Artificial Intelligence for Eco-Didactic Installations through Interactive Museological Experience to Encourage Sustainable Action

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Abstract

Interactivity has demonstrated significant efficiency in enhancing the informal learning experience. Environmental museums offer a diverse range of interactive experiences, encompassing both digital and analog mediums, to educate visitors about the environment and sustainability. Studies show that Artificial Intelligence (AI) technologies have enriched digital interactivity by incorporating features such as real-time data processing, object recognition, and personalized recommendations. The implementation of these technologies in public spaces, such as museums, has started and rapidly developing. Given these, the study aims to establish potential alliances between museological learning, interactivity, and AI to amplify the impact of environmental learning experiences in the public space. The integration of AI and interactivity has the potential to foster effective learning experiences, ultimately leading to behavioral changes toward sustainable practices. This study delves into the impact of the interactive agents deployed at the Biosphere Environment Museum in Montreal. This is achieved by examining visitors' experiences with interactive installations and questioning how these experiences reflect into the daily life. The study adopts a design ethnography research method, employing primary ethnographic and qualitative approaches to collect data. As a result, interactive installations are preferable comparing to non-interactive installations. The study concludes by reflecting on potential future outcomes.

Keywords: AI, eco-didactic, sustainability, museological experience, interactivity, interactive learning

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1. Introduction

Interactive museological experiences foster stimulating informal learning environments that actively engage visitors and encourage them to explore. By offering opportunities for multisensorial experiences, reciprocation, and personalized learning paths, these interactive exhibitions promote high levels of cognitive engagement (Pallud, 2017). In particular, for environmental subjects, multisensorial experience potentially increases the recall rate by activating multiple human senses in a holistic approach (Ntalla, 2021). Such immersive experiences not only contribute to the overall enjoyment and satisfaction of visitors but also enrich the educational value of museums. The digital technologies supporting these immersive experiences range from touch screens to spatial movement recognition, and virtual reality headsets. Moreover, Artificial Intelligence (AI) is becoming increasingly prevalent in contemporary digital art due to recent advancements, offering features such as facial recognition, generative data, personalized content, and more (Audry, 2021; Stark & Crawford, 2019).

In that regard, this study explores the hypothesis that the integration of Artificial Intelligence (AI) technologies enhances the digital interactive experience in eco-didactic context by providing assets such as customizable suggestions, object recognition, real-time data processing, resulting in enhanced informal learning in the context of environment. The term "eco-didactic" stands for educational and experimental materials designed to create ecological awareness (Cucuzzella, 2019). Existing eco-didactic public installations significantly affect people by making public space a "place of change." According to Cucuzzella et al., "public spaces can become hinges for exchanging knowledge towards awareness and eco-action" (2020, p. 11). Therefore, the main goal is to establish potential connections between AI, interactivity, and museological learning to amplify the influence of informal environmental education, fostering behavioral change towards more sustainable and ecological practices. This study investigates the Biosphere Environment Museum in Montreal, QC, Canada to explore interactive museological learning in environmental subjects and reveal the suitable implementations of AI technologies. The study aims to achieve the following objectives: (1) investigate interactive museological learning at Biosphere, (2) conduct a visitor's survey on the interactive demonstrations (3) analyze the survey data and offer insights into enhancing these exhibitions through utilization of AI technologies, (4) discuss potential applications in the public realm. To achieve these objectives, the study adopts a design ethnography research method (Müller, 2021), utilizing ethnographic and qualitative approaches for empirical primary data collection with field notes, photographs, and videos (Carter & Henderson, 2005; O'Reilly, 2011). In this regard, the theoretical framework provides a comprehensive literature review focusing on the role of interactivity in enhancing the learning experience, with particular emphasis on the public space experience and the integration of AI technologies in interactive installations.

2. Theoretical Framework

2.1 Interactivity in Learning Experience

In the literature, as Ntalla (2021) mentions, by referencing the theories of Vygotsky & Cole (1978) and Piaget (1966), play and learning are associated closely. These constructivist theorists claim that action and discovery enhance learning and knowledge, as in games with specific rules, especially engagements of cultural influence and social interaction. Ntalla also mentions Dewey's work which states that activity is directly linked to the construction of knowledge, and learning occurs throughout the experience. This makes the learner an active participant. Falk and Dierking mention one of the motivations for learning is being outside of the classroom, which is self-learning outside the school environment. Their study investigates museum learning. They explain three contexts for museological learning experience: Personal, sociocultural, and physical. Accordingly, learning is a personal experience that requires "prior knowledge and experience" (p. 19). Regarding sociocultural context, they claim that meaning making occurs when humans try to "make sense of the world through social interaction with others" (p. 38). They state that the most remembered is the physical context, which is the series of experiences that an individual has while learning (e.g., what they did, saw, how they felt, etc.). Learning occurs when the prior experiences are adequately framed within the physical setting of the individual. Learning is immersed within a physical context. Therefore, as neuroscientist has revealed, spatial learning is associated with all kinds of learning since they are "influenced by the awareness of the place" (p. 62). Given these, in this study, we engage with the learning experience through the museum context, where individuals voluntarily want to learn.

