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AR you aware? Augmented Reality in zoos to highlight the trashy truth of human waste impacts

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Abstract

The environmental impacts of human activities are widely acknowledged, but the ramifications of inadequate waste management on threatened species in distant habitats often remain overlooked. This study explores the potential of Augmented Reality (AR) technology in zoos as an educational tool to raise awareness regarding unsustainable practices in high biodiversity ecosystems. By leveraging newer AR technologies, animals in zoos can serve as effective ambassadors, conveying sustainability messages and showcasing the challenges faced by threatened species in their natural habitats. Through a comprehensive examination, this paper sheds light on the valuable insights and potential applications of utilizing AR technology for conservation education. While the impact on knowledge change was not found to be statistically significant, the incorporation of AR has the potential to enhance visitors' perception of new scenarios, thus augmenting the educational value of zoos by introducing novel elements, exemplified by the representation of the detrimental effects of unsustainable waste management in delicate ecosystems. Furthermore, the results demonstrate that the majority of users perceive the utilization of AR in zoos as a highly positive experience, fostering increased engagement and extended periods of observation within the habitats. However, the findings of this study also demonstrate that AR does not necessarily offer an education solution despite its potential to enrich the visitor experience in the context of zoos. Therefore, more objective-focused designed and curated AR experiences need to be developed, to unveil the education potential of AR in zoos and aquariums.

Introduction

Zoos and aquariums fulfil a crucial role in various facets pertaining to the preservation and conservation of biodiversity. They serve as educational centres (Carr and Cohen 2011; Schwan et al. 2014), research hubs (Rose et al. 2019), and facilitators of species survival through both financial and technical support in the animals' native habitats, as well as through captive breeding programs (Gusset and Dick 2011; IUCN 2014). Additionally, these establishments provide a unique opportunity to instil positive values and promote sustainability practices among visitors (Sjögren et al. 2015). However, achieving effective engagement and behaviour change among visitors presents a complex challenge (Abrash Walton et al. 2022; Botha et al. 2021; Schwan et al. 2014). Traditional signage has shown limited effectiveness in influencing visitor behaviour within zoo settings (Parker et al. 2018; Tay et al. 2023), while recent technological advancements hold promise in enhancing the visitor experience and creating novel educational opportunities (Carter et al. 2020; Loureiro et al. 2020; Lugosi and Lee 2021; Syiem et al. 2024).

Virtual Reality (VR) technologies have exhibited remarkable potential as a professional tool in diverse disciplines across various research fields, in addition to serving as an invaluable resource in education (Geroimenko 2020; Kamińska et al. 2019; Nelson et al. 2020). Within the educational context, VR has garnered substantial interest among the teaching community due to its accessibility, functional versatility, and capacity to enhance students' cognitive abilities through immersive experiences that foster empathy and bolster motivation (Bower et al. 2020). Notably, VR has demonstrated significant success in immersing viewers in different scenarios, eliciting empathy by offering a firsthand experience, and providing new fundraising opportunities (Milk 2015; Nelson et al. 2020).

Augmented Reality (AR) has assumed a significant role within simulation technologies, primarily owing to its hardware-independent nature. Unlike other simulation technologies, AR does not necessitate specialized equipment, as commonly available mobile phones possess sufficient computational capabilities to operate complex applications utilizing this technology (Challenor and Ma 2019). Furthermore, the field of environmental education offers numerous potential applications for AR (Bachiller et al. 2023; Cranmer et al. 2023; Ducasse 2020; Elmqaddem 2019; Fauzi et al. 2019; Gurevych et al. 2021; Lu and Liu 2015).

Despite being consistently associated with positive outcomes in terms of engagement and knowledge, Augmented Reality (AR) has only recently garnered escalating research interest (Ariza-Colpas et al. 2023) and remains relatively unexplored and understudied within the context of zoos (Alalwan et al. 2020; Mulders et al. 2020; Saul Arboleda and Diego Balanta 2019; Wohlgamuth et al. 2019). This novel technology allows for "environmental immersion" offering a myriad of opportunities for enhancing the educational landscape and visitor experience within zoo exhibits by introducing virtual elements that highlight various environmental concerns, such as waste, oil spills, and invasive species (Challenor and Ma 2019; Pimentel 2022). By integrating AR, zoos can provide a novel and immersive learning environment that transcends traditional educational methods (Syiem et al. 2024).

