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How Do Students Respond to the Intended Affordance of Augmented Reality Dinosaur Exhibits in a Science Museum?

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Abstract
As augmented reality (AR) gains prevalence, various AR exhibits are being installed in science museums. However, few research has thus far examined the extent to which these exhibits can improve visitors' learning. This study qualitatively evaluates the effectiveness of an AR dinosaur exhibit at the Gwacheon National Science Museum in Korea and examines the implications for its improvement. Eight elementary school students experienced the AR dinosaur exhibit, and their reactions were captured by audio and video recordings. Science museum experts were also interviewed to understand the intended affordances of the exhibit. The students' responses to the intended affordances were examined by analyzing their tour of the AR dinosaur exhibit. We found that the exhibit attracted the visitors by catching their attention. However, they did not pay attention to the exhibition's primary purpose of improving scientific understanding or reasoning. Some unintended interactions, unrelated to the intended affordances, also emerged. The limitations of the examined AR dinosaur exhibit suggest implications for improving AR exhibits in the future.

Keywords Augmented reality · Affordance · Dinosaur exhibit · Science museum

Introduction

Technological products such as computers, smart boards, and smartphones have great potential to help students learn about science (Hug et al., 2005; Shapley et al., 2011). As opportunities to use technology increase, it can support students' understanding of scientific knowledge and development of scientific problem-solving skills (Guzey & Roehrig, 2009; Slykhuis & Krall, 2011). Teaching methods have been employing presentation tools such as Microsoft PowerPoint, which have replaced blackboards, for a long time now. When Padlet was introduced as a collaboration tool to support students' cooperative learning, space-time restrictions on students sharing their thoughts disappeared (Fisher, 2017; Lowe & Humphrey, 2018; Zhi & Su, 2015). In scientific experiments, various sensors are connected to a microcomputer such as Arduino or Raspberry Pi to collect data, and if necessary, digital data are transmitted to the IoT platform for remote measurement (Ga et al., 2021).

Augmented reality (AR) is promising in the field of EdTech given its visual presence, immersion, and ability to share information in new and engaging ways, and has the potential to offer virtual experiences at low cost (Dick, 2021). Teaching and learning materials adopt AR technology to overcome the limitations of static 2D images (Fan, 2021). These AR learning materials are connected to physical textbooks through included QR codes or seamlessly integrated into digital textbooks through hyperlinks or embedded formats.

Science museums use AR technology in their exhibits in various forms: a flat display that can be manipulated through touch; the projection of images on physical exhibits that can be operated by hand (Yoon et al., 2012a, b); a combination of a physical exhibit that can be operated by hand, along with flat displays (Yoon et al., 2018); the projection of images onto a large screen with a projector (Kitalong et al., 2009); and the use of head-mounted displays (Sugiura et al., 2019). They also provide virtual tours using AR technology, so that visitors can engage without physically visiting (Kitalong et al., 2009).

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Several institutions introduced virtual tours when it became difficult for people to visit in person owing to COVID-19 (Lee et al., 2023). AR exhibits that recognize and respond to user gestures have also recently emerged. Seo and So (2022) developed an AR exhibit that allows visitors to experiment with changing the shape of a wire through gestures to understand how the thickness and length of the wire affect its resistance. To promote English language learning in the context of a science museum, Chen et al. (2023) had visitors wear smart glasses to tour the museum and receive information related to learning English through smart glasses. As such, science museums are using AR technology to redesign their exhibits to provide visitors with a richer experience.

However, the mere use of innovative technologies does not ensure visitors' learning. The design, implementation, and integration of AR technology in the educational environment are important to achieve its full value (Wu et al., 2013). Studies on exhibits using AR have investigated the improvement in visitors' understanding of scientific concepts (Chen et al., 2023; Seo & So, 2022; Yoon et al., 2012b; Yoon et al., 2018), their motivation (Chen et al., 2023), and their responses (Sugiura et al., 2019). While previous studies have focused on visitors' interest in or conceptual understanding of exhibits, this study analyzes the interaction between visitors and exhibits from an affordance perspective. Moreover, it examines how visitors respond to each of the affordances that make up an exhibit, and ultimately whether they acquire scientific knowledge and engage in scientific reasoning as intended by the exhibit. Hence, in this work, the following two research questions were formulated based on a study of an AR dinosaur exhibit at the Gwacheon National Science Museum in Korea:

1. What is the intended affordance of the AR dinosaur exhibit?
2. How do visitors respond to the intended affordance of the AR dinosaur exhibit?

AR in Education

AR refers to technology in which digital information related to the real world is superimposed on the background of the real world. AR has three key features (Azuma, 1997; Carmigniani & Furht, 2011). First, the real and virtual worlds are combined. Second, real-time interactions take place. Third, real objects and places in the background are connected to floating digital information. AR has been around for over 50 years, but its use only expanded to many other areas in recent years, as the development of mobile devices has made it easier for the public to access it (Sommerauer & Müller, 2014).