Interactivity has become an essential part of museums, which adopt various engagement modes such as touchable components, multimedia, and sensory encounters. Irida Ntalla's study "Play and Manifestations of Playfulness in Interactive and immersive museum spaces" (2021) examines the notion of play and playfulness in interactive and immersive museums that exhibit environmental subjects, such as climate crisis. Ntalla states that interactivity has become an essential part of the museums, which can be seen in the case studies (Barry, 1997; Dicks, 2004), and these interactive installations invite visitors into an environment they can "interact, engage and learn" (Falk & Dierking, 2000, 2004; Hornecker, 2008). Ntalla's exploration of an interactive and immersive installation titled "The High Arctic Installation" reveals that these types of multisensorial and spatial experiences can alter the perception of boundaries, play, and playfulness, especially regarding adult audiences. Ntalla argues that play and fun are seen as a child's feature in Western Society; despite this, the author noticed "enthusiasm" amongst the adult and child audiences, which they mentioned in the interviews that the experience was fun. Ntalla reflects that spatial and multisensorial components challenge the perception of playfulness in adult participants and underline the oppositions, such as serious against non-serious. Therefore, the author considers interactivity a holistic compound of interactions between body and mind and emotions and perception that can change the boundaries of play and playfulness (Ntalla, 2021).

Another example of interactivity is in science-based learning; Chao-ming Wang and I-Ting Chen's study

"Applying Interactive Technology to Construct a Popular- Science Teaching Aid System for Protecting Cetaceans along Sea Coasts" (2021) aims to develop an innovative interactive teaching aid system that educates people on the rescue of cetaceans, which are animals such as dolphins and whales. They introduce interactive technology as a tool with high potential for popular science education. They claim that using this technology could make the learner an "active investigator" and alter the learning environment to be an environment that the learner can internalize and have an explorative experience. This could lead to effective learning. Therefore, they adopted a game-play approach on a smart tablet, including five levels for users to pass. They exhibited the teaching aid system publicly and evaluated it with a questionnaire. They concluded that their system could spread knowledge regarding the presented subject. Regarding learning effectiveness, they measured users' knowledge with knowledge-based questions, and 81.7% of the participants answered them all correctly. They determined that interactivity could create attention, deliver related content, construct user confidence, and satisfy them through playfulness (Wang & Chen, 2021).

In this respect, related literature shows that interactivity is significantly effective in scientific communications about environment-related subjects, for instance, climate change (Lesen et al., 2016). As mentioned earlier, learning occurs spatially by being aware of the surrounding space and making sense of the world through prior experience within a community. This raises the question of the most effective place to learn about the environment socially. This study considers the public realm an effective place for raising eco-awareness and explores its possibilities. The public realm contains publicly open places, such as urban greenery, transportation hubs, museums, libraries, etc.

2.2 Interactivity in Public Space

Interactive communication in public space initiates through movement-based engagements. The essence of these interactions lies in the richness and meaning of the performed motions (Hummels et al., 2007). The built environment plays a decisive role in shaping and influencing movement patterns. Therefore, the space design allows one to achieve the desired activity patterns by physically standing in the movement path (Gehl, 2011). Digital displays are a commonly utilized interactive communication method in public spaces, for instance, museums, transportation hubs, and shopping malls. According to Parker et al., there are four factors to consider in designing public interactive displays: People, location, community, and time. Moreover, they associated nine aspects with these factors: privacy, trust, appropriation, relevance, location, ownership, collaboration, identity, and time. Each of these nine aspects is associated with one of the four factors that collectively define the value of the public displays offered to the users. They highlighted the visibility problem of these displays, which they connected to their perceived value of them. They recommended employing the value in the focus of the design and distribution process, along with supported guidance. They also revealed the community usage of the displays in providing information, gathering opinions, hosting interactive events within the community, and allowing individuals a platform to express their voices (Parker et al., 2020).

Another form of interaction in public space is responsive installation arts. Lancel et al. investigated the social connections in their interactive "Saving Face" installation in different cultural public spaces. The aim is to share an experience of social touch and alter the perception of seeing and being seen, touching and being touched. Participants make social connections on screen by feeling their faces and those of others. They concluded that interactive experiences on social touch could be applied in public spaces with smart technologies to create interactive social connections between individuals. However, they also pointed out this raises hesitant dialogues (Lancel et al., 2020).

It is essential to investigate the design progress of these interactive installations to gain knowledge in considering different aspects. Kao's study aims to explore the development of interactive installations in public spaces, examining the intricate connection between design practices and individuals' encounters with these installations. Therefore, the research presents a place-oriented framework for designers to guide them through the installation design process. The study includes the users' perspective by addressing how these installations influence people and their perception of the space. In conclusion, the study shows that place-oriented design enhances the sense of space by encouraging reciprocal interactions and place-oriented conversations (Kao, 2021). Another study by Shuwen and Chool-Shoo defines the characteristics of interactive installations and examines their applications in public spaces, such as transportation hubs, urban squares, and indoor spaces. They claim three characteristics: interactivity, temporal and spatial features, and synthesis. They suggest various strategies for the design and application processes of interactive installations. They conclude that there is a need for coordination between interactive installation and the environment based on human-oriented principles (Shuwen & Chool-Soo, 2021). Different types of responsive technologies are being used for interactive installations. According to De Wall et al.'s research which aims to create shared knowledge on these technologies, there are mechanisms for applying them, highlighting the spatial qualities and potential benefits of networked urbanism. These are Sense of place, (playful) interaction, personalization, routing and legibility, and control. They concluded that rather than focus on space or objects individually, the spatial design must embed responsive elements in a spatial setting. Furthermore, they claim that socio-spatial analysis of the space and local stakeholders have an essential role in the design process (de Waal et al., 2021). Different reality technologies, such as Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR), also contribute to the creation of multisensorial interactive experiences. Derda et al.'s study explores the "experience space" from the practitioner's perspective in the meaning-making process by interviewing MR artists regarding the problems that occur while experiencing the relevant space. The study aims to identify these problems and provide a profoundly detailed perspective under "in-betweenness, inseparability, and (un)realness." The study concludes that the relationship between augmenting technologies and space is mutually dependent with significant consequences for augmentation, the experience of the user, and mediation of the feeling of the place. Therefore, they emphasize that multi-sensuality is important regarding spatial experiences of augmented reality (Derda et al., 2021).