The incorporation of AR in zoos opens up a world of new learning possibilities. Virtual overlays can depict real-world environmental challenges, allowing visitors to observe and interact with virtual representations that bring pertinent issues to the forefront (3DQR GmbH 2023). Through this innovative approach, AR has the potential to bridge the gap between theoretical concepts and tangible experiences, fostering a deeper understanding of environmental concerns among both children and adults (Syiem et al. 2024).

For children, AR has the potential to transform learning into engaging and interactive activities. By offering a playful and gamified approach, AR captures children's attention and motivates them to explore and learn. Through virtual elements and interactive scenarios, children can actively participate in educational experiences that promote environmental awareness and sustainability practices (Bachiller et al. 2023; Gurevych et al. 2021; Moorhouse et al. 2019).

For adults, AR offers an opportunity for heightened engagement and enriched experiences. By incorporating virtual elements that seamlessly blend with the natural environment of the zoo, AR deepens visitors' immersion and connection to the educational content (Syiem et al. 2024). The interactive nature of AR allows adults to actively explore complex environmental issues, facilitating a holistic perspective and fostering a sense of personal responsibility towards sustainable practices (Cosio et al. 2023).

This study employs AR as a novel approach to facilitate the dissemination of topics that are often deemed challenging to promote, such as sustainability contents. By leveraging AR technology, the educational aspect surrounding this crucial topic can be strengthened, providing a new avenue for effective knowledge transfer and awareness-building.

The limited amount of empirical evidence concerning the efficacy of AR technology within the zoo context constitutes a central challenge when it comes to implementing such components. Nevertheless, studies have demonstrated that the integration of modern interpretation and virtual technologies can prolong visitor dwell time within zoo enclosures and museums, and improve visitor experience (Bachiller et al. 2023; Bowler et al. 2012; Pradiniet al. 2024; Kelling and Kelling 2014; Koo et al. 2019; Moss et al. 2010). In this study, we employed AR technology with the objective of presenting visitors to zoo animal enclosures with extraordinary scenarios with the spotlight in the irresponsible consumption, production, and waste management, thereby elucidating the consequences of unsustainable practices (Figure 1). By adopting this approach, we sought to examine the feasibility of utilizing AR as an educational tool for raising awareness on the subject. Furthermore, we also aimed to gauge the additional benefits of this technology, encompassing aspects such as visitor engagement, entertainment value, and duration of enclosure exploration.

AR enables us to establish connections between the challenges faced by numerous species in their natural habitats and our own behaviours, thereby facilitating the presentation of the current state of remote environments that have been compromised by the accumulation of debris (Figure 2, Figure 3). By leveraging AR technology, it becomes feasible to provide a visual representation of the reality in these environments, shedding light on their altered state due to human activities.

The primary objective of this study is to examine the extent to which the utilization of AR contributes to the acquisition of knowledge concerning waste management practices. Additionally, the study aims to explore the potential predictive role of individuals' attitudes towards nature in determining their knowledge about waste management. Through a comprehensive analysis, the study seeks to discern the influence of AR technology on knowledge acquisition and elucidate the interplay between attitudes towards nature and waste management knowledge.

Materials and Methods

In order to assess the effects of AR on visitors, we designed simulated environments incorporating virtual elements. These AR experiences were specifically created to immerse viewers in authentic settings within natural environments, wherein animals are faced with various threats arising from the adverse effects of deforestation and pollution. By presenting viewers with these augmented scenarios, our study sought to examine the impact of AR technology in fostering a deeper understanding of the challenges confronted by wildlife within these ecologically vulnerable habitats (Figure 2).