Education is one of the most promising areas for the use of AR (Wu et al., 2013), especially science education. Because its contents allow for the coexistence of real and virtual items and interaction with two- and three-dimensional synthetic objects (Kerawalla et al., 2006), AR helps learners enhance their spatial ability and understand abstract concepts (Arvanitis et al., 2009; Cheng & Tsai, 2013; Fan, 2021) that cannot manifest in the real world (Klopfer & Squire, 2008).

With the recent development of AR technologies, devices have become cheaper, various applications running on AR devices have been developed, and AR has been used more actively (Goff et al., 2018). AR is used in various fields of education, especially medical education. For example, by rendering organs three dimensionally, swiveling objects, and cutting cross-sections in a particular direction, the appearance of organs in three dimensions can be observed even outside the limited space-time of a classroom, and solve the problem of cadaver shortages for anatomical learning (Chang et al., 2010; Hedegaard et al., 2007; Yeom, 2011). In chemistry, AR helps students understand intermolecular interactions by visualizing the spatial relationships and interactions among molecules in three dimensions (Aw et al., 2020). In mathematics, AR is used to teach 3D geometric concepts. AR enables students to learn concepts faster than with traditional methods by visualizing and interacting with objects directly in 3D space (Cerqueira & Kirner, 2012).

AR in Science Museums

AR is also used in various exhibits in science museums. Takahashi et al. (2013) designed an AR exhibit of a baleen whale fossil using a laser projection system called "big fat wand." They studied the effects of AR on users' interest, ability, and knowledge construction. Users were encouraged to become interested in the exhibits, and they used the devices with ease. However, participants' prior knowledge was too high to confirm the effectiveness of AR in constructing knowledge. Yoon and Wang (2014) investigated the affordance of the "magnetic maps" exhibit, which allows users to use handlebar magnets in real time to capture and display the magnetic field depicted by field lines on a computer screen. In this exhibit, AR technology was used to show dynamic changes in magnetic fields. As students move the magnet, the visualization on the screen changes, encouraging them to engage deeper and for longer. Hsiao et al. (2016) designed an AR exhibit called "weather observers" on climatology and studied how it affects users' learning. Users showed better learning achievement and motivation than those who used traditional multimedia. Huang et al. (2016) investigated whether eco-discovery AR-based learning models and systems are effective for ecological learning in a botanical garden, finding that users showed positive emotions and improved learning outcomes. Atwood-Blaine and Huffman (2017) studied how the mobile AR game "The Great STEM Caper" affected interactions in a science museum and learned that users were interested in the game overall.

The application of AR technology to exhibits arouses learners' interest (Atwood-Blaine & Huffman, 2017; Takahashi et al., 2013) and makes them more active in watching and interacting with exhibits (Huang et al., 2016; Yoon & Wang, 2014). Learners' conceptual knowledge and cognitive skills improve through the use of AR (Yoon et al., 2012a, b). The above-mentioned studies show that applying AR to science museum exhibits enhances visitors' interest in and interaction with them as well as aids their knowledge acquisition. However, only the overall effect of AR exhibits has been investigated. No detailed analysis has thus far examined how each part of the exhibit influenced users. To understand how AR technology can be used in exhibits to promote science learning, it is necessary to study the interactions between each part of the exhibit and the learner's experience in detail. Examining how each part of the exhibit contributes to the learning experience and ensuring that it aligns with the exhibit's intention helps us improve the exhibit to better science learning.

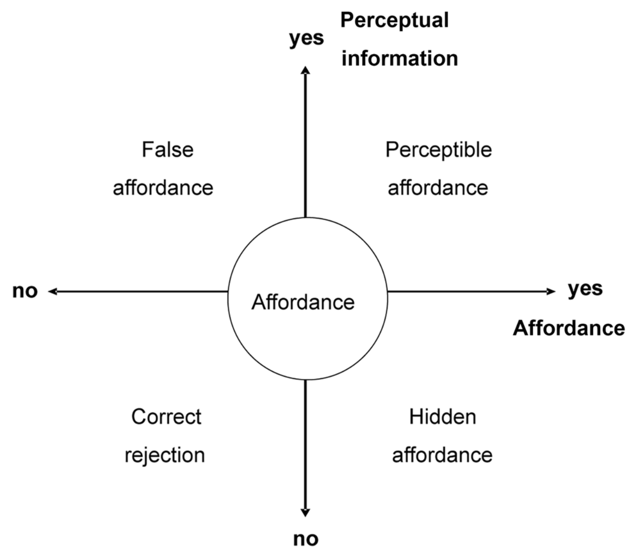

Fig. 1 Classification of the exhibit's affordance. Source: modified version of Gaver (1991)

Affordance

Gibson (1979) stated that "the affordances of the environment are what it offers the animal, what it provides or furnishes, either for good or ill." Affordances are information about the environment that provides potential actions for an agent. As such, affordances are not solely in the domain of the world or solely in the domain of the agent; they depend on the relationship between the embodied agent and its world. According to Norman (1988), affordance is related to aspects of the design of objects that suggest how they should be used. Norman defined affordances as having actual and perceived properties. For example, the affordance of a ball includes all perceived suggestions on how the ball could be used as well as its actual properties such as its shape, physical material, and bounciness. When actual and perceived properties are combined, affordance appears as a relationship between an object and the individual acting on the object (Norman, 1999).