2.3 AI Integration for Enhanced Interactivity

People's increase in daily activities on digital online platforms (e.g., finding information, receiving services, and engaging with communities) changes their needs fulfillment habits. This change applies to expectations from public space services and other engagements. Therefore, the solutions should be convenient for providing new needs. For example, smart technologies for public spaces provide platforms to consider, evaluate, redevelop, and intervene in these open spaces in a case-sensitive and flexible approach (Ayman Abdel-Aziz et al., 2020). There are various patented studies on interactive space technologies (Brooks et al., 2020; Chaney, 2020; Pradeep et al., 2015). Similar technologies are seen in interactive projects like the aforementioned "Saving Face," which creates playful environments (Lancel et al., 2020); Samsung's interactive space "Resonance" for 2019 Milan Design Week which allows visitors to interact with the space by using smart technologies (Samsung, 2019); and Özel Office's project "Cypher" (2018) which is a sculptural installation that combines robotics, sensory systems, Virtual Reality, and machine learning for an interactive experience (Özel, 2018). Some of these interactive examples implemented various AI technologies.

Regarding AI, there are two main categories, according to Taulli: "machine learning" and "deep learning." Machine learning focuses on self-learning: "A computer could learn and improve by processing data without having to be explicitly programmed" (p. 71). Which means "a computer could be trained to make accurate predictions" (p. 71). In essence, it is about collecting data and making relations in between. For example, the computer could be trained with a particular item's image, and it gets better at recognizing it in other images. On the other hand, Taulli describes deep learning as "a subfield of machine learning" (p. 71), which processes great amounts of data to make relations and patterns. One of the networks for deep learning is the convolutional neural network (CNN), which analyzes data section by section and is for complex applications such as image recognition (Taulli, 2019, pp. 41, 71).

Sarker proposes five types of AI: analytical, functional, interactive, textual, and visual. Analytical AI identifies, interprets, and communicates data patterns. It can give insights and solutions. Functional AI, like its analytical counterpart, discovers data and performs actions, such as the Internet of Things (IoT) and robotics. Interactive AI (e.g., smart personnel assistants and chatbots) automates communication. Textual AI analyzes text and processes natural language, such as speech-to-text conversation and text recognition. Visual AI recognizes items and classifies and sorts them. Also, it transforms videos and images into insights and is used to train machines. Moreover, visual AI is usually applied in Augmented Reality and computer vision. Different techniques could be applied to create these AI types, such as machine learning, neural networks and deep learning, frequent pattern mining, reasoning, natural language processing, computer vision, and pattern recognition. These techniques are already used within the fields (e.g., healthcare, smart city, security, education, and business) (Sarker, 2022). Studies show that various technologies, such as smart digital displays and facial recognition systems, can be adopted in interactive public spaces.

For instance, Li's study focuses on AI artworks that engage with visitors at international Art & Tech exhibitions. The machines continuously learned and transformed the artworks in some of these engagements. Some artworks altered the ecological systems through real-time data, while others adapted visitors' movements and presented AI versions of these movements. And some of them provided insights into AI-operated futuristic cities. This body of work shows how AI can benefit a city regarding education, mobility, healthcare, and city-wide developments (Li, 2020). Klipphahn's study questions the AI-art connection through artistic and academic research collaborations for automated intelligent behavior. He indicates that it is crucial to internalize AI systems to create well-designed automated systems for society (Klipphahn, 2021). Lin explains that one of the many ways of using AI in art is as a valuable tool for the design or creation process. Alternatively, there is the integration of AI in art production by creating art with AI algorithms. Artists can use AI in creative thinking by combining human creativity with algorithms. Lin's study claims that the opportunities AI provides for the art world have changed traditional art patterns and created new forms of art (Lin, 2020).

There are discussions on the creative value of the artworks created using AI. Miller's study investigates machine creativity through computer-generated artworks. He notes that computer creativity is already seen in games and medical research; some creative works include literature, music, and art. He indicates that computers will produce extraordinary artwork only if they can achieve creativity (Miller, 2019). Moreover, according to Forbes, artists and designers who generate data with machine learning use creative AI examples of such methods include imitating data, visualizing the working principles of the algorithms, mapping features between datasets, creating unusual mappings from inputs to outputs, and criticizing and these systems' societal impact. With these techniques, one can replicate artworks, generate new ones, and design new ways of connecting with existing artworks. The author highlights the opportunities created to experience and analyze cultural artworks and data (Forbes, 2020). Furthermore, creating digital content with AI allows artists to form a new reality that significantly impacts the perception of reality. Wróblewski's study examines the digital arts that contain artistic messages, indicating that this impact affects individuals and societies (Wróblewski, 2019).

For AI artwork classifications, Mendelowitz categorizes AI into four metrics: Perception, introspection, actuation, and self-mutability. Considering these metrics, he defines five AI artwork categories. He classifies them with the following five metrics: (1) "AI-based artwork whose intelligence function is based exclusively on its internal state (introspection) and ignores any sensory input (or has no sensory input) can be classified as generative." (2) "AI whose actuation is based almost entirely on perception while ignoring its internal state can be termed reactive." (3) "Artwork whose intelligence function is influenced by both perception and introspection but does not modify its internal state is interactive." (4) "AI-based art that changes its internal state in response to perception and responds to a combination of its perceptions and internal state is learning." (5) "An artwork that has no actuation can never effect a change outside of its internal state. It is, from the perspective of the public, static" (Mendelowitz, 2020).