A signage display was developed to present intriguing and consequential information pertaining to waste management. This included statistics regarding the annual disposal rates of plastic and electronic waste (Ritchie et al. 2018; Weee-Forum 2021), the number of species adversely affected by plastic pollution (Tekman et al. 2021), and data concerning the toxicity of smartphones (Chen et al. 2018). The purpose of this curated signage was to effectively convey key data related to waste management, raising awareness among viewers about the ecological impact of waste materials (Figure 4).

A comparison was conducted between conventional interpretation methods and virtual interpretation, aiming to ascertain the potential of AR as an educational tool in terms of knowledge and attitude changes. To evaluate the impact of AR as an educational tool within the zoo setting, two distinct conditions were compared. In the experimental condition, visitors were provided access to a mobile phone equipped with AR software (AliceAR, DEUSENS), which was pre-installed and made available at

Table 1. Survey conducted to all participants. Multiple-Choice Questions and Answer Options on Waste Management and Environmental Impact in the survey. The table presents the questions asked along with the provided answer options for each question. *Correct answer for questions one, two, three and five. Response four in correct order from most to least species affected (Chen et al. 2018; Ritchie et al. 2018; Tekman et al. 2021; Weee-Forum 2021).

Questions asked	Answer 1	Answer 2	Answer 3	Answer 4
Which is the waste we produce most in the world?	Electronic waste	Plastic waste*	Nuclear waste	-
How many million tons of plastic waste are produced annually?	500	30	275*	-
How many million tons of electronic waste are produced annually?	90	57*	125	-
Which animal group has the highest number of species affected by plastics in the ocean?	Fish	Seabirds	Crustaceans	Mammals
Which is the most toxic component of smartphones for wildlife?	Aluminium	Nickel	Copper*	-

the entry point of the animal enclosure. This AR software enabled participants to experience a simulated representation depicting the deleterious effects of waste and residues that pose a threat to species in their natural habitats (Figures 1, 2, and 3). Additionally, the software displayed a virtual sign, presenting informative facts regarding the detrimental consequences of waste and providing information on actionable steps to mitigate the associated risks (Figure 4). In contrast, participants in the control group were exposed solely to conventional information signs containing the same information as presented in the virtual sign.

Data Collection

After their visit to the enclosure, participants from both conditions were requested by a researcher to complete a brief survey lasting approximately five minutes (Table 1). The researcher used a tablet to collect the information using an app-based survey form (Microsoft Forms). Subsequently, the data was exported to Microsoft Excel for analysis.

To mitigate potential biases, the researcher followed a standardized procedure wherein the mobile phone equipped with AR software was offered to participants, who were instructed to look through it without engaging in any further interaction or exchange of information. It was ensured that participants could only view the virtual sign when pointing towards the specific location where it was positioned.

A total of 110 responses were obtained and aggregated for analysis, with 55 responses originating from the control group exposed to conventional signs, and the remaining 55 responses

Figure 1. A Komodo dragon *Varanus komodoensis* walking through rubbish in the Komodo National Park (photo credit Dave Gardner SV Anjea 2018).

Table 2. Gender and age for the AR and Control groups, in percentages

		Augmented Reality group	Control group
Gender	Male	65.46%	63.64%
	Female	32.73%	30.91%
	Other / prefer not to say	1.82%	5.46%
Age group	<16 years	7.27%	7.27%
	16-26 years	18.18%	9.09%
	27-36 years	49.09%	34.55%
	37-46 years	23.64%	38.18%
	47-56 years	1.82%	10.91%

stemming from the AR group. Demographic information for the sample is presented in Table 2.

The survey went through a pilot study phase where the validity and reliability of its items were assessed and adapted; the final survey gathered basic information (age, gender and whether the visitor was alone, in a group, or visiting with children), as well as five multiple-choice questions designed to determine changes in the knowledge and understanding of the participants based on the information that was available in the enclosure (Table 1). To capture the duration of participants' engagement with the enclosure, the researcher timed each individual as they entered the designated area (dwell time). Data collection was carried out in a randomized manner, employing an alternating sequence between the experimental and control groups, over a specified

Figure 2. Komodo dragon in its habitat at Bioparc Fuengirola, enhanced with virtual trash and informative signage.

period spanning from April to July 2022 using only weekdays when the park was neither too crowded nor too empty.