In contrast to Norman's affordance, Gibson's affordance does not rely on the actor's capacity to perceive it (Soegaard, 2015). Gaver (1991) defined affordance by subdividing it into four categories and provided the following examples: A glass of water affords "drinking," regardless of whether one is thirsty. A ball affords "throwing," regardless of whether one has seen a ball. A pit covered with straw may be invisible, but certainly affords "falling." Affordances thus exist whether they are perceived or not, but it is because they are inherently about important properties that they need to be perceived (Gibson, 1979).

Gaver's subdivision of affordance was based on perceptual information and the existence of affordance (Fig. 1). In this figure, the horizontal axis (affordance) is related to the designer's intention and the vertical axis (perceptual information) is related to a user's realized interaction (Achiam et al., 2014). Gaver's four categories of affordance are described in further detail below:

- Perceptible affordance: Intended affordance appears through the perception of specific information.
- False affordance: Unintended affordance appears through the perception of specific information.
- Hidden affordance: Information is not recognized. Intended affordance is not accomplished.
- Correct rejection: Information is not recognized. There is no intended affordance.

Affordances of Museum Exhibitions

Visitors to science museums learn science by interacting with exhibits (Lucas et al., 1986). Science exhibits offer visitors opportunities to learn, and they exploit these learning opportunities by choosing to interact and engage intellectually with such exhibits (Rennie & McClafferty, 2002). Sandifer (2003) studied 61 exhibits at the Reuben Fleet Science Center in California and investigated how the characteristics of interactive exhibits account for differences in visitors' attention. The 61 exhibits were investigated to see if they were open ended, technologically novel, user centered, and stimulated the senses. The correlations among those properties, attracting power, and the average holding time were also analyzed. The researcher found a significant correlation ($p < 0.05$) between technical novelty and average holding time as well as between sensory stimulation and technical novelty. A strong significant correlation ($p < 0.01$) between open-ended and average holding time was also found. However, the study could not explain why the attracting power and average holding time varied based on the properties of the exhibits. Therefore, a qualitative approach is necessary to understand the interaction between exhibits and visitors in detail (Rennie et al., 2003).

Affordance can be a lens that helps qualitatively analyze the interactions between exhibits and visitors. Shin (2011) defined affordance related to visitors' learning as "learning affordance" and investigated its possibilities and usefulness. Shin partially modified Gaver's (1991) framework to define the area corresponding to "learning affordance" and described the learning process of students who watch exhibits according to this framework. Shin confirmed that "learning affordance" can be a good tool for expressing and understanding a visitor's learning process.

Ioannidis and Løvlie (2022) studied the design processes for the "Light House" exhibit by analyzing users' responses to the initial artifact, using the feedback to improve the exhibits, and repeating the process. Affordances in the initial artifact primarily allow affordances that the designer wants the user to re-purpose. Through this, the designer examines users' interactions with the artifact, looking for re-purposed novel uses. Based on users' responses to the allowed affordance in the initial artifact, it is modified according to the exhibit's intention and gradually refined into "encourage and discourage affordance," which suggests users' possible utilization of the artifact. In the process, the exhibit comprising "encourage and discourage affordance" is created.

In summary, while Ioannidis and Løvlies (2022) and Shin (2011) highlighted the possibility of studying exhibits from an affordance perspective, for AR exhibits, studies analyzing the interaction between visitors and exhibits from this perspective are lacking.

Method

Research Context

Participants

Eight elementary school students in the fifth and sixth grades, living in Seoul and Gyeonggi-do, participated in this study. The Korean science curriculum covers fossils in grades 3 and 4 (Ministry of Education in Korea, 2015); hence, the study participants had already learned about the creation of fossils, past living things, and the environment. They were recruited through announcements posted online for the local community. The parents of all eight participants found the recruitment announcement and encouraged their children to participate. The participants voluntarily agreed with their parents' suggestion.

Target Exhibition

The Gwacheon National Science Museum opened in 2008. A large Edmontosaurus fossil is displayed in its Natural History Hall (Ⓑ of Fig. 2). The head of the Edmontosaurus fossil was purchased while the rest of the fossil was still being excavated. More than 90% of the Edmontosaurus' entire body was subsequently excavated, and the value of the fossil increased dramatically. The Edmontosaurus fossil has a unique bite mark near its tail, indicating that it had been bitten by a carnivorous dinosaur. As a fossil with a bite mark is rare, it has gained in importance. The skull of the Cretaceous carnivorous dinosaur Gorgosaurus, whole-body replicas of Stegosaurus and Triceratops, and the skull of a Tyrannosaurus are displayed around the Edmontosaurus fossil.