Özel's projects, which can be considered both interactive and learning AI, delve into interactive architecture with his two spatial interactive installations which utilized AI technologies. They are titled: "Cerebral Hut" and "Aether Project." These spatial works aim to imitate smart behaviors by transforming their architectural structure via motion sensors. Users are allowed to activate the motion of the structure. For instance, Cerebral Hut's surfaces capture and save the motions of several users and create loops of space and user presence. On the other hand, Aether employs a motion tracker device, enabling users to control its geometric shapes. Özel defines space as a robotic entity that works with sensory agencies, form, and motion, and it is "de-contextualizing human consciousness outside the body's boundaries through technology." The study concludes that architecture, as an interactive and intelligent form, can propose an alternative way to isolate new technologies (Özel, 2014). Interaction between the user and device is mainly credited to the impact of the device's independent actions. Pazdur-Czarnowska claims, "Man becomes their activator, and his participation in the act of creation - the foundation of the machine-learning cycle." (Wróblewski, 2019, p. 237).

An essential issue that should be addressed in AI works is collecting data considering privacy and ethics. Stark and Crawford focus on thirty artists touching on the privacy, identity, surveillance, and power that occurred with data collecting (Stark & Crawford, 2019). In another study on this issue, Torresen reviews the future of AI and robotics and the ethical issues that must be addressed to avoid a dystopian future. The study categorizes the ethical considerations into two groups: The first concerns the development process; engineers should consider the possible ethical challenges (e.g., misuse, manual system inspection). The second one is that the system itself should make moral decisions. In considering these points, the study suggests that developers will have created the ideal user experience and safety. Moreover, AI systems should be easily inspectable to detect and prevent mistakes. Also, the AI system should not be manipulated, and its behaviors should be predictable (Torresen, 2018).

Considering these, we first investigate the interactive exhibitions at The Biosphere environmental museum utilizing field observations and questionnaires.

3. Methodology

This study employs a design ethnography research method, which is a method that tries to understand how users engage with a design object (Müller, 2021). This methodology is adapted to investigate the interactive demonstrations at the Biosphere Environmental Museum in Montreal, QC, Canada. We selected The Biosphere due to its emphasis on ecological and scientific themes and, as a museum, it adopts a didactic approach in presenting its installations. The approach of this experiment is empirical, and the primary data collection adopts ethnographic and qualitative methods using field notes, photographs, and videos (Carter & Henderson, 2005; O'Reilly, 2011).

Two (2) Research Questions (RQ) were asked to explore the interactive demonstrations in the museum: (1) What are the interactions and experiences of the viewers with interactive eco-agents? RQ-1 aims to help analyze the characteristics, similarities, and or differences between interactive experiences. (2) What influences viewers' responses to interactive eco-agents? RQ-2 aims to help explore the design decisions made for the interactive installations if these decisions lead to specific viewer responses. In addressing these questions, observations were carried out on two busy days (13th and 19th November 2023), evaluating the overall interest of individuals in interactive and non-interactive demonstrations, as well as the exhibition areas they navigate. A questionnaire that contains six (6) multi-choice questions was prepared based on the field notes. Questions were designed to evaluate the visitors' interest in exhibitions, the frequency of their museum visits, their experience with the interactive installations, and their feelings on the ecological theme.

The observations at the Biosphere were conducted on Sunday, the 13th, and Saturday, the 19th of November 2022, spanning from 2:00 pm to 4:00 pm, totaling four hours. These specific days and time slots were chosen to capture high visitor density. Approximately 70 individuals visited during this observation period, with the visitor profile predominantly composed of families with young children and students (from high school to university). The survey phase took place on Saturdays, specifically January 14, 21, and 28, 2023, with total of twenty-five (25) participants aged 18-64. The survey is exclusively administered to adult visitors.

The Biosphere is a museum, located in Park Jean-Drapeau, Montreal, is a part of a complex of nature and science museums known as Montreal Space for Life[1]. Two (2) exhibitions have been selected to investigate in the scope of the research: "Ecolab" and "This is not an Umbrella." *This is not an umbrella* exhibition shows the different characteristics of "meteorology, the science of weather." It is an immersive and interactive exhibition that provides insights into weather science. *Ecolab* exhibition demonstrates the "scientific research method" by creating an interactive laboratory space focusing on water and air pollution. The exhibition aims to present to the public how scientists work to solve pollution-related problems efficiently.

The limitation of this study lies in the scarcity of environment-themed museums with interactive installations in Montreal. Despite attempts to include the Montreal Science Center, which houses more interactive displays, in our research, permission was not granted. Therefore, the Biosphere remained our sole option.

4. Results and Discussion

4.1 Observation findings

4.1.1 This is not an umbrella

The context of "This is not an umbrella" was precisely realistic and relatable. It might even be discomforting in terms of eco-anxiety. The exhibition comprised an open floor layout divided into three sections. The entrance section followed a linear layout, while the second and third sections were arranged in a circular manner (Appendix 1). Dim ambient lighting was complemented by bright spotlights directed towards the installations throughout in the space. Two projectors were strategically positioned to serve as light sources for the installations crafted using umbrellas. In the entrance, a large video was projected onto one of the walls, while informative cardboards hung from the ceiling and audiovisual elements were presented throughout section one. The second section featured an interactive touch-surface game, projected from above onto a circular stand where four players can engage simultaneously. In the third section, visitors navigate along the circular path, encountering digital touch screens and analog demonstrations both inside and outside the circle. The exhibition provides a wealth of everyday examples and connections, including explanations of scientific concepts underlying common weather-related phrases and idioms (e.g., "it is raining cats and dogs").