Additionally, in order to obtain information regarding participants' attitudes towards nature, we used the Nature Connectedness Index (NCI, Richardson et al. 2019), since these attitudes are known to play an important factor in peoples' motivations and behaviour (Otto et al. 2016). A PCA using Varimax rotation was conducted, obtaining a significant Bartlett's test of sphericity (P=0.001), similar to that obtained by Richardson et al. (2019), the overall Kaiser-Meyer-Olkin measure was adequate (0.788) although lower than the measure obtained by Richardson et al. (2019) (0.913). Similarly, Cronbach's alpha was acceptable (0.781), although it was lower in our sample than that obtained in the original scale (0.92), showing lower internal consistency. While we did not analyse criterion validity of the scale, the scale has been previously shown to have good concurrent validity with previously existing nature connectedness measures (Richardson et al. 2019).

This research received ethical approval from the Bioparc Foundation Ethics Committee, ensuring that the study meets the highest ethical standards, including informed consent, anonymity, and confidentiality. Participants are informed of their right to withdraw at any time without penalty, and no personally identifiable information is collected. Data is processed in accordance with GDPR guidelines, ensuring full compliance with data protection regulations. The ethical review certifies that the research aligns with the institution's commitment to animal welfare, education, and public engagement, fostering a deeper understanding of conservation efforts through immersive technology.

Data analysis

In this study, a Generalized Linear Model (GLM) analysis was conducted to predict the overall knowledge level based on the data collected. Attitudes towards nature, as measured by the Nature Connectedness Index (NCI), were included as a covariate, while the experimental condition (AR or conventional signs) was considered as a categorical factor. Additionally, other factors such as gender, age, and whether the visitor was accompanied by a partner or children were identified as potential variables that can be further explored using the gathered data.

Furthermore, several logistic regression analyses were performed to predict individual question responses. Attitudes towards nature (NCI) were used as a covariate in these analyses, and the experimental condition (AR or standard interpretive signs) was included as a fixed effect to assess the potential influence of AR technology in specific cases. For question four, which allowed for partially correct responses and required identifying the group of animals most affected by plastic waste in the oceans, a GLM with a Poisson distribution was employed to accommodate the nature of the data.

Linear regression analyses were used to test the difference

Figure 3. Komodo dragon habitat at Bioparc Fuengirola, incorporating virtual trash and informative signage