The AR dinosaur exhibit was installed on October 1, 2017, when the natural history museum was renovated (Gwacheon National Science Museum, 2017). Therefore, the AR exhibit was not designed at the same time as the other exhibits or according to the overall concept of the hall. As shown on the map of the hall, the respective locations of the AR screen (Ⓐ of Fig. 2) and Edmontosaurus fossil (Ⓑ of Fig. 2) mean visitors cannot see both simultaneously. The figures of the dinosaurs are superimposed on the AR screen's background, which is a real-time view of the exhibition hall (Fig. 3). Footprints are drawn on the floor in front of the AR screen to indicate where visitors should stand to best view it (Ⓒ of Fig. 2). The AR video is 75-s long. When the video begins, the Stegosaurus, Triceratops, and Edmontosaurus appear on the dinosaur fossils in the background, wander around, and graze on the floor. The Gorgosaurus then appears, and the Stegosaurus and Triceratops exit. At 00:34 on the video's timeframe, the Gorgosaurus runs in and bites the Edmontosaurus' tail. This scene relates to the bite mark on the tail of the Edmontosaurus fossil. Next, the Tyrannosaurus appears and fights with the other dinosaurs. They all exit one after another, except the Tyrannosaurus, which remains and walks around, and the video ends with the dinosaur with its mouth wide open toward the audience, which appears quite threatening if the viewer is standing on the footprint markings. No motion sensor is installed in this AR exhibit, so this video is played on a continuous loop.

Data Collection

In this study, three types of data were collected: video and audio recordings during the visitors' tours of the hall and

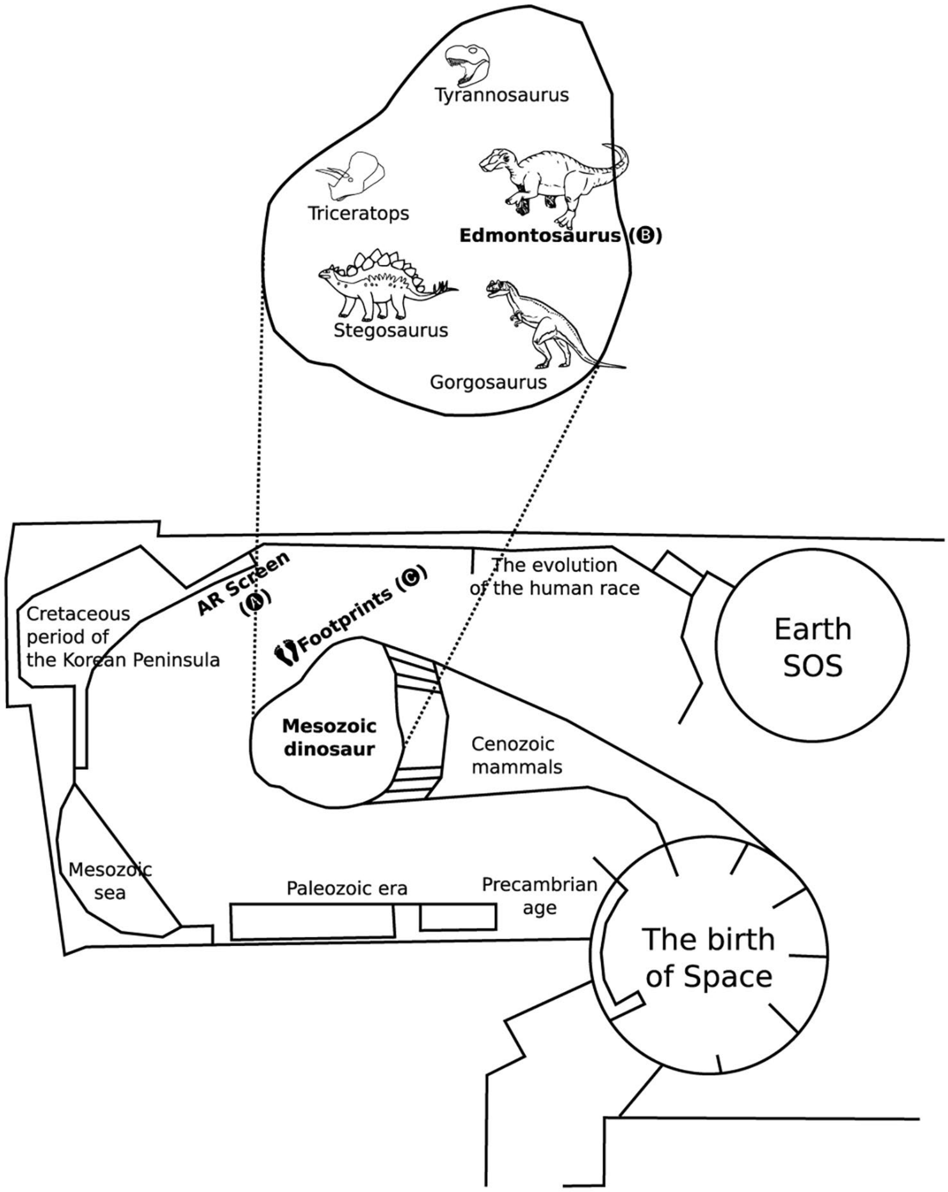

Fig. 2 Map of the exhibition hall

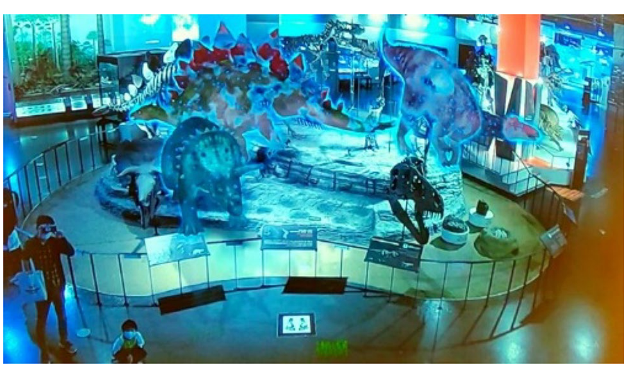

Fig. 3 Dinosaur image superimposed on the fossils in the exhibition hall

audio recordings of interviews with researchers after the tour. The visitors paired up and freely visited the Natural History Hall. We asked the students to watch the AR video in pairs while maintaining dialogue with each other. To ensure that both the participants were comfortable talking to each other, we paired close friends. The conversation between each pair of students was recorded using a voice recorder hanging around their necks and subsequently transcribed. Each student's behavior was also observed by two staff following and recording them with a video camera. Finally, after the tour, the researcher interviewed each pair of students. These semi-structured interviews were recorded and transcribed (Table 1).

Table 1 Main interview questions

Category	Content
General questions on the museum	• How many times have you been to this science museum? • Do you like science? Are you interested in dinosaurs?
Specific questions related to the AR exhibition	• Have you ever seen dinosaurs in the AR exhibition? • What kind of video did you watch? Please describe the content of the video you watched • Do you remember what was written at the bottom of the screen? • Have you checked the wounds on the tail of the Edmontosaurus fossil? • Why does the Edmontosaurus fossil have a scar on its tail? • Did you match the dinosaurs in the AR video with the fossils in the hall?

Analysis

Intended Affordance of the Exhibit

The intended affordance of the exhibit was explored during interviews with natural history museum experts working at the science museum. Had this hall been managed by one person for a long time, an interview with that person would have been the best option. However, the person in charge of the hall since its initial opening had been replaced. As various people's ideas are reflected in the history of this hall, it was not necessarily ideal to interview the current person in charge. It was therefore decided to interview a doctor of environmental education instead, who happened to have studied natural history museums, was working in this museum at the time of the study, and was aware of the history of the exhibition hall. In this way, the researchers explored the intended affordance of the AR dinosaur exhibit. Next, the main intended affordance of the exhibits was extracted through repeated discussions among the researchers. Following this, the intended affordance of the exhibits was determined.

Visitors' Responses

As a perception is a reaction of the nervous system and occurs in the brain, it is difficult to judge from the outside how visitors perceive an object (Goldstein, 2009). Therefore, what visitors perceived was indirectly deduced from their responses, which were observable. Visitors' responses were examined based on their behaviors (e.g., waving, running, and pointing at dinosaurs) captured by the video and audio recordings of their tour of the hall as well as their interview responses after the tour.

We used the constant comparative approach, a widely recognized technique in grounded theory analysis (Creswell, 2014). We iteratively examined the video footage of the visitors, audio of their conversations, and interview transcripts to analyze how they responded to the intended affordances. As we watched the videos, we marked the transcribed scripts with estimated perceived affordances (i.e., the responses to the intended affordances by the visitors) in the aspects of behavior (e.g., physical responses such as walking, waving, and reading aloud), emotions (e.g., psychological responses such as joy, surprise, and comfort), and cognition (e.g., cognitive thinking such as understanding scientific concepts, reasoning, and making predictions). These three classifications provided a lens through which to view the phenomenon as we uncovered the perceived affordances from the collected data. In cases in which the video footage was insufficient to understand the visitors' reactions, we referred to the interview data. We listed all the perceived affordances and categorized them by grouping similar items together. Lastly, the perceived affordances were classified into perceptible and false affordances, according to Gaver's (1991) classification. Perceived affordances include only those perceived by the visitor; hence, correct rejection and hidden affordance in Gaver's classification, which correspond to cases where the visitors are not aware of the perceptual information, do not appear here. Data analysis was conducted by three researchers, who are also the authors of this paper, and any disagreements among the researchers during the analysis were resolved through iterative discussion.

Results

Intended Affordances of the Exhibit

Five intended affordances of the exhibit were found (Table 2). Intended affordance 1 was related to the appearance of the dinosaurs in the AR video. The AR images comprised a combination of the real and virtual worlds (Tamura et al., 2001),

Table 2 The intended affordances of the exhibits and perceived affordances of the visitors

	Photo	Contents	Intention	Perceived affordance	
				Response	Gaver's classification (# of perceived visitors)
Intended Affordance 1		Flesh-filled dinosaurs superimposed on the dinosaur bone fossils.	It identifies the fossils to which the dinosaurs correspond and provides information on the appearance of the dinosaurs.	1A. Guessing which dinosaurs they were based on the dinosaur's appearance in the AR video (cognition)	Perceptible (5)
				1B. Identifying the dinosaurs by comparing AR video with physical fossils (cognition)	Perceptible (1)
Intended Affordance 2		Dinosaurs move among the audience.	It draws the attention of the visitors and induces interest by allowing them to feel the liveliness of dinosaurs.	2A. Feeling the presence of being with a dinosaur (emotion)	Perceptible (3)
				2B. Shaking hands (behavior)	False (1)
Intended Affordance 3		Footprints on the floor.	In the final scene, a dinosaur threatens the visitors standing on the footprints placed on the ground, attracting their attention.	3A. Standing on the footprints (behavior)	Perceptible (2)
				3B. Thinking that the video starts when the visitors stand on the footprints (cognition)	False (2)
Intended Affordance 4		One dinosaur bites another's tail.	To provide a scaffold for inferring the cause of the bite mark on the Edmontosaurus fossil	4A. Discovering the cause of the wound on the dinosaur's tail (cognition)	Perceptible (2)
				4B. Being surprised or afraid to see a dinosaur appearing around in the AR video (emotion)	False (2)
Intended Affordance 5		Text written at the bottom of the AR screen.	Telling the visitors what to focus on in the video provides clues to the connection between the video and fossil exhibits.	5A. Reading the text (behavior)	Perceptible (6)
				5B. Trying to understand the reason for the bite mark, following the text (cognition)	Perceptible (2)

where the real world was the exhibition hall and served as the background, while the dinosaurs constituted the virtual world that was superimposed onto the fossils (Fig. 2). This visual representation informed the visitors that the flesh-filled dinosaurs on screen corresponded to the bone fossils in the background and allowed them to imagine what the dinosaurs actually looked like. Intended affordance 2 pertained to the dinosaur that appeared in intended affordance 1, but crossed the fence where the fossils were located and approached the visitors. As those dinosaurs seemed to coexist with the visitors in the very same space, their "live" appearance was closely felt and evoked lively interest in the exhibit. Intended affordance 3 concerned the footprints on the floor, which marked the spot where the visitors had to stand to view the AR video screen. In the last scene, the dinosaurs threatened the visitors at this location, which attracted their attention and enhanced their interest in the exhibit. Intended affordance 4 appertained to the scene in which one dinosaur bit another's tail. Before the installation of the AR exhibit, the Edmontosaurus fossil exhibit was an important part of the hall, and the main activity pertaining to it was to infer the cause of the wounds in the tail. The AR exhibit supported this by serving up "evidence" of that incident. Intended affordance 5 was related to the text appearing at the bottom of the AR video screen: "Why does the Edmontosaurus have a scar on its tail?" The text told the visitors that they could find out why the Edmontosaurus' tail was scarred by watching the AR video. The phrase "Check out the wounds left on the fossil!" hinted at the bite mark on its tail.

Visitors' Responses

From the video footage of the visitors, we found 10 indicators of perceived affordances that were connected to five intended affordances identified in the expert interviews (Table 2).

Intended Affordance 1: Flesh-Filled Dinosaurs Superimposed on the Dinosaur Fossils

The scene in which the flesh-filled dinosaurs were superimposed on the dinosaur fossils aimed to allow the visitors to intuitively recognize that the dinosaurs corresponded to the fossils in the hall. Except for two visitors (students 7 and 8) who passed by without paying attention to the AR video, all the other visitors noticed that the flesh-filled dinosaurs shown in the video corresponded to the fossils in the background. However, most did not try to identify the dinosaurs by checking the fossil exhibits or their panels. Instead, they looked at the dinosaur's appearance in the video and guessed which ones they were (perceived affordance 1A; students 1, 2, 4, 5, and 6).

> Student 2: (Tyrannosaurus has appeared) Is that a Tyrannosaurus?
> Student 1: (Pointing to the dinosaur on the AR screen) Isn't that two Tyrannosauruses?
> Student 2: I don't know.
> Student 1: Two look the same.
> Student 2: Look a little different.
> Student 1: But you said he's a Tyrannosaurus? (During the tour)

Student 3 watched the dinosaurs in the AR video and the fossils alternately to match them (perceived affordance 1B). However, he was already interested in the dinosaurs and had seen the same AR exhibit before. Therefore, it was difficult to confirm whether he had been able to identify the dinosaurs because of the current visit.

> Researcher: Have you been here many times?
> Student 4[1]: I came when I was in elementary school, and whenever this museum held special events downstairs.
> Researcher: Then you must have seen this AR exhibit a lot.
> Student 3: Whenever I came here to see the dinosaurs, I stayed here all day.
> Researcher: You have already seen which dinosaurs were in this AR video in the past, right?
> Student 3: Yes, I memorized what happened, when it appeared, and so on. (Interview after the tour)

Intended Affordance 2: Dinosaurs Moved Around Among the Audience

When the visitors saw the moving dinosaurs in the AR video, they responded with interest by saying things such as "Awesome" (student 2), "It's amazing" (student 2), "I am buried (by the dinosaur)" (student 1), and "It almost stepped on me" (student 5), as if they were in the same space (perceived affordance 2A). As these reactions correspond to the intended affordances, intended affordance 2A is a perceptible affordance. However, there was an unintended reaction to the AR exhibit. Student 5 saw a moving dinosaur and waved his hand to say hello (perceived affordance 2B). This exhibit did not have a camera that recognized the visitors' movement. It simply played the pre-recorded video repeatedly. Because AR exhibits typically respond to the movement of visitors using installed cameras—as does the AR exhibit installed at the entrance of the Natural History Hall—student 5 must have thought that this exhibit would be similar.

Intended Affordance 3: Footprints on the Floor

Some visitors stood on the footprints and watched the AR video (students 3 and 7; perceived affordance 3A) because they thought they would have to stand there to play the video (perceived affordance 3B).

> Student 3: The video is played if we stand here … (During the tour)
> Student 7: Stand still on the footprints and the dinosaurs will appear. (Interview after the tour)

This exhibit did not have any sensors to grasp the visitors' movement and only showed the same scene repeatedly. The students' expectations that the video would be played or that dinosaurs would appear were different from the intention of this exhibit. Most students did not stand on the footprints. Only one person could stand on them at a time, so most visitors stood outside the footprints (students 4, 5, 6, and 8). Some did not see the footprints before watching the video because the AR video caught their attention first (students 1 and 2). Intended affordance 3 was originally intended to have the visitors stand on the footprints so they would be surprised to see the dinosaur threatening them. However, none of the participants had the intended response because they had all left before the corresponding scene appeared.

Intended Affordance 4: One Dinosaur Bites Another's Tail

After watching one dinosaur bite the tail of another, some students understood how the latter had sustained damage (perceived affordance 4A). However, many did not see the scene (students 4, 7, and 8). While some saw the scene, they did not think it had any special meaning (students 1, 5, and 6). The statement below shows that they either did not pay attention to the scene or did not connect it with the dinosaur fossil exhibit with the scar on its tail.

> Researcher: You saw one dinosaur biting another in this AR video, right? What do you think this means?
> Student 1: I probably saw it, but I did not really think about it. (Interview after the tour)

Only two students linked the scene to the dinosaur fossil exhibit with the scar on its tail. One saw the dinosaur fossil exhibit before seeing the AR exhibit, so he knew why the dinosaur fossil had a scar (student 2). The other had visited this science museum frequently and liked this exhibit. As he

[1] Students 3 and 4 are twins and had always visited the science museum together.

had watched the video several times, he already knew the content well (student 3).

> Researcher: What did you see in the video?
> Student 3: Dinosaurs appear first. After that, the dinosaurs roam around and play. When the Gorgosaurus comes out, the Stegosaurus sees it and runs away. Then ... (omitted). The herbivorous dinosaur steps back and the Stegosaurus comes here slowly and tries to attack it while "huh-huh-huh." Then, the Gorgosaurus sneaks back ... sneaks ... sneaks ... the end.
> Researcher: How do you know all this?
> Student 3: When I first saw this, I watched this video at least five times ...(Interview after the tour)

Some students who saw the dinosaur bite the tail of another responded emotionally (perceived affordance 4B), while others were surprised or frightened, and said, "God's blood!" (student 6) and "Wow! I'm scared" (student 7). These reactions were not intended.

Intended Affordance 5: Text Written at the Bottom of the AR Screen

The focus question appeared at the bottom of the AR screen to guide the visitors on what to focus on while watching the video. Except for two visitors (students 4 and 6) who did not notice the text displayed on the screen, most visitors read it (perceived appearance 5A). However, as most saw the text after watching the AR video, they did not watch the AR video in line with the focus question that appeared on the screen (students 1, 2, 3, 5, 7, and 8; perceived affordance 5B), and no visitor watched the AR video again after reading the text.

> Researcher: Have you seen this? "Why did Edmontosaurus have a scar on its tail?"
> Student 4: I did not see it. I did not even know it was there.
> Researcher: But if you look at the bottom of the screen here, it says why the tail is scarred, right? You don't think about finding meaning by associating the fossil display with the video, right?
> Student 1: I almost just glanced at something … (Interview after the tour)

Discussion

It is a challenge for science exhibits to capture the attention of visitors. According to Boisvert and Slez (1995), exhibits attract the attention of only 5–26% of visitors. Given that all the study participants were attracted to the AR dinosaur exhibit, it was successful in grabbing their attention. The visitors passing by this exhibit stopped walking as they were amazed at the sight. They watched the scenes where flesh-filled dinosaurs appeared from the dinosaur fossils and where the dinosaurs escaped the fence and approached the visitors. They thought it was interesting and responded by exclaiming, "Wow!" and "It's amazing." Intended affordances took advantage of AR's unique characteristics of combining real space and virtual imagery, making this exhibit effective in capturing the attention of the visitors.