Regarding navigation, despite the exhibition being in a compact space, visitors found it challenging to identify the intended path. Many visitors required assistance in following the narration and even missed some of the installations. Among the visitor profile, adults actively engaged with the installations, often taken the opportunity to explain the provided information to their children. Visitors exhibited greater interest in tangible games, interactive touch screens, and analog interactive installations compared to infographic boards briefly. Very few people had stopped to read the infographic boards for a brief period. Audiovisual and informative boards could

[1] Montreal Space for Life. https://espacepourlavie.ca/en/about-space-life

have been more attractive. Analog interactive installations attracted more attention than digital interactive touch screens.

4.1.2 Eco lab

Eco Lab was curated as a scientific laboratory focused on water pollution, aimed at transforming every visitor into a researcher and facilitating education on the scientific research method. Visitors engage in a structured scientific process, progressing through steps that include observation, questioning, hypothesis formulation, experimentation, data collection and analysis, and drawing conclusions. The exhibition layout unfolds within a spacious rectangular area, offering an open-plan design (Appendix 2). Installations were strategically positioned on both the walls, and in the center, featuring elements such as a water samples station and a trivia game station. Despite the sequential steps of the scientific method guiding the visitor's path, deviations occurred, particularly around central installations or due to crowd congestion, disrupting the intended narration.

The exhibition features interactive installations addressing topics such as air pollution, human anatomy, and virus contamination, including a touch-screen trivia game. These installations sparked extensive conversations among the visitors, encouraging dialogue, idea exchange, and shared observations. Groups often engaged with others' interactions, especially in playful installations such as the trivia game and the depiction of air pollution within various rooms of a house. The installation simulating different rooms in a house, named Houseroom, emerged as the most popular. Following closely, another favored installation showcased human anatomy, where pressing buttons illuminated corresponding parts. However, a minority showed less interest of felt somewhat intimidated, limiting their engagement to visual observation.

To summarize, interactive installations drew more attention in both exhibitions compared to informational boards and audiovisual presentations (e.g., videos). Interestingly, analog interactive installations proved more captivating to visitors than their digital counterparts. This observation underscores the influence of playfulness on the audience.

4.2 Survey results

The survey was conducted on Saturday, January 14th, from 2:00 to 4:30 pm, with the participation of twenty-five (25) adults. The survey consisted of six multiple-choice questions focusing on interactivity and experience, including an age categorization query. The questionnaire is provided in both English and French (See Figures 1-6). Participants were required to be 18 or older and have visited the interactive exhibitions to meet the selection criteria for this field study. According to the information provided, the age distribution among participants was as follows: 10 individuals fell within the 25-34 age range, followed by 6 participants in the 18-24 age group. The 35-44 and 45-54 age groups each had 4 participants, and there was 1 participant in the 55-64 age range. Notably, there were no participants aged 65 or older. Consequently, the majority of participants were between the ages of 18-34.

In the initial question (Figure 1) regarding the frequency of their visits to interactive exhibitions, the majority of the participants, ten individuals each, indicated "when I have the chance" and "occasionally." The remaining five participants chose "rarely," suggesting a generally moderate level of interest in such exhibitions.

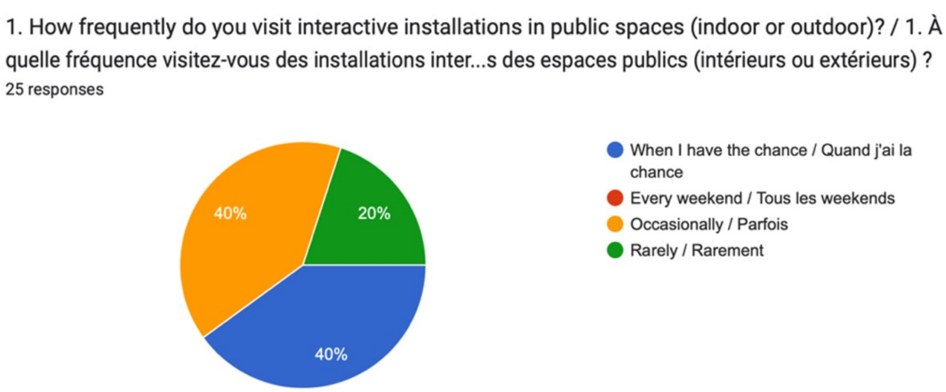

Figure 1. The frequency of the visit to interactive exhibitions.

In the second question (Figure 2) concerning interest in public spaces, most participants indicated a high level of interest, with "very interested" being the most popular response. The next common response was "somewhat interested," particularly for festivals and indoor and urban spaces. When it came to museums and art galleries, the majority expressed a "somewhat interested" sentiment, with only one more participant selecting "very interested." In contrast to other public spaces, which each had only one participant respond with "not interested," museums and art galleries had 2 participants who indicated this sentiment.