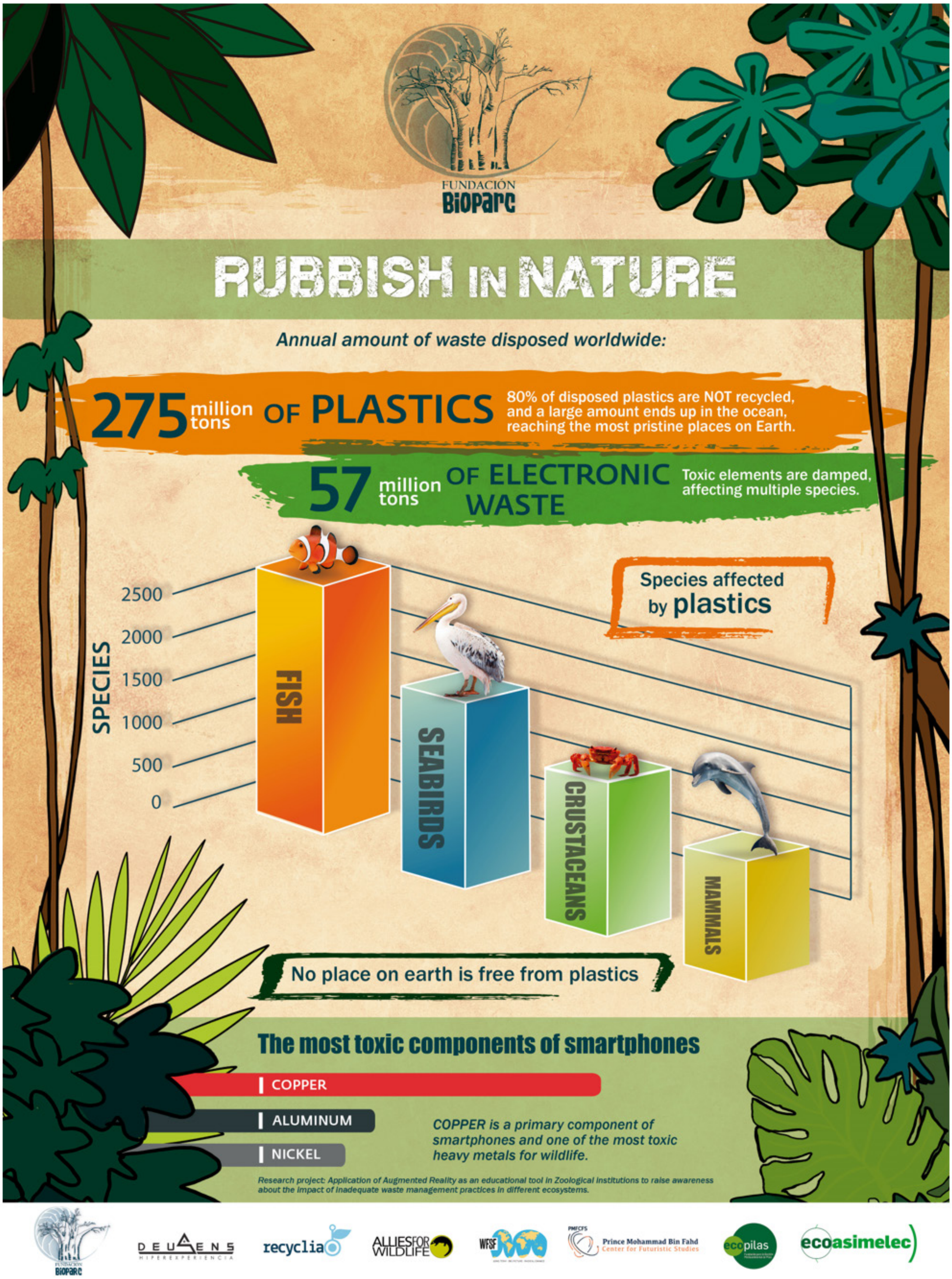

Figure 4. Signage utilized during the study displaying information pertaining to waste management, encompassing statistics on the annual disposal rates of plastic and electronic waste, the number of species impacted by plastics, and data concerning the toxicity of smartphones.

Table 3. Descriptive statistics for dwell time.

Experience	Median	Standard deviation
Conventional signs	72	56.234
Augmented reality	90	50.465

in total knowledge between participants in the experimental condition versus those in the control group while controlling for the relationship between the duration spent in the area and the knowledge. Additional tests examined the effect of the group for each survey question. T-tests were also used to assess if there was a significant difference in dwell time between the experimental and control groups (Figure 6).

In order to study the effect of Augmented Reality (AR) on dwell time, we applied the Mann-Whitney test to examine disparities in the duration, measured in seconds, spent within the exhibit. This analytical approach was chosen due to the non-normal distribution of the variable (Table 3). Results

Model for Total Knowledge

The generalised linear model (GLM) for Total Knowledge is not significant ($X^2_{(94.87)}$=4.512, P=0.719). This result indicates that none of the variables, including Augmented Reality, can predict a greater knowledge acquisition.

Templates for questions individually

The models that analyse questions 1, 3, 4 and 5 are not significant, indicating that neither the use of Augmented Reality nor the Connection with Nature index predict a higher probability of correct answers.

The model to predict the second question (How many million tons of plastic waste are dumped annually?) is statistically significant ($X^2_{(98.96)}$=9.063, P=0.011). The odds ratio associated with the type of experience indicates that the participants who viewed the traditional signage had a higher probability of answering the question correctly. The score on the Connection with Nature index does not significantly predict the probability of answering correctly. Figure 7 shows the probability (between 1 and 0) of successfully answering the question based on the type of experience.

