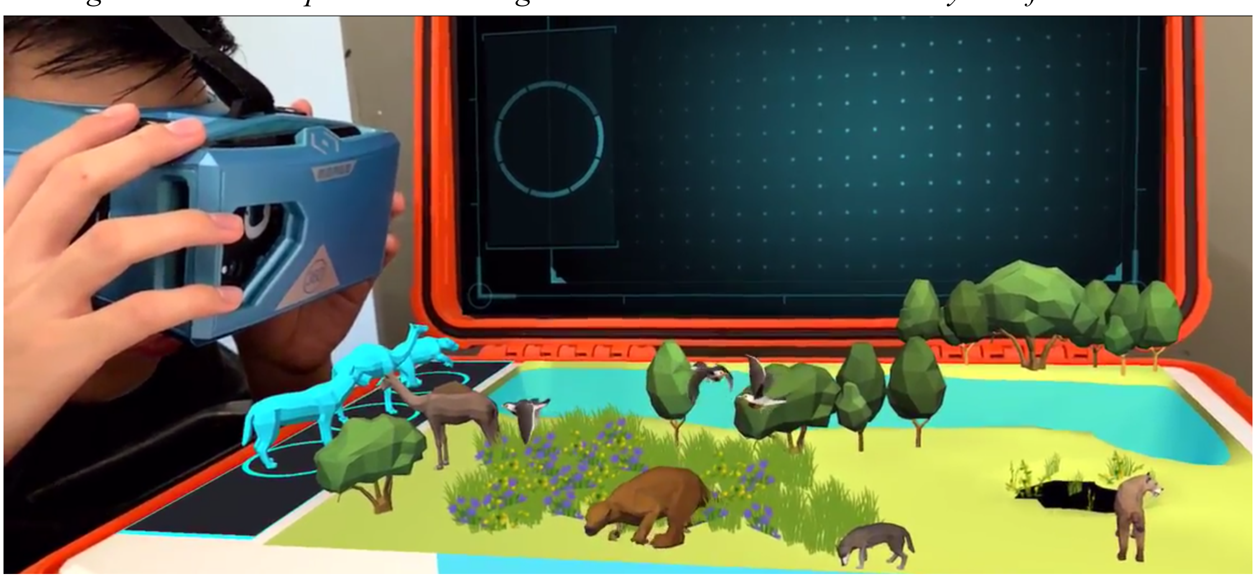


Figure 2: Field Experience - Back to La Brea's Ice Age and Entrapment

Key Results. All conditions showed strong engagement and highly significant learning, with nearly all major content areas well-understood. AR conditions also showed benefits in the Field Experience for length and content of visitors' verbal explanations of scientific content and processes compared to the Control, but produced similar performance on multiple choice knowledge items. Across both the Pit 91 and Field Experience, AR using handheld smartphones produced comparable or better learning outcomes than low-cost Headsets which embed phones. Analysis of self-reported emotions showed potential advantages for Headset AR, such as higher Interest and positive sense of Surprise. However, this must be balanced against findings that Headsets could also increase negative emotions such as Frustration.

Implications on AR Design. The results of this work indicate that when designing AR experiences: a) both small-scale and life-sized AR can produce strongly significant learning gains and reduce misconceptions using only smartphone hardware; b) phone-based AR (without headsets) offers comparable outcomes, with fewer logistical hurdles; and c) AR headsets may produce greater affective engagement, particularly in larger-scale/immersive environments, but may have trade offs with negative emotions that may affect certain populations or contexts (e.g., unfamiliarity or discomfort with headsets, heat/humidity effects).

Broader Impacts:

Scientifically Grounded Paleoart. As a broader impact for the process of science, this work rigorously documented and published the process for developing the 3D paleoart (virtual plants and animals from the Ice Age). This is an important contribution that should be followed for paleoart more generally, because artistic depictions of prehistoric animals and scenes are often a primary way that the general public learns about this science. By documenting and referencing what scientific sources influenced paleoart, that art can be more easily updated or replaced as new discoveries are made. This work contributes to emerging guidelines and approaches for ensuring that paleoart communicates the best current understanding from scientific findings.

AR Filters. In addition to the full experiences, AR filters were created which allow a phone to overlay a single animal for limited interactions and "selfies." These filters allow users to view and interact with the 13 extinct species of Pleistocene animals on any smartphone, at any time. Filters were created and shared for multiple platforms: Snapchat, Instagram/Facebook, and using app-less AR from Sketchfab. In the year that they have been active they have been implemented in events at La Brea Tar Pits (LBTP) and LA County Natural History Museum (NHM), outreach events both museums have participated in, site tours at the Tar Pits, and in classrooms. The filters are accessible through LBTP and NHM social media and both websites. Signs on-site at La Brea Tar Pits also provide the AR filters with fun facts about each of these animals in Hancock Park for visitor use. These filters have been accessed over 500,000 times since their release.