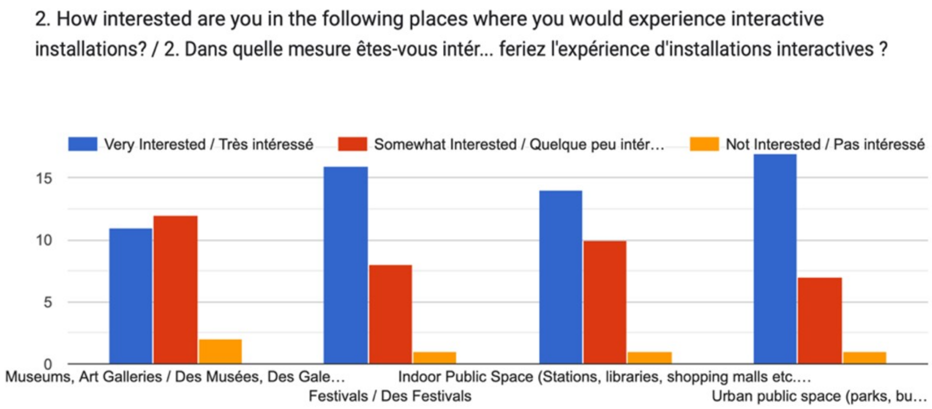

Figure 2. The interest for the different types of public spaces.

In the third question (Figure 3) regarding the definition of visitors' experiences, the majority of participants, 10 in total, chose "informative, didactic" while 9 participants selected "all of the above." The next popular response was "unique, different" chosen by 6 participants, followed by "joyful, entertaining" with 5 people. Only 1 participant responded with "none of the above." These results suggest that the exhibitions successfully provided informative and didactic experiences that pleased the visitors.

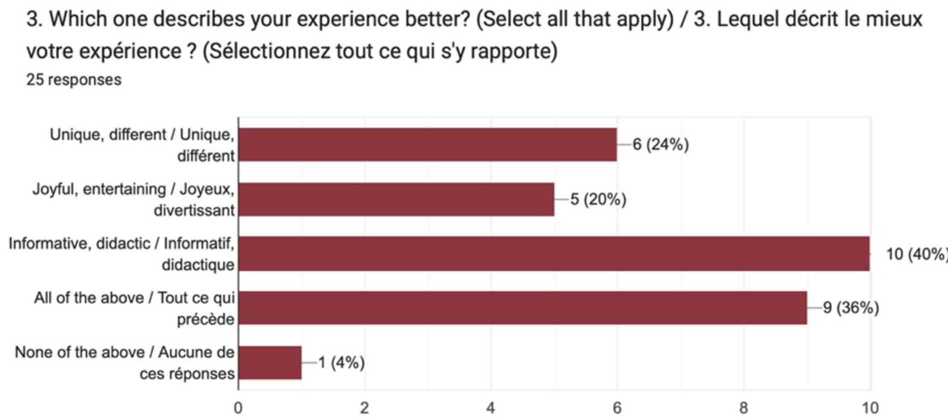

Figure 3. The experience of the interactive installations.

For the fourth question (Figure 4) regarding the eco-content, 15 respondents chose "informed," 4 selected "hopeful," and 3 opted for "all of the above." In contrast, only 1 participant indicated feeling "overwhelmed," and another participant responded with "none of the above," specifying their answer as "informed and hopeful."

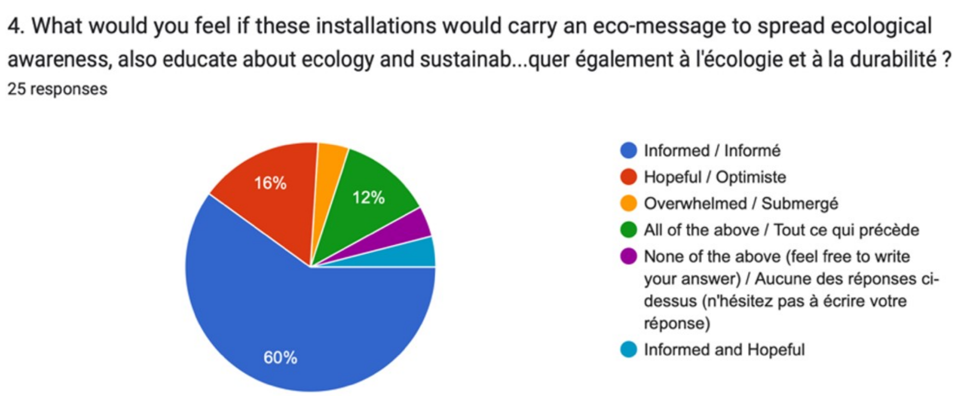

Figure 4. The impact of the eco-message.

Regarding the fifth question (Figure 5) about reflections on daily life, the majority responded with "slightly (2 times a week), with 10 respondents. The following answers were "considerably (4 times a week)" and "rarely (1 time a week)" with 6 participants each. Only 1 respondent answered, "not at all."

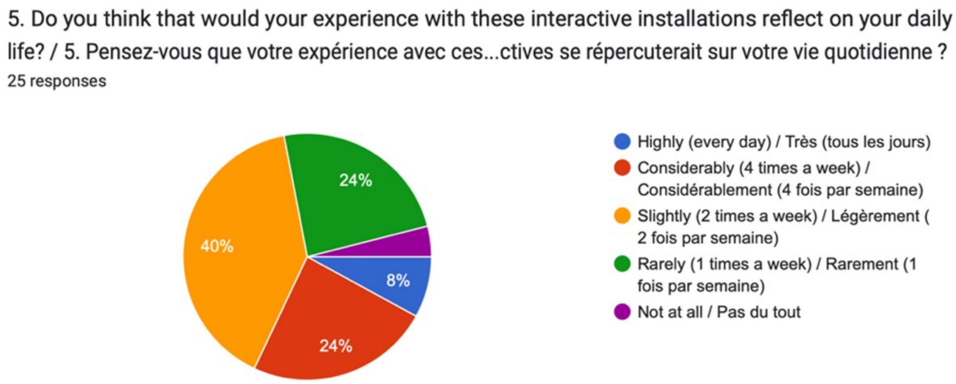

Figure 5. The impact of the interactive installations in daily life.