Experience

We collected information via Likert questions to see whether the visitors liked the AR experience. 70% of visitors responded strongly agreed, 18 agreed, 10% somehow agree and 2% somehow disagreed. No disagreed or strongly disagreed were recorded (Figure 5).

Dwell Time

Participants in the augmented reality (AR) condition exhibited a mean dwell time of 108 seconds (SD=50), while individuals who did not utilize AR spent an average of 95 seconds (SD=56) in the exhibit. The Mann-Whitney test did not yield a statistically significant outcome; however, it revealed a trend towards significance (W=1820, P=0.066) (Table 3).

Conclusion and Recommendations

The findings of this study indicate a prevalent lack of awareness and comprehension regarding the capabilities and prospective applications of Augmented Reality (AR) technologies. Notably, the use of conventional and virtual signage did not yield significant disparity in the extent of knowledge change observed among participants. The results highlight the importance of developing more objective-driven and curated virtual experiences for zoos and

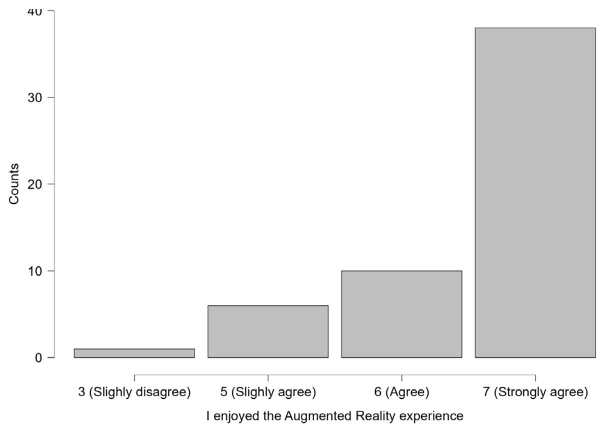

Figure 5. Detailed breakdown of likert scale (1-7) responses by participants that used Augmented Reality.

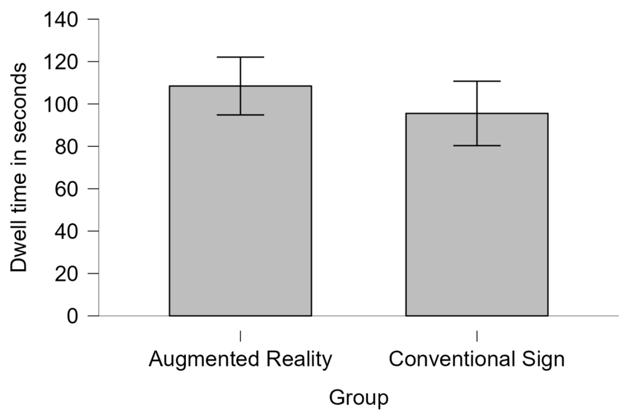

Figure 6. Differences in dwell time for participants in both groups.

aquariums to effectively use this technology as a valuable resource for conservation education. This approach will ensure that virtual experiences are not only engaging but also educational, helping to foster a deeper understanding and commitment to conservation efforts among participants.

The overwhelmingly positive feedback received after the use of AR and the notable increase in visitor dwell time are aligned with similar studies in different fields (Cranmer et al. 2023, Koo et al. 2019) and suggest potential advantages offered by these technologies within the context of zoo displays.

While this study highlights the need for enhanced education and exposure concerning the potential and future implications of AR technologies, the immediate impact on knowledge acquisition from signage, whether virtual or conventional, was not significant. Nonetheless, the favourable reception of AR by participants indicates the inherent value of these immersive technologies in engaging and captivating zoo visitors. The extended dwell time observed among participants further underscores the novel and interactive nature of AR experiences, suggesting their potential for extended engagement and heightened visitor satisfaction also shown in other studies (Bachiller et al. 2023; Pradini et al. 2024; Kelling and Kelling 2014; Koo et al. 2019).