However, some limitations were revealed around whether watching the exhibit led to the visitors' scientific understanding or reasoning. First, although the visitors recognized that the flesh-filled dinosaurs corresponded to the bone fossils in the background, most failed to correctly identify the dinosaurs. While they discussed this among themselves and ventured guesses, they did not make any additional effort, such as comparing the bone fossil exhibits or panels to ascertain which dinosaurs they were seeing. It was structurally difficult to compare the AR video with the bone fossil exhibits or panels because visitors had to look back, in the opposite direction of the AR screen, to do so. As a spatial arrangement of exhibits in a science museum is also an affordance that influences visitors' learning, it is necessary to consider spatial arrangements between related exhibits to allow visitors to perceive and respond to their intended affordances (Atmodiwirjo, 2014).

Second, this exhibit's main scientific reasoning activity was to determine the cause of the scar on the tail of the Edmontosaurus fossils, but the visitors did not grasp this intention. The text "Why did the Edmontosaurus have a scar on its tail?' appeared at the bottom of the screen, but the visitors did not read it before watching the AR video. This could be ascribed to the brightness of the screen, as people tend to pay attention to brighter objects. While the AR screen was bright, the text appeared in a relatively dark area, without any special illumination. The students were drawn to the AR video first and the text only caught their eye afterward. As the students watched the video without a specific goal in mind, even when they saw a carnivorous dinosaur bit the tail of the Edmontosaurus, they did not infer any special connotations from the scene.

Third, the visitors attempted unintended interactions with the exhibits. The exhibit did not contain sensors that could detect the movement of visitors and the same video was played repeatedly. The visitors nonetheless tried to interact with the dinosaurs in the AR video by waving their hands at the screen. The footprints on the floor served to entice visitors to stand on them, as there was a scene in which a dinosaur threatened the visitor who stood on the footprints. Some visitors stood on it, consistent with the exhibit's intended affordances. However, the reason the visitors stood there differed from the exhibit's intention. The visitors thought that the video would only start playing when they stood on the footprints. Those visitors' behaviors were influenced by their prior experience with other AR exhibits (Osiurak et al., 2017). Visitors expected to interact with the AR exhibits based on their prior experience, but this expectation was futile because there was no related function. Although false affordance is inefficient and leads visitors to inappropriate actions (de la Fuente et al., 2015), understanding it is meaningful for improving exhibits. The existence of false affordance means that there is a sociocultural convention or expectation of the visitors related to it (Achiam et al., 2014). A false affordance perceived by many visitors will be an effective perceptible affordance, given the appropriate intention.

Conclusion

Research has paid attention to how AR exhibits affect visitors' conceptual knowledge development (Hsiao et al., 2016; Yoon et al., 2012a, b), interaction with exhibits (Atwood-Blaine & Huffman, 2017; Hsiao et al., 2016; Huang et al., 2016; Yoon & Wang, 2014), and interest in exhibits (Takahashi et al., 2013). This study examined how visitors perceived and responded to the affordances of an AR dinosaur exhibit in Korea by analyzing the process of watching the exhibit.

We found that the cases in which the visitors responded according to the exhibit's intention were less frequent than those in which they did not. Some false affordances were found. Not all the visitors responded ideally to all affordances with perceptible ones. As the visitors' viewing of this exhibit did not improve their scientific understanding or reasoning, it is necessary to examine why the intended affordances were not perceptible to visitors and why they responded in different ways. Although these affordances did not induce behavior that met the purpose of the exhibit, they were effective in stimulating other behavior. If the design were to be changed such that the appropriate behavior could be linked to those affordances, false affordances would become effective and perceptible.

Several limitations must be considered when interpreting the results of this study. First, the participants did not voluntarily visit the science museum to tour the exhibits; they visited to participate in the study. Further, being organized into pairs to encourage interaction as well as being followed and recorded by two research assistants may have interfered with the students' spontaneous watching. To overcome these limitations, the researchers recruited pairs of students and encouraged them to tour without restrictions.

Second, the small number of participants in this study may make it difficult to generalize the findings. The perceived affordances of these eight students interacting with the exhibit cannot be assumed to include all the affordances associated with the exhibit. By reducing the number of participants, we could examine the visitors' interactions with the exhibit in more detail at an individual level. However, as-yet undiscovered perceived affordances may still be associated with this exhibit.

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Availability of Data and Materials The datasets of this research are not publicly available for protecting participants' identity.

Declarations

Ethical Approval The research design was reviewed and approved by the Chuncheon National University of Education's Institutional Review Board (No. 2021-23).

Consent to Participate Informed consent was obtained from participants prior to data collection. Participants were informed that they were free to decide whether to participate in this research and that there were no penalties for not participating.

Consent for Publication Participants were aware that their data would be included in the published paper and had given explicit consent.

Competing Interests The authors declare no competing interests.

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