Finally, in the sixth question (Figure 6) regarding the effectiveness of interactivity, 12 participants responded with "considerably effective," followed by 9 answers indicating "highly effective." 1 participant responded, "slightly effective." In contrast, 3 participants thought it was not effective at all.

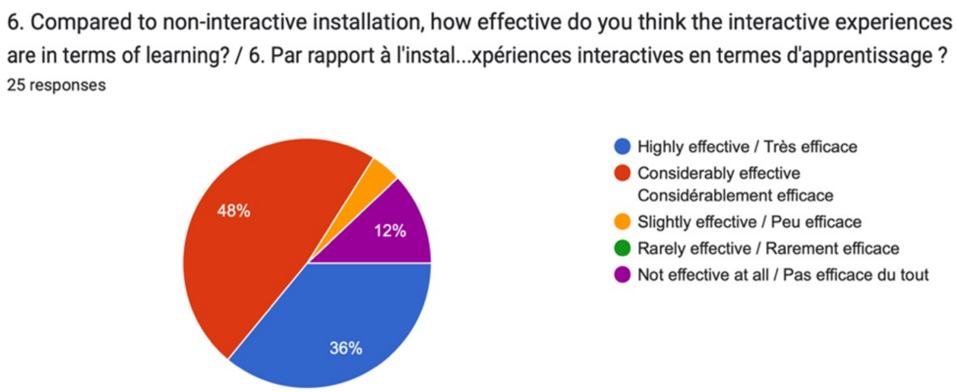

Figure 6. The comparison between interactive and non-interactive installations.

Table 1 summarizes the survey responses as percentages, illustrating the answers across different age groups. In the table, under the "interest in places" domain, "V" indicates Very Interested, "S" indicates Somewhat Interested, and "N" indicates Not Interested.

4.3 Discussion

Visiting Frequency: This data suggests an interesting age-related trend in the frequency of visiting interactive installations or exhibitions. Among those aged 18-24, there appears to be a high level of interest, with half of the participants reporting visits whenever the opportunity arises. In the 25-34 age group, while a significant portion still visits opportunistically (40%), the remaining participants in this age group pay visits infrequently or rarely. The trend shifts in the 35-44 age group, where more than half visit when they have the chance. For the older age groups (45-54 and 55-64), the majority visit occasionally. This pattern may reflect differing levels of interest or availability of time for engagement with interactive exhibitions across various age demographics. Further exploration into the factors influencing these patters could provide valuable insights.

Interest in Places: This data reveals interesting variations in the level of interest in different public spaces across age groups. Among participants aged 18-4, there is a consistent high level of interest in all types of public spaces. In the 25-34 age group, interest becomes somewhat lower. The 35-44 age group demonstrates a notably lower interest in museums and art galleries compared to other public spaces. The 45-54 age group shows a split interest, with half being very interested in all public spaces and the other half expressing more interest in festivals. The 55-64 age group leans towards indoor public spaces, particularly museums and galleries. These variations may reflect evolving preferences and priorities across different life stages, indicating the need for diverse strategies in designing interactive exhibits targeting various age demographics.

Table 1. Survey answer percentages.

Criteria	**Ages**												
	18-24 (6)			**25-34 (10)**			**35-44 (4)**			**45-54 (4)**		**55-64 (1)**	
Visiting Frequency													
When I have the chance	0.50			0.40			0.75			-		-	
Occasionally	0.16			0.30			0.25			0.100		0.100	
Rarely	0.33			0.30			-			-		-	
Interest in Places	**V**	**S**	**N**	**V**	**S**	**N**	**V**	**S**	**N**	**V**	**S**	**V**	**S**
Museums/Art Galleries	0.66	0.33	-	0.30	0.70	-	0.25	0.25	0.50	0.50	0.50	0.100	
Festivals	0.66	0.16	0.16	0.60	0.40	-	0.50	0.50	-	0.10	-		0.100
Indoor Public Space	0.66	0.33	-	0.40	0.50	0.10	0.66	0.33	-	0.50	0.50	0.100	
Outdoor Public Space	0.66	0.16	0.16	0.80	0.20	-	0.75	0.25	-	0.50	0.50		0.100
Interactive Experience													
Unique, different	0.16			0.50			-			-		-	
Joyful, entertaining	-			0.20			-			-		-	
Informative, didactic	0.50			0.10			0.50			-		-	
All of the above	0.16			0.20			0.50			0.100		0.100	
None of the above	0.16			-			-			-		-	
Environmental Awareness Context													
Informed	0.66			0.60			0.50			0.75		0.100	
Hopeful	0.16			0.20			-			0.25		-	
Overwhelmed	0.16			-			-			-		-	
All of the above	-			0.10			0.50			-		-	
None of the above	-			0.10			-			-		-	
Other	-			Informed, hopeful			-			-		-	
Daily Life Reference (eco-message)													
Highly	0.16			-			0.25			-		-	
Considerably	0.33			0.20			0.25			0.50		-	
Slightly	0.16			0.40			0.25			0.50		0.100	
Rarely	0.33			0.30			0.25			-		-	
Not at all	-			0.10			-			-		-	
Interactive versus Non-Interactive													
Highly effective	0.33			0.40			0.25			-		-	
Considerably effective	0.33			0.50			0.25			0.50		-	
Slightly effective	0.33			-			0.25			0.50		0.100	
Rarely effective	0.33			-			0.25			-		-	
Not effective at all	-			0.10			-			-		-	

Interactive Experience: This data indicates diverse perceptions of the interactive experience across different age groups. Participants in the 19-24 age group largely characterized their experience as didactic and informative, while the 25-34 age group expressed a more varied range of responses, with half defining their experience as unique and different. The 35-44 age group showed a split response, with half finding the experience informative and didactic. The last two age groups, 45-54 and 55-64, leaned towards agreement with all the responses. These variations highlight the subjective nature of interactive experiences and suggest that a one-size-fits-all approach may not be suitable. Customizing interactive exhibits to cater to different preferences and expectations within various age demographics could enhance overall visitor satisfaction. For instance, Artificial Intelligence technologies have the potential to enhance the personalization of exhibits ensuring equally engaging experiences for all visitors.