The results highlight the potential of AR technology as an engaging and entertaining tool within the zoo environment, suggesting its possible applications for educational and interpretive purposes. While the immediate impact on knowledge change may not be statistically significant, the experiential and entertaining nature of these technologies holds promise for fostering a deeper connection with the subject matter. Encouraging longer visits and increased dwell time spent exploring exhibits can provide additional opportunities for visitors to absorb information and develop a stronger appreciation for conservation and sustainability efforts as observed in other studies (Lu and Liu 2015; Pimentel 2022).

Further research is warranted to explore the specific elements within VR and AR experiences that contribute to prolonged engagement and positive feedback. Evaluating the content, design, and interactive features of these technologies can enhance their educational efficacy and ensure optimal outcomes. Additionally, investigating the potential correlations between participants' personal characteristics (such as age, prior knowledge, and attitudes towards technology) and the benefits derived from AR experiences can provide valuable insights for tailoring educational approaches and maximizing their impact.

In summary, although the differences in knowledge change between virtual and conventional signage were not substantial, the positive feedback and increased dwell time observed among participants highlight the inherent benefits of AR technologies in the zoo context. By capitalizing on the interactive and immersive nature of these technologies, zoos can effectively engage and educate visitors, fostering a deeper understanding of environmental conservation and sustainability issues. Ongoing research and development efforts should continue to explore ways to optimize the educational potential of VR and AR technologies to enrich the educational experiences offered within zoos.

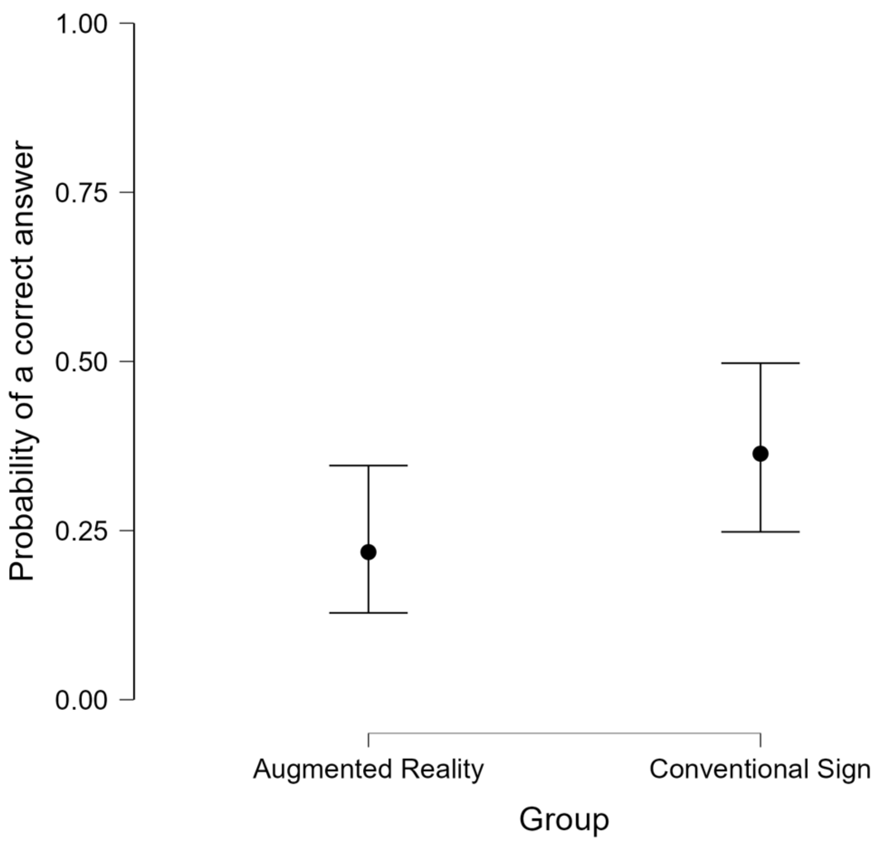

Figure 7. Ratio of correct responses for participants in each condition.

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