Literature Review and Field Interviews. After reviewing 62 papers and 72 projects on AR & VR in the museum field (informalscience.org/xr-museums-review-current-state-field), the evaluation team found that the most fruitful applications of AR or VR were in outdoor settings, historical or inaccessible sites. Additionally, the literature revealed that timeline shift or scale change were also beneficial applications. However, there were mixed or unsubstantiated findings on whether museum visitors gained more content knowledge through AR and VR compared to other tools and whether the technology boosted visitors' perception of the museum as up-to-date. Nevertheless, the findings did suggest that AR and VR could generate excitement over the technology, increase interest or curiosity in the content, evoke emotional responses to the content, or create a sense of "being there" that resulted in a changed perception of or connection to a place.

NTSA Short Film. A documentary-style 6 minute video communicating how this project used AR for science learning was created and shared at the 2023 National Science Teacher Association conference (NSTA), which presents how AR was used in this project as a pedagogical tool. This video is posted online and should be effective in communicating the science and technology of the project itself more widely for years to come.

Project Goals

The two main goals of this project were to:

1. Advance Knowledge: Study how mobile AR design choices for immersion and interactivity impact visitors' engagement and understanding of science.
2. Communicate Science: Leverage the most effective AR to communicate on-site paleontology research from the La Brea Tar Pits to the public. The learning goals are to help visitors: a) understand the scientific process (e.g., why scientists revise hypotheses); b) understand how ecosystem changes at La Brea were impacted by shifts in climate; and c) repair misconceptions and increase knowledge about paleontology research at La Brea.

To accomplish these goals, we designed, implemented, and evaluated public response to multiple AR exhibits at the La Brea Tar Pits. Each exhibit involved multiple test conditions, encompassing different levels of immersion (no AR, touchscreen AR, and headset AR) and interactivity (non-interactive, selection, and manipulation). Pre- and post-tests of study participants included questions designed to test scientific knowledge gain and visitor willingness to engage with AR experiences in a museum setting.

Approach

I. Background Concepts

Field-based studies have indicated benefits of AR experiences. In a study conducted by Kamarainen et al. (2013), sixth graders from three classrooms participated in EcoMOBILE, a curriculum that supported AR activities in an outdoor pond environment. As part of the study, students used an AR application installed on a mobile device to conduct observations of virtual media that were overlaid on an outdoor pond and collect water quality samples. As a result of the intervention, findings suggested that students felt more efficacious about their ability to understand scientific topics and perform specific skills as well as demonstrated learning gains from pretest to posttest. To extend this work, Grotzer et al. (2015) recruited fifth and sixth graders to participate in an EcoMUVE Pond Module, a virtual pond environment that allowed participants to engage in an immersive ecosystem setting. Their findings indicated that the incorporation of AR not only produced learning gains and deepened conceptual understanding but were also linked to knowledge transfer as it pertained to ecosystem concepts.

Based on reviews of literature, AR has the potential to facilitate understanding while also supporting long-term knowledge retention, group collaboration, and motivation by making the relationship between information and objects salient (Radu, 2014). The immersive experience or additional novelty that students may experience when first interacting with AR may contribute to increased interest, engagement, and attention, as demonstrated by Dunleavy and colleagues (2009). As indicated in prior studies, the incorporation of videos, 3D images, and sound into an AR experience can be utilized to heighten students' attention, and support learners in the process of new knowledge acquisition as well as conceptual shifts in understanding.

Although investigations to date have generally focused on the use of AR in classrooms and schools, scientific understanding and engagement can also be fostered within informal science environments (Banks et al., 2007; National Research Council [NRC], 2009). Given that a single museum exhibit can reach hundreds of thousands or even millions of visitors, these settings hold enormous potential to create a lasting impact on learning and engagement with science (Schwan et al., 2014). Informal science learning environments, such as museums, provide unique opportunities for science learning. Unlike classrooms, participation is voluntary and learners are positioned to exert control over the activities they participate in (Falk, 2001). Oftentimes, learners engage in these informal science activities based on their personal interests, curiosity, or sense of identity. Due to the exploratory nature of informal learning environments, AR can play a unique role in empowering visitors to explore content of interest in a more engaging format.

II. Design Considerations for Augmented Reality: Visual Immersion and Interactivity

Increased empirical studies are needed to demonstrate when and how to leverage AR experiences so that they reinforce critical concepts rather than merely entertain visitors. Unfortunately, most AR experiences cannot systematically evaluate design choices (Dünser & Billinghurst, 2011), since they only compare an AR design against a baseline activity (Merchant, Goetz, Cifuentes, Keeney-Kennicutt, & Davis, 2014). However, with increasing use of AR, the growing questions are about "how to augment." Studies on AR for informal learning often address most design choices at the formative stages, so effect sizes for user outcomes are seldom reported (FitzGerald, Ferguson, Adams, Gaved, Mor, & Thomas, 2013; Bacca, Baldiris, Fabregat, & Graf, 2014).

In this project, we are interested in two high-level design factors for mobile AR: visual immersion and interactivity. These impact both the learning experience and the development so extensively that multiple versions are seldom empirically compared. These factors also have unique considerations for informal learning, such as how to balance immersion against situational awareness (e.g., 3D viewers reduce field of view) and visitor expectations about time to spend at an exhibit (e.g., interactivity increases holding time; Allen, 2004). One goal of this project was to systematically compare qualitatively different AR designs that communicate equivalent science content, so that we can study these tradeoffs empirically. The second goal is to leverage these findings by publicly releasing an AR experience that promotes engagement, increases understanding of science, and reduces misconceptions.

III. Research Approach: Design-Based Research

This project had five design phases for each AR experience, as outlined in Table 1. These are the 1) User Task Analysis, 2) Expert Review, 3) Formative Studies, 4) Comparative Research, and 5) Selection of Best Condition for Public Usage. These stages are derived from a hybrid design and evaluation model that integrates the iterative, agile methodology for AR design from Gabbard &

Swan (2008) with the structured design phases from Gabbard, Hix, and Swan (1999). These design methodologies are considered to be both comprehensive and cost-effective for AR design and evaluation (Dünser & Billinghurst 2011). The result is our user-centered design and evaluation process as shown in Figure 1.

Table 1: Project Design and Research/Evaluation Stages

1) User Task Analysis: User stories, storyboards, and design guidelines from similar informal and AR experiences.
2) Expert Review: Mockups and prototypes evaluated by external experts (Advisory Board, External Evaluator, La Brea Tar Pits/NHMLA staff not directly involved in project). Results used to revise prototypes and update task analysis.
3) Formative Research: Iterative small-scale user studies (N=5 to 20) to study usability and refine survey and test items. Results and prototypes presented for expert feedback and used to revise each design.
4) Comparative Research: For each AR design and the control, a larger-sample study for statistical comparisons between designs on engagement and science learning. Record evidence on logistical and usability issues.
5) Selection of Best Condition for Public Usage: Evaluate and suggest the best design for public use, based on outcomes of interest. Disseminate results and design principles.

Outcomes of Interest: There are two primary outcomes we expected to impact: 1) greater engagement through an immersive experience and 2) reductions in misconceptions and increases in scientific knowledge. The primary outcomes were statistically analyzed to compare the efficacy of each design, based on a study where groups of recruited visitors are randomly assigned to conditions. In addition to the primary outcomes, usability and logistics for AR designs will also be collected (e.g., effects of heat/weather, help needed to set up the app).

Based on these metrics, we initially hypothesized that when compared across designs:
H1) Higher visual immersion for AR would result in greater engagement
(Pre-project expectation: Headset > Touchscreen > Baseline)
H2) Higher interactivity would result in greater learning from the AR
(Pre-project expectation: Manipulation > Selection > Baseline)
H3) Higher engagement would be positively associated with greater learning.

However, based on the multiple years of research in this project, the actual outcomes across conditions were more nuanced and appeared to be influenced by the type of AR experience (e.g., life-sized vs. table-top). For example on H1, greater visual immersion (headsets) appeared to only be relevant to affect and engagement in the larger-scale experience. Additionally, the headset-based AR showed both higher positive affect and higher negative affect, thus this condition was mixed in terms of benefits. Similarly, H2 for higher interactivity improving learning did not hold for the tabletop experience and its apparent benefits were limited to explanation quality in the Field Experience. That said, H3 did hold consistently, where self-reported affect factors were a strong indicator of greater learning.

III. Augmented Reality Experiences for Science Learning at La Brea Tar Pits Museum

Two Augmented Reality (AR) experiences were developed, where each was designed using an iterative, design-based approach that culminated in a randomized controlled comparison study.

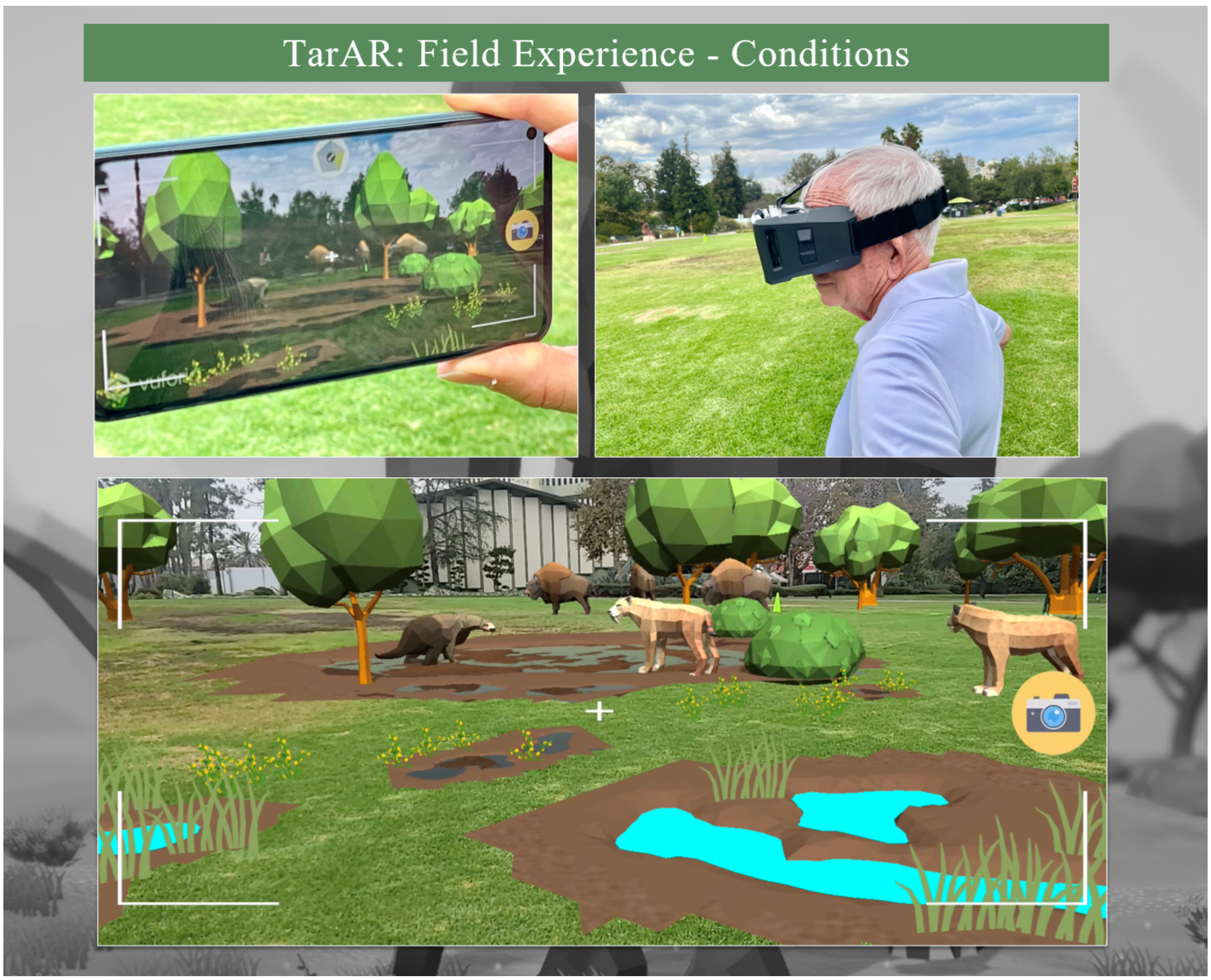
1) Pit 91 Experience: A portable tabletop AR interaction where learners "dig" up fossils and use them to reconstruct a simulated environment based on fossil evidence. Each fossil cycle supported structured hypothesis testing, where they revise their hypotheses about the climate at La Brea during the Ice Age.

Figure 3: AR Conditions for the Pit 91 Experience

2) Field Experience: A full-scale "back in time" AR interaction which overlays a narrative Ice Age scene onto modern-day Hancock Park, which is part of the La Brea Museum grounds.

Learning Objectives: We identified major learning goals based on common visitor misconceptions identified by the La Brea Tar Pits staff, and areas of research that learners often have difficulty understanding. These learning objectives were revised through an iterative process by the advisory panel and the entire team in a series of in-person and online meetings. Based on this, we developed three learning themes to align AR experiences to: Reconstructing Ecosystems, Scientific Methodology, and Ice Age Entrapment.

Figure 4: Field Experience Condition Examples (upper: handheld vs. headset; lower: higher-interactivity condition where the learner takes and selects pictures as an added activity)



AR Modalities: After identifying themes we designed the modes of AR experience delivery to implement and test (building operational definitions and examples of selection vs. manipulation tasks which could retain information-equivalence with respect to content coverage, but which

would impact how learners act on the AR environment). Through iterative testing we settled on testing several different experimental conditions for AR that make sense in a museum context:
a) Visual Format: How the AR view is experienced, through a headset vs. on a phone;
b) Interaction Level: Higher interaction vs. lower interaction; such as selection/tap vs. manipulation via an AR-enhanced tool.

Measures: We developed a set of measures for the usability (e.g., technology acceptance, presence) and pilot testing of the multiple conditions (e.g., engagement, affective responses, test items for specific learning objectives).

II. Empirical Studies: Iterative Design-Based Research and Randomized Studies

A. *Pit 91 Experience* was the first of two full AR experiences designed and implemented by the Tar AR project. This experience took place in the Pit 91 (in situ excavation site) viewing station at La Brea Tar Pits, and took the form of a guided exploratory game.

- Experience design: This experience took place on a mobile table that was built specifically for this purpose, supporting structured hypothesis testing.
- Control exhibit: A specially-designed large sized poster was developed which was content-equivalent to the Pit 91 main learning objectives, presenting both the fossils and how they helped reconstruct the ecosystem.
- Main Learning Objectives: Tar Pits capture a broad set of the ecosystem (plants, birds, fish, megafauna). The Ice Age climate at La Brea was only a little cooler and a little wetter than today. Many animals and plants present during the Ice Age remain at La Brea today, but the megafauna are extinct. Science involves a repeated cycle of collecting observations and revising hypotheses based on new information.
- Usability testing: Two usability cycles improved each of the four AR conditions to ensure users could complete AR interactions reliably and to pilot new measures.
- Comparison Study (N=245):
  - 135 Participants spread across the 5 conditions pre-COVID, which was suspended in Spring 2020 due to COVID-19 shutdowns. Due to some conditions showing slightly different pre-test averages and other minor patterns due to fewer samples, a second post-COVID collection was conducted.
  - 110 Participants completed the 5 conditions in June 2021.

B. *The Field Experience* was an AR experience. This experience involves inspecting virtual fossils found in the tar, then traveling back in time to see how animals and plants became entrapped in the tar.

- Experience Design: There were four distinct versions of the experience (high vs. low interactivity; headset vs. handheld). In higher interactivity, participants take pictures of the events and select their favorites at the end.

- Control exhibit: We developed the control experience, which has been installed at La Brea Tar Pits as a permanent addition. This installation is a large, partially transparent sign which emulates an AR overlay by showing versions of the entrapment scene over the transparent background that allows seeing the field behind the sign. The sign includes all of the same information as the AR experience in a more standard museum format. As with the Pit 91 sign, it was designed to be a high quality authentic comparison for a professional traditional exhibit.
- Learning objectives: Tar Pits capture a board set of the ecosystem (plants, birds, fish, megafauna). More predators were trapped in the tar due to prey getting stuck in the tar. Many animals and plants during the Ice Age remain at La Brea today, but the megafauna are extinct.
- Usability testing: Conducted usability testing on the AR experience and limited testing with the sign to help improve conditions, instructions, and measures. The number of subjects completing an AR condition was 46 (with specific counts by condition: Handheld Low 14, Handheld High 11, Headset Low 14, Headset High 7, sign 12)
- Experiment (data collection):
    - 184 Participants completed the study in Summer 2022, with 148 in an AR condition (Handheld Low 41, Handheld High 42, Headset Low 31, Headset High 34), as well as 36 in the sign control condition.

Figure 5: Field Experience Control Condition Semi-Transparent Sign

II. Digital Paleoart: Scientifically-Grounded Paleoart for AR and other Media (22 3D models)

To implement the AR experience we partnered with a 3D modeling design group (PolyPerfect) to create scientifically-accurate low-poly models of 22 species of Pleistocene flora and fauna, some of which are extinct and some of which are still in Los Angeles today. We determined that the low-poly aesthetic best suited the needs of this project for several reasons: It allowed us to create scientifically accurate models without providing a level of detail beyond our current scientific understanding. These models also take far less processing power than more complicated models, allowing us to create an experience which features interactions between models that is lightweight enough to run on a normal smartphone. The low-poly aesthetic is one that many people are familiar with and enjoy, making it an excellent vehicle for engagement with visitors.

The process of developing these models was documented in detail in an influential journal article (Davis et al., 2022), intended to promote greater citation and documentation about the choices made to develop paleoart and to communicate this innovation to museum exhibit designers. This is a particularly important issue, as paleoart is one of the primary mechanisms through which science about ancient animals and plants is communicated.

Figure 6: The TarAR 22 Scientifically-Grounded Digital Paleoart Models

Key Results

Results from Pit 91 and the Field Experience showed many similarities, but also a few notable differences. These differences may be related to their design, as they are qualitatively different as being big versus small AR experiences (Field Experience is life-sized, while Pit 91 is tabletop). Pit 91 was collected both prior to and after COVID-19 shutdowns, the results were similar across both data collections for the comparison study. Field experience data collection was delayed by COVID-19, but was collected within a single study period.

I. Pit 91 Main Results

Both quantitative and qualitative analyses were applied to explore the data collected. From these, the main findings were as follows.

Learning Gains: Highly significant learning gains were observed for all AR conditions and for the sign condition. Observed gains were established both for open-response answers and for knowledge test items (e.g., multiple choice). The AR handheld phone with a tool (high interactivity) showed a statistically significant decrease in climate misconceptions versus other conditions, but conditions otherwise were not significantly different.

Explanation Quality: AR conditions showed some advantages versus the control on forming a high quality explanation for "What do you think the environment of LA looked like during the Ice Age?" based on a keyword dictionary tuned to capture essential concepts and terms. The Phone+Manipulation condition showed a particular advantage on this metric.

Engagement and Affect: While some differences in affect were observed, these were not universally consistent between conditions. In general, all conditions were highly engaging, with the presence of the real-life open tar pit in the same room being a strongly engaging factor (all conditions looked at the pit first).

Learning-Affect Interaction: Based on factor analyses and regression on the affective factors, higher science interest appears to be associated with greater learning even after controlling for pretest knowledge.

Strongest Condition: Given that conditions performed comparably, the strongest candidate conditions were the handheld AR (e.g., no headset). In this context of tabletop AR, the headset increased logistical requirements and software development time, but did not result in substantially different learning or engagement. Among handheld AR, an argument can be made for both touchscreen (low interactivity) or tool-based (high interactivity). The condition with the tool showed a small advantage for reducing misconceptions in open response answers. However, users also reported some difficulties using the tool, as they needed to use one hand on their phone and the other on the tool. Finally, the sign condition performed strongly in this context where users were instructed to review it, with a specific advantage for "list type" items (e.g., select what was preserved in the tar among a list). In general, the large size of a sign enables presenting more items together at one time, while the AR enables presenting content interactively over time (e.g., a narrative, a simulation). This suggests a complementary role for each.

II. Field Experience Results:

Data for the comparison study was collected in Summer 2022, with the following main results:

Learning Gains: All AR conditions and the Control showed significant learning gains. As with the Pit 91 experience, multiple choice items did not show significant differences between conditions. However, open response answers to "What are some different ways something could get stuck in the tar?" Entrapment showed significantly higher rates of detailed mechanisms, specifically: accidentally walking into it (e.g., not noticing it due to grass or puddles), and scavengers getting stuck (e.g., birds).

Engagement & Affect: An analysis of emotions into factors found that emotions grouped into four factors (named for their strongest emotion item): interest, frustration, scared, and surprise.

- Interest was higher for AR: AR conditions showed significantly higher levels of a factor comprising interest, curiosity, and inquisitiveness. Emotions related to surprise (positive) were also significantly different between conditions, but only some conditions were higher than the control. The Phone+Low Interactivity condition had the highest levels of interest and surprise.
- Headset Increase Negative Affect (Slightly): Headset conditions showed a significant and slightly higher level of the frustration emotion factor and a scared/anxious emotion factor, versus non-headset or control conditions. With that said, negative emotion factors were low overall on a 5-pt scale, with conditions ranging from 1.24-1.99 on the frustration factor and scared/anxious factor 1.07-1.69. As the headsets were highly basic, more advanced models might do better but are still likely to be higher than a familiar phone-based interaction.

Explanation Quality: Open response results also showed differences between conditions, particularly with respect to the length of verbal responses that participants gave:

- Telling a Story: AR conditions with higher interactivity showed a higher word count ($p < 05$) versus the Control or the low-interactive AR conditions. Among analysis of LIWC features (Linguistic Inquiry and Word Count), AR also resulted in more visual language words and a greater use of past-voice words versus present-voice words.
- Different ways something could get stuck in the tar (Entrapment): AR conditions had a significantly higher word count than the Control poster ($p < .01$), with high-interactivity conditions also higher than lower-interactivity AR conditions. Participants with higher interaction were more likely to mention certain events with suggested interaction

opportunities, such as animals eating plants (e.g., acorns) or pursuing/chasing other animals.

- Anything Surprising/Think Differently: AR conditions showed a higher word count than the Control ($p < .05$). Different AR conditions were not significantly different on word count. Among frequent categories of surprise, participants using AR were more likely to be surprised by ($p < .05$): Animals getting stuck due to food chains (predation, scavenging), Diversity in size of animals in the Ice Age (big and small), and Capabilities of AR technology.

Strongest Condition: AR conditions showed significant advantages over the Control, both for open response explanations and affect factors associated with learning. While no single AR condition was dominant, Phone-based AR with higher interaction (Phone+High) was the most well-rounded. Higher-interaction AR conditions produced stronger explanations (both for Phone and Headset). However, the Headset conditions introduced greater logistical challenges and small increases in frustration. Phone+Low Interactivity showed the highest affect (interest, surprise), but with weaker explanations than high interaction conditions. As such, the ideal experience likely depends on audience expectations and the experience goals. Phone+High interaction was a good balance, Phone+Low showed stronger positive affect but weaker explanations, and Headset+High had both positive and negative affect factors.

Broader Impacts

Both the 3D paleoart assets and media have been leveraged extensively for outreach efforts beyond the museum and as interaction points in the public park around the La Brea Tar Pits and Museum.

AR Filters. We created AR filters for Snapchat, Instagram/Facebook, and using app-less AR donated to us by Sketchfab to expand the usage of the 3D models beyond the two full AR experiences available at the Tar Pits. These filters allow users to view and interact with the 13 extinct species of Pleistocene animals on any smartphone, at any time. In the year that they have been active they have been implemented in events at La Brea Tar Pits and LA County Natural History Museum, outreach events both museums have participated in, site tours at the Tar Pits, and in classrooms. The filters are accessible through LBTP and NHM social media and both websites. Additionally, recently we have installed signage including the AR filters with fun facts about each of these animals in Hancock Park for visitor use.

As of March 10, 2023 these filters have been accessed over 500,000 times since their initial releases in February 2022:

- Snapchat: 435,400 views and 25,416 shares
- Instagram/Facebook: 121,562 impressions and 128,151 opens

- Sketchfab: 29,212 views

For a report on these filters and associated QR codes to try them, see:
https://nhmlac.org/press/mammoths-meet-metaverse

NSTA Video. A professionally produced 6 minute video was recorded and shared at the National Science Teacher Association conference, which shares how AR was used in this project more widely as a pedagogical tool. This video should be effective in communicating the science and technology of the project itself more widely for years to come. The video can be found here:

https://www.youtube.com/watch?v=Nh7dIBIH3ks

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Publications and Recognition

The results have been shared both by academic channels and through broader outreach and media interviews. The project has also been shared through social media outreach (as aligned to recruiting and education efforts), word-of-mouth at conferences, and through a variety of press releases and media coverage. Additionally, the AR filters have been utilized at several outreach events by NHM/LBTP, including City of STEM and events in partnership with other museums.

We are in communication with other organizations (Tule Springs Fossil Beds National Monument, Alf Paleontology Museum) and individual teachers who are looking forward to implementing the AR filters, and hopefully other aspects of this project, in their own outreach efforts.

I. Academic Publications

Publication of results is ongoing, with multiple journal and conference publications completed and a number of other publications in preparation or revision to disseminate results broadly. For the best summary of publications for this project with full-text available, we recommend reviewing the NSF Public Access Repository (PAR) for the project. As a collaborative project, there are two lists but these should typically contain comparable publications. We recommend checking the first list, and if the text is unavailable, also look through the second:

- USC: https://par.nsf.gov/search/award_ids:1810984
- La Brea Tar Pits: https://par.nsf.gov/search/award_ids:1811014

Publications:

- Davis, M., Nye, B. D., Sinatra, G. M., Swartout, W., Sjöberg, M., Porter, M., Nelson, D., Kennedy, A.A.U., Herrick, I., DeNeve Weeks, D., and Lindsey, E. (2022). Designing scientifically-grounded paleoart for augmented reality at La Brea Tar Pits. Palaeontologia Electronica, 25(1). DOI: 10.26879/1191
- Kennedy, A. U., Thacker, I., Nye, B.D., Sinatra, G.M., Swartout W.R., & Lindsey, E. (2021). Promoting interest, positive emotions, and knowledge using augmented reality in a museum setting. International Journal of Science Education, Part B, DOI: 10.1080/21548455.2021.1946619. (Related, but on pre-grant pilot data)

Conferences and Talks:

- Lindsey, E., Herrick, I., Kennedy, A., Nye, B., Davis, M., Nelson, D., Porter, M., Swartout, W., Sinatra, G. (October 2021). Augmented Reality in Natural History Museums: Impact on Visitor Engagement and Science Learning. Geological Society of America *Abstracts with Programs.* Vol 53, No. 6. doi: 10.1130/abs/2021AM-371425
- Nye, B., Nelson, D., Herrick, I. R., Sinatra, G. M., Kennedy, & A. A., Davis, M., Sjoberg, M., Ghate, P., Swartout, W., & Lindsey, E. (November, 2021). Science big and small: Visiting the ice age through miniature and life-sized AR experiences. Poster presented at the American Psychological Association Technology, Mind, and Society Annual Meeting.
- DeNeve Weeks, D., Lindsey, E., Davis, M., Kennedy, A., Nye, B., Nelson, D., Porter, M., Swartout, W., & Sinatra, G. 2022, Tar AR: Researching how Augmented Reality activities can facilitate visitor learning at La Brea Tar Pits: Geological Society of America

Abstracts with Programs, v. 54, no. 2, doi: 10.1130/abs/2022CD-373373 https://gsa.confex.com/gsa/2022CD/webprogram/Paper373373.html

- Kennedy, A. A. U., Jacobson, N., Thacker, I., Sinatra, G. M., Lu, X., Sohn, J. H., Nelson, D., Rosenberg, E. S., & Nye, B. D. (2018). Re-living paleontology: Using augmented reality to promote engagement and learning. American Psychological Association. San Francisco, CA. {Kennedy:2018va}
- Sinatra, G. M. (2019). Keynote address: the power and peril of AI in education. Presented at the International Conference on Media in Education, Shenzhen, China. {Sinatra:2019vu}
- Davis, M. (2019). Virtual reality, augmented reality, and real reality: thinking holistically about the spectrum of immersive technologies in museums. PaleoBios, 36 (Supplement 1), 118. http://doi.org/10.5070/P9361044177 {Davis:2019ez}
- Kennedy, A. A., Thacker, I., Sinatra, G. M., Nye, B., Lindsey, E., Swartout, B. & Nelson, D. (2020). Reliving paleontology: Correcting scientific misconceptions with augmented reality in a museum setting.. AERA Annual Meeting. San Francisco, CA (Canceled due to COVID). {Kennedy:2020uc}
- Davis, Matt (2021). Tar AR: Bringing the past to life in place-based augmented reality science learning. MuseWeb 2021. https://mw21.museweb.net/proposal/tar-ar-bringing-the-past-to-life-in-place-based-augmented-reality-science-learning/ {Davis:2021ts}
- Herrick, I., Sinatra, M. G., Kennedy, A., Nye, B.D., Swartout, W.R., & Lindsey, E. (2021). Tar AR: Connecting the Past with the Present in Informal Science Learning.. AERA Annual Meeting. Online. {Herrick:2021uc}
- Herrick, R. I., Sinatra, M. G., Kennedy, A., Nye, B., Swartout, & W., Lindsey, E., (2020, April 18–19). Tar AR: Using AR to Enhance Science Enjoyment and Informal Science Learning, [Poster Session] 2020 APA Annual Meeting 2020, Washington, DC.

II. Public Communication and Recognition

Notable public communication and recognition from this project was achieved, including:

- Falling Walls Science Breakthrough Nomination: The project was also nominated and recognized as a finalist for the Falling Walls Science Breakthrough of the Year for 2022 in the Art + Science category: "Augmented reality: time travel and teaching tool" (https://falling-walls.com/science-summit/finalists-2022/).
- National Science Teachers Association (NSTA): Professional communication video of results presented and shared at the NSTA conference. (https://www.youtube.com/watch?v=Nh7dIBIH3ks).
- Scientific American: The journal article in Paleontological Electronica article and additional parts of the project were covered in articles by Scientific American (https://www.scientificamerican.com/article/ice-age-animals-come-to-life-via-augmented-reality/)

- Science: (www.science.org/content/article/augmented-reality-brings-back-extinct-ice-age-animals)

Other Media Interviews & Outreach:

- BBC (https://www.bbc.co.uk/newsround/60618249)
- Jing Culture & Commerce (https://jingculturecommerce.com/natural-history-museum-los-angeles-la-brea-tar-pits-paleoart-ar/)
- Science News for Students (https://www.snexplores.org/article/smartphones-bring-ice-age-animals-to-life-augmented-virtual-reality)
- The Week Junior Science + Nature Magazine (physical magazine, no link to include)
- Numerama (https://www.numerama.com/sciences/870303-ressuscitez-des-mammouths-en-realite-augmentee-avec-votre-smartphone.html)
- The Daily Beast, (https://www.thedailybeast.com/scientists-built-an-augmented-reality-tool-to-resurrect-extinct-animals-for-museums?ref=home)
- IFLScience (https://www.iflscience.com/the-metaverse-now-has-scientifically-accurate-mammoths-62819)
- Daily Record (https://www.dailyrecord.co.uk/lifestyle/money/museum-creates-metaverse-collection-26404691)
- VR Scout (https://vrscout.com/news/scientists-resurrect-extinct-animals-using-ar-technology/)
- earth.com (https://www.earth.com/news/extinct-ice-age-animals-join-the-metaverse/)
- Interesting Engineering (https://interestingengineering.com/innovation/extinct-animals-metaverse)
- Mashable (https://in.mashable.com/science/28156/walk-with-woolly-mammoths-in-the-metaverse-as-scientist-recreate-ice-age-with-augmented-reality)
- Engineering and Technology (https://eandt.theiet.org/content/articles/2022/03/researchers-create-accurate-virtual-models-of-ice-age-animals-for-metaverse/)
- CNET (https://www.cnet.com/science/biology/extinct-ice-age-animals-will-be-digitally-resurrected-in-the-metaverse/)
- Phys.org (https://phys.org/news/2022-03-scientifically-grounded-paleoart-ar.html)
- Science Daily (https://www.sciencedaily.com/releases/2022/03/220302092713.htm)

- Beverly Press (https://beverlypress.com/2022/03/la-brea-tar-pits-unveil-virtual-models-of-ice-age-animals/)
- blooloop (https://blooloop.com/museum/news/nhmlac-la-brea-tar-pits-extinct-animals-ar/)
- Hey SoCal (https://heysocal.com/2022/03/03/paleontologists-from-la-brea-tar-pits-develop-scientifically-accurate-extinct-animals-in-vr/)
- Center for Data Innovation: 10 Bits: The Data News Hotlist (https://datainnovation.org/2022/03/10-bits-the-data-news-hotlist-352/)
- Mirage News (https://www.miragenews.com/mammoths-meet-metaverse-735103/)
- Verve Times (https://vervetimes.com/designing-scientifically-grounded-paleoart-for-ar/)
- NHM press releases:
  https://nhmlac.org/press/mammoths-meet-metaverse
  https://nhm.org/stories/are-hollywoods-ice-age-animals-money
- USC Press Release (https://news.usc.edu/148747/usc-partners-with-la-brea-tar-pits-on-augmented-reality-venture/)