Environmental Awareness: This data underscores noteworthy differences in how different age groups perceive and respond to eco-messages. Older participants, typically from the 45-64 age groups, leaned towards feeling more "informed" about eco-content. Younger participants, particularly 18-34 age range, exhibited a mix of responses, including both "hopeful" and "informed." This suggests that younger individuals might be more open to messages that evoke a sense of optimism and hopefulness about environmental issues. Similarly, the younger demographic may have a greater inclination toward hopefulness, given that it directly pertains to their future.

Daily Life Reference (eco-message): When assessing the effectiveness and relativity of installations, older age groups tended to view them as more effective, responding with "considerably." In contrast, younger age groups often chose responses indicating a lower degree of impact, such as "slightly" or "rarely." This could indicate varying levels of engagement or interest in the content presented, with older participants possibly finding it more impactful or relevant.

Interactive versus Non-Interactive: The unanimous agreement across all age groups that interactive installations are more effective than non-interactive ones is a noteworthy finding. This aligns with the broader trend of the educational and entertainment sectors increasingly incorporating interactive elements to enhance engagement. These insights suggest that, regardless of age, interactive approaches hold considerable promise in conveying messages effectively. Furthermore, according to the field observation findings, analog and mixed-media interactive installations garnered more attention compared to their digital counterparts. This preference may stem from the richer interaction provided by analog installations, which offer multiple components to engage with, as opposed to digital installations that primarily rely on touchscreens.

These findings provide valuable insights into participants' perceptions of interactive installations with notable trends emerging across age groups. Despite the limited availability of interactive opportunities, participants displayed a consistent interest in visiting such installations when the chance arises, indicating a general enthusiasm for interactive experiences. Interestingly, the majority of participants perceived their experience as primarily only informative and didactic, suggesting a potential gap in providing entertainment and aesthetic values in these installations. This raises considerations for designers, educators, curators to enhance the engaging elements of interactive exhibits to cater to diverse preferences and learning styles. The evaluation of eco-messages highlights a nuanced perspective among age groups. Younger participants, while expressing satisfaction and hopefulness with eco-installations, do not necessarily find them entertaining. This suggests a need for a balance between informative content and engaging presentation to captivate the interest of younger audiences. On the other hand, older generations seem to anticipate a more significant impact on their daily lives from these installations, indicating a varying expectation of outcomes based on age. This can suggest that younger individuals might already possess knowledge of, or engage in, sustainable practices in their daily lives, possibly influenced by growing global awareness. Crucially, the unanimous agreement across all age groups that interactivity (both analog and digital) enhances the efficiency of installations underscores the potential of interactive elements in elevating the overall effectiveness of educational experiences. This aligns with broader trends in educational technology, emphasizing the importance of hands-on and engaging approaches to enhance learning outcomes.

In summary, these findings provide valuable considerations for the design and presentation of interactive installations within the environmental context, emphasizing the importance of balancing information with entertainment, understanding diverse age-related expectations regarding impact, and recognizing the universal positive perception of interactivity in enhancing educational experiences.

5. Conclusion

The study envisions creating connections between AI, interactivity, and museological learning to bolster informal environmental education, ultimately fostering behavioral changes towards more sustainable practices. The increasing popularity and unique capabilities offered by AI, such as real-time data processing, personalization, data generation, image recognition, position it as a valuable asset not only for enhancing entertainment value but also for the learning experience and the quality if the interactive engagement. AI algorithms facilitating interactive-direct interactions have the potential to provide highly engaging experiences. Moreover, with the capacity to generate data, AI can translate visitors' input into artistic creations, actively involving them as participants and placing them in the spotlight. Additionally, AI can create personalized learning paths, boosting the efficiency of the learning experience. Given that public interactive works range from light installations to sound sculptures, while many of these installations can be deemed entertaining, there is frequently a degree of uniformity among these works. Moreover, many public art installations are designed to appeal to social media users, prioritizing visually aesthetic experiences over meaningful interactive engagement (Olgen & Cucuzzella, 2023). AI can offer captivating, entertaining, and educational experiences in public spaces, reaching a wide and diverse audience. Furthermore, AI can be a valuable contribution to societal impact, potentially transforming the landscape of traditional public eco-art (Olgen & Cucuzzella, 2024). Certainly, the incorporation of not solely AI-enhanced digital interactions but also a variety of mixed-media components can significantly enrich the interactive engagements.

The theoretical framework and case study findings underscore the fundamental importance of the relationship between interactive installations, humans, and physical space in establishing meaning within a place-oriented approach. Designing effective interactive spatial installations necessitates fostering reflective and reciprocating engagements that promote a profound connection between individuals and their surroundings.

Equally important, incorporating AI technologies into artworks requires careful consideration of transparency, privacy, safety, and creative value. Therefore, integrating these aspects in the environmental context can contribute to an approach that significantly enhances the impact of the overall private and safe experience. Transforming public spaces into eco-didactic forums has the potential to profoundly impact individuals' awareness, knowledge, and behaviors, fