

Balancing Attention in an Immersive Augmented Reality Multiplayer Game for Museum Education

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Abstract: Augmented reality (AR) is increasingly used in cultural heritage exhibitions, yet many systems are designed for single users and can make visitors feel isolated. This study examines how immersive AR games can support group interaction while maintaining attention and interest in the physical exhibits. In a mixed-methods study, 90 participants played a multiplayer AR game we developed for a natural history museum. The game combined a dinosaur fossil with virtual content and collaborative game mechanics. Data were collected through observation, a questionnaire, and interviews. Results show that the game fostered a shared experience, with virtual elements attracting the most attention, while the fossil remained present. After gameplay, participants showed significantly greater interest in examining the fossil and learning about the dinosaur.

Keywords: Co-presence, Location-based AR, Collaboration, User study, Attention, Game-based learning, Museum education

1. Introduction

Museums and cultural heritage (CH) sites seek more and more to support the casual learning of their visitors with technology, especially Augmented Reality (AR). AR refers to the visible overlay of virtual objects and information onto the perception of the physical world, thereby blending digital and real environments (Cavallo and Forbes, 2019). Research findings indicate that AR can enhance active visitor engagement with the exhibits and support education and learning (da Silva et al., 2019). In museums, smartphones and tablets are primarily used for this purpose, as these devices are widely available and easily accessible. Head-mounted displays (HMDs), on the other hand, offer the advantage of enabling hands-free use and creating a more immersive experience. However, their everyday use remains limited. Furthermore, the use of such devices can create a sense of isolation, whereas museum visits often take place together with family members or friends.

In this context, the development of AR games for groups is progressing relatively slowly. This creates a tension between the fundamentally social nature of a museum visit and the often individually oriented design of AR games and digital experiences in CH (Bitter and Spierling, 2024). Studies in the field of education suggest that collaborative AR experiences can have positive effects on learning outcomes and foster positive interaction among peers, particularly in group and multi-person settings (Upadhyay et al., 2024).

To address this gap, we designed and implemented an educational multi-player AR game for a natural history museum, to be played with see-through Meta Quest 3 devices. The design goal was to facilitate co-located social interaction with appealing virtual elements, whilst also maintaining interest in the physical exhibit – a dinosaur fossil (see Figure 1). As this requires visitors to divide their attention between three targets – the real fossil, the virtual augmentations and their co-players – we carried out a study to examine this balance. Further, we analysed effects of the intervention on engagement for learning.

We present the findings of our qualitative study based on 90 participants playing the immersive AR game in pairs at the museum. In the following, we first discuss the current state of the art in multi-user AR for exhibitions, after which we describe our study and prototype before diving into the results and their discussion.

2. Related Work

2.1 Multiplayer Augmented Reality

Multi-player AR games are still a small and “new” field, with a lack of established frameworks, best practices, and design standards despite AR’s rapid growth in general (Syed et al, 2023). In comparison to virtual reality (VR), where collaborative applications in training, simulation, therapy, and entertainment are established (Cipresso et al., 2018), multiplayer AR remains underexplored.

Central to multiplayer AR are questions of presence and awareness. Sereno et al. (2020) highlight three interlinked forms of presence: Physical presence, or the sense of plausibility rooted in realistic physics and object

behaviour; social presence, both among collaborators in the AR environment and with bystanders; and engagement, the cognitive, emotional, and behavioural involvement that, when strong, may induce flow states. In addition, multiplayer AR experiences can be categorised along the time dimension – synchronous and asynchronous – and along the space dimension – co-located players vs. remote players (Serenio et al, 2020).

Groups at museums can be classified into two categories (Bitter and Spierling, 2024). A group of visitors can be made up of people with equivalent roles, such as friends or a family. In this case, there is no pre-defined leader of the group, and every member of the group would seek to have the same quality of experience as the others. In contrast, a group can be made up by an expert (e.g., museum guide or teacher) who is then the leader of the group, and multiple non-expert visitors.

2.2 Attention in Immersive Augmented Reality

To find a balance between perceived virtual and physical objects in AR applications for cultural heritage exhibits, aimed to offer a playful educational interaction while respecting the actual object, it is helpful to look at how AR influences users' attention and task performance.

Fan et. al. (2025) showed that AR combined with an authentic environment may have a positive impact on a visitor's engagement with a CH site. They developed two AR apps for two different sites in Mongolia: one for a native rural environment (a forest) and one for an artificially created environment (a museum). Participants were shown videos and still images of both sites, with and without AR, whilst their heart rate variability and eye movements were measured, followed by a questionnaire. The data shows an increased eye fixation duration and number of fixation points for the AR environments, from which the researchers conclude enhanced visual attention (varying with gender, educational level and professional background). The questionnaire results suggest that integrating AR had greater positive effects in the rural setting than in the artificial environment.

Satkowski and Dachsel (2021) compared the influence of differently cluttered backgrounds in a production hall on user performance in AR analysis tasks. The amount of clutter barely influenced the participants' actual performance at solving the tasks. However, it affected the participants' solving time and their perceived task performance, as they felt distracted by more cluttered backgrounds.

Additional to the real environment, the design of the app itself also influences the users' attention and physical task performance (with AR as a virtual aid). Wolf et. al (2023) compared 5 AR visualizations of pedicle screw trajectories in spinal fusion surgery. They differed in their abstraction level (2D or 3D representations of surgery tool poses and vertebrae) and AR element positioning (direct overlay versus offset). The researchers found a significant impact on task performance; the best performing variant was the offset presentation of anatomical information, not the directly overlaid one.

Kim et al. (2025) analysed the impact of virtual density and a visual guide on participants' performance in an AR search task in an indoors environment with virtual and physical objects. They found no significant difference in recall of physical vs. virtual objects, but higher source confusion for physical objects (an inaccurate memory mixing up or confusing virtual and real objects (Bonnail et al., 2024)). In a similar study in a wide outdoor area, Kumaran et al. (2023) analysed how AR navigation aids impact search performance and object recall with physical and virtual objects that had to be categorised. Participants were less accurate at classifying real objects, leading to the conclusion that their attention shifted from physical objects towards virtual elements.

While there is a moderate amount of research into the distribution of users' attention between physical and virtual objects in AR, there is only little on multiplayer AR. Our study explores how players in an HMD-based AR museum game additionally pay attention to their co-player, without neglecting the real exhibition.

3. Study Design

The study is based on an immersive multi-player AR prototype that we built for a natural history museum, featuring a *Parasaurolophus* fossil (Figure 1). We tailored the mini game to this exhibit, as described in Section 4. The study investigates how players' focus was distributed during the game, which was aimed at preserving attention toward the physical exhibit while enabling group interaction with virtual objects. Our hypotheses are:

- H1. Visitors pay most attention to the virtual elements.
- H2. Visitors also pay attention to the real *Parasaurolophus* fossil.
- H3. Visitors collaborate easily during the game.
- H4: Visitors show increased interest in the topic of the game.

We conducted the evaluation onsite at the museum, inviting regular visitors to participate. We used a mixed method design with observation during the game, an interview after the game and questionnaires divided into pre-game and post-game sections. Two observers filled observation sheets during the experience logging technical issues or notable behaviours or utterances of the two players. Another developer was in charge of monitoring hardware, game software and network connection for potential errors. A fourth researcher conducted the interviews after the experience and handed out questionnaires.

For this study, the following sections of the questionnaires were particularly crucial: 1) an attention-balance triangle in which the participants marked their remembered focus during the game with a cross (post-game); 2) self-assessment of interest in the exhibit and motivation to get more information (pre- and post-game for comparison); 3) demographics (pre-game).

For the qualitative analysis after the evaluation, we used an inter-rater method to form codes for content analysis. Two researchers coded three randomly chosen interviews independently; afterwards they integrated and aggregated the codes to build the code set used in the final analysis.

4. Prototype Design

In a collaborative two-player AR game, players learn to make an informed guess about the look of the *Parasaurolophus*, a species of dinosaur. Paleontologists analyse fossil bones and develop theories about the dinosaur's appearance based on living animals. Players imitate this process by applying different animals' colours and patterns to a virtual *Parasaurolophus* (Figure 1), using information given by the game supported by AR overlays over the real fossil.

After the start of the game, a virtual abstract tutor character, located in front of the real fossil, calls the players using visual and spatial audio cues. When both players are inside a close range indicated by a virtual hexagon on the floor, the tutor explains the game and assigns tasks. Additionally, these tasks are displayed on a virtual sign next to the circle as a reminder. During onboarding, the tutor also provides initial information about the dinosaur.

The character explains how scientists base their theories about the skin or feather appearance of dinosaurs on modern-day animals that have similar life conditions. Players are prompted to find a plausible combination of colours and patterns of contemporary animals, which they can apply to a virtual *Parasaurolophus* that appears next to the fossil. They interact by walking around and stepping into virtual hexagons on the floor, each of which is a portal for a different animal living today, whose life conditions are then to be compared with those we assume for the dinosaur. Stepping into a portal directly applies and changes colours and patterns to the virtual dinosaur. Playing in a team of two, one player has the role to define the base colour, and the other player determines its pattern and head. While walking through the portals, they can discuss with each other, coordinate their chosen positions, and finally decide on their hypothesis of the dinosaur's appearance. Concluding, this decision receives feedback by the tutor regarding its plausibility. The portals also provide information by text and audio explanations on the *Parasaurolophus*'s diet, habitat, and social behaviour.

The game mechanic of this playful educational experience is designed to support collaboration among the players, who can proceed at their own pace. Certain content, such as the tutor's explanations and the animals' colour change, is displayed synchronously for both players, while other virtual information—activated using buttons in a special portal—is visible and audible only for the player currently interacting.

The prototype is implemented in Unity (Unity Technologies, 2026) and runs as an Android build on Meta Quest 3. The Meta XR Core SDK (Meta, 2026) integrated features such as passthrough and spatial anchors to display virtual content around the physical exhibits, positioned in the same location for all participants. Photon Fusion (Exit Games, 2026) is used to synchronise content and interactions over a network. The network is provided via a mobile sim card router.



Figure 1: Upper middle: Game environment. Blue hexagon with the abstract tutor (an animated bubble), in front of the projection of a prehistoric forest scene with virtual *Parasaurolophus* dinosaurs, as well as yellow animal hexagons and a 3D- virtual *Parasaurolophus* with its characteristics displayed above it. Lower right: Two players standing in animal portals. One player assigning a pattern to the virtual dinosaur. Lower left: More temporary information triggered, here virtual fossils on the ground

5. Results

5.1 Demographics

We conducted our evaluation with 90 participants both in English (14 cases) and in German (76 cases). 48 participants identified as female, 40 as male and 2 as diverse. Age groups were diverse with 21 subjects in the group 18-25 years, 32 within 26-35 years, 8 within 36-45 years, 9 within 46-55 years, 11 within 56-65 years, and 9 within 66-75 years. Most participants (73) had no or little prior experience with AR or VR. Similarly, 85 subjects had no or little prior knowledge about the *Parasaurolophus*.

The main reason for their museum visit was tourism (35 cases), followed by recreation (23). Participants mostly visited the museum together with one other person (39 cases), followed by groups of three (15). Within these groups, others were their partner (34 cases), followed by their close friends (23 cases). The person they played with was most often their partner (29 cases), followed by a stranger (18 cases) and their friend (17 cases).

5.2 Impact of the Intervention on Motivation and Thematic Interest

To answer H4, we assessed changes in the participants' attitudes towards related themes and the exhibit itself with pre-post questionnaires. We compared the participants' self-reported interest before and after the game, in relation to the *Parasaurolophus* itself, dinosaurs in general, and the scientific approach to hypotheses.

- *Parasaurolophus*: The conducted Student's T-Test suggests that participants had more interest after playing our game ($p < .001$, mean pre = 3.60, mean post = 3.84. Cohen's d suggests a medium effect size ($|d| = .54$).
- Dinosaurs: Student's T-Test suggests that participants had more interest about dinosaurs in general after playing the game ($p = .03$, mean pre = 4.09, mean post = 4.21). Cohen's d suggests a small effect size ($|d| = .20$).
- Scientific approach to hypotheses about dinosaurs: Student's T-Test suggests that participants had more interest about after playing our game ($p = .004$, mean pre = 3.93, mean post = 4.17. Cohen's d suggests a small effect size ($|d| = .29$).

We also compared the subjects' self-reported motivation prior and after the game to 1) have a closer look at the *Parasaurolophus* exhibit, and 2) search more related information individually.

- Closer look: The conducted Student's T-Test suggests that participants were more likely to have a closer look at the exhibit after playing our game ($p < .001$, mean pre = 3.51, mean post = 3.84). Cohen's d suggests a small to medium effect size ($|d| = .34$).
- Information search: Student's T-Test suggests that participants were more likely to research more information about the *Parasaurolophus* after playing our game ($p < .001$, mean pre = 3.07, mean post = 3.42). Cohen's d suggests a medium effect size ($|d| = .41$).

5.3 Balance of Attention

During the interview, we assessed the attention distribution of the participants during the experience with the help of an equilateral triangle that spans between the physical *Parasaurolophus* fossil, the virtual elements and the co-player (Figure 2). Most participants focused on the virtual elements, with some attention also given to the co-player and the physical fossil. In the lower-right triangle, most data points clustered in A3, indicating low attention to the exhibit and divided attention between the virtual elements and the co-player. By contrast, the upper-right triangle shows a hotspot independent of quadrants with greater attention to the physical exhibit. Table 1 shows the distribution of the demographics across the triangle by quadrants as defined in the lower left part of Figure 2. We can see that the distribution across the quadrants remains independent of demographics.

We asked the participants to comment on the location of their data point in the interview. The virtual elements made up the main focus of the participants during the game (48 mentions). 20 mentions rated the attention on the virtual elements as high. Aligned with our demographics that showed that most participants didn't have any prior experience with AR or VR, the main reason given for this high attention on virtual elements was the novelty factor: "so beautiful, so new, so fascinating". Many participants were fascinated by the bright, glowing virtual elements; two said they were "captivated". As a second reason, subjects described that the virtual elements were the interactive part of the game and therefore gained such high attention and defined the playground of the game. One participant summed this up: "I was so fascinated (...) from the images I would say, so that I paid more attention on that, because it is very beautifully designed, with all of these elements, that you can really walk around, it's really cool".

The high visual presence and its novelty factor influenced the attention on the physical *Parasaurolophus* fossil. 56 mentions stated the attention on the physical fossil was low, with a little higher attention in the beginning of the game (15 mentions). Four subjects reported that the virtual elements covered the physical world. Similarly, 12 mentions claimed that the real world and virtual elements were difficult to distinguish. Two participants only understood during the interview after explanation that the physical fossil was indeed real and not virtual, and another reported her need to regularly check without HMD what was real and what was not. Another reason given for low attention was the obvious presence of the physical fossil before the game and therefore concentration on the new virtual elements. One participant with previous AR experience found that the Meta Quest 3 feature of camera pass-through reduces the clarity of the real world, and reduces the field of view which lowered the attention on the real world in total.

The third point of the triangle concerns the attention on the co-player. The justifications of the participants for their data point does not always match. As we can see in Figure 2, few data points are in the quadrants directly at the right side of the triangle. However, a high attention on the co-player was stated 23 times, and 26 times a low attention. Three times the co-player was found to be the main focus. 14 times the attention on the co-player was higher in the beginning of the game, and 16 times vice versa. The need to help the co-player was stated 7 times. One pair mentioned in that regard that the virtual elements were stressful and the co-player was a helpful anchor. Like the physical world, the co-player was sometimes covered by the virtual elements and difficult to see (10 times). Therefore, a participant mentioned they were worried about knocking over their co-player. One participant stated that it was "bizarre to get in contact with" the co-player during the experience. The main reason to focus on the co-player was to coordinate the collaborative colouring interaction.

Over the course of the game, the attention distribution stayed the same for some participants (19 mentions). 7 mentions stated that the attention distribution was undergoing major shifts. The most frequently mentioned reason for that was the different states during the game, which changed between interactive and passive.

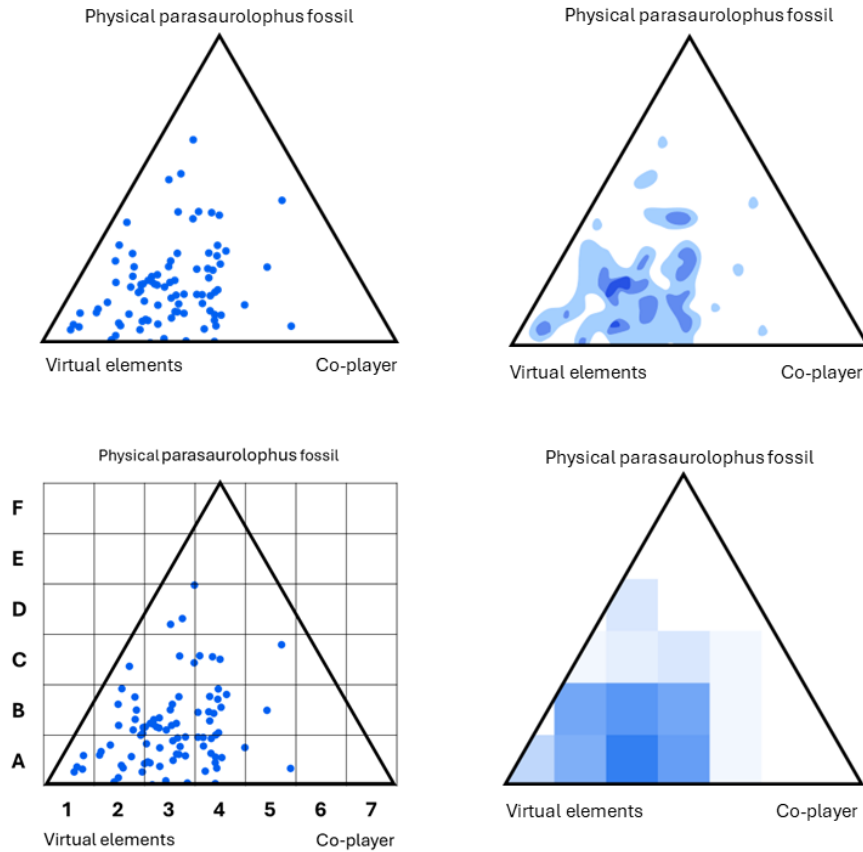


Figure 2: Attention distribution during the game. Upper Left: Data points from 90 participants. Upper Right: Heatmap showing the frequency of data points (darker colour means higher frequency). Lower Left: Triangle divided into quadrants to compare the demographics of the data points per section. Lower Right: Heatmap of the frequency of data points per quadrant

Table 1: Count, age distribution, gender distribution and AR experience distribution per quadrant of the attention triangle

Quadrant	Age Mode	Gender Mode	AR Experience Mode	Co-player Mode
A1	56-65	female	none	acquaintance
A2	26-35	female, male	little	other
A3	26-35	female	none, little	stranger
A4	18-25	female	little	partner
A5	46-55	female	none	stranger
B2	26-35, 18-25	female	none	stranger, friend
B3	26-35	male	little	partner
B4	26-35	female	none	partner
B5	26-35	female, male	none, little	partner
C2	46-55	female	moderate	close family member
C3	56-65, 26-35	male, female	none	close family member, partner
C4	56-65, 26-35, 18-25	female	none	partner
C5	26-35	female	none	friend
D3	18-25, 26-35, 66-75	male, female	moderate, little, none	friend, other, partner

In general, the attention distribution was mostly found positive (38 mentions). When asked whether the low attention on the physical fossil impaired their experience of the game, most participants found that it did not

harm their experience (17 mentions), because they could see the physical fossil before and after the game. Instead, the animated virtual elements enriched the exhibit and increased immersion. Two participants underlined that even after the game, the projection enriched the physical fossil, because seeing how the *Parasaurolophus* might have looked like directly on the physical exhibit is not an everyday museum experience. Other than that, 13 times it was stated that the attention balancing is dependent on the learning goal of the game: “I had the feeling that the goal was to make this virtually more engaging and that’s why I rather had the feeling that consciously I shouldn’t have focused on (the real fossil).” “I think that if I were just walking around here wearing these VR glasses, I’d feel like I’d be missing out on all the exhibits. But since I’ve already looked at them before and can look at them again now, I don’t find it a problem or a shame or anything like that.” Still, the connection to the real exhibition was rated important by some participants (10 mentions) because this is an experience that takes place in a museum: “I’d definitely say it’s very important, because then you’re not just immersed in your own film through the glasses, bumping into things or whatever—you also have a connection to the other exhibits and such that are all around you. You’re more likely to glance over and take a look at what the other exhibit actually looks like and see what you might be able to take away from it (...) it doesn’t really take you out of the exhibition, but it just feels like an additional element—not like I’m walking into a room to watch a film, but rather I’m still here and taking that in”. “Yeah, I mean, you’re here to look at the exhibits, and (um) that’s just supposed to be something supportive and not overshadow the other stuff”. Finally, 6 times it was noted that there are possible improvements of the AR experience, such as making it more clear during the game what is real and what is not, for example by using virtual signs that draw attention to the real, physical parts of the game.

6. Discussion

We expected that most attention would focus on the virtual elements, while the co-player and physical dinosaur would receive some attention. Our hypothesis showed to be true, as only a few participants located themselves in quadrant A1 and the qualitative data show a balanced distribution of attention. There are no discernible patterns linked to age, gender, previous AR experience and the relation to the co-player that influence the distribution of the data points. Instead, the qualitative results suggest that novelty strongly influenced this pattern, and that attention may become more evenly distributed once people grow accustomed to the medium. H1 was therefore supported, while H2 was only partially supported.

The dominance of virtual elements is consistent with Kumaran et al. (2023), who likewise found attention shifts from physical to virtual content. At the same time, our findings differ from Kim et al. (2025), who found no significant recall difference between physical and virtual objects. A likely explanation is that, in our game, virtual elements were not only present but central to task completion. Attention to the fossil was also likely shaped by design and hardware constraints. Some participants reported constraints of the HMD device. In line with Satkowski et al. (2021) and Wolf et al. (2023), our findings suggest that visual arrangement matters: virtual overlays could occlude the exhibit, and the Meta Quest 3 passthrough may have blurred the boundary between real and virtual content. This may also relate to the source-confusion effects discussed in prior work and reported by some of our participants. For future designs, more offset placements and less visually dominant overlays may help preserve awareness of the physical artifact.

The collaboration findings add a multiplayer perspective that remains underexplored in AR heritage research. Many participants interacted with their co-player while paying little explicit attention to them. This can be interpreted positively: coordination may have been smooth enough not to require constant monitoring, which suggests low interaction overhead and good usability. Attention was closely coupled with the current game mechanic: during passive listening intervals, it was lower, and during active intervals, it was higher as the task needed to be coordinated. Overall, participants liked playing together with another person. H3 was therefore broadly supported.

The significant outcomes of our questionnaire results imply that the small attention on the physical dinosaur fossil did not interfere with the increased interest in the topics of the game and the increased likeliness to gather more information later on and have a closer look on the exhibit after the game. Thus, the limited attention to the real fossil does not imply that it was irrelevant. Participants still understood the experience as taking place at the physical exhibit, suggesting that the fossil functioned as a contextual anchor rather than a constant visual target. This extends prior heritage AR work by indicating that an AR game tied to a physical exhibit may support engagement with the exhibit and learning motivation on its topic even when moment-to-moment attention is directed elsewhere during the game. H4 therefore remains supported.

7. Conclusion

This paper explored the attention distribution between co-players, the physical exhibit and the virtual elements of an immersive multiplayer AR experience at a natural history museum with regard to the learning-related outcomes. We found that visitors primarily attended to virtual elements, while the real *Parasaurolophus* fossil received comparatively little sustained visual attention and collaboration required only limited explicit attention to the co-player. Despite this, the experience significantly increased participants' interest in the exhibit and topic and strengthened their intention to inspect the fossil more closely and seek additional information afterwards. These findings suggest that, in heritage AR, meaningful learning-related engagement does not necessarily depend on continuously looking at the authentic artifact. Instead, the physical exhibit can serve as a contextual anchor that supports curiosity and post-visit exploration, as participants were aware of the presence of the physical exhibit because they saw it prior to playing the game, and knew that they could have a closer look again after the game. Most participants experienced AR for the first time and their fascination for the virtual elements was increased by the novelty factor. We conclude that a multiplayer AR game related to an exhibit can spark interest across all tested demographics and encourage people to continue exploring the topic even after their visit.

Future work should further investigate how collaboration design, visual design and exhibit-dependent mechanics shape attention, learning, and long-term engagement.

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AI Declaration: AI tools were used for grammar, style checking and improvement purposes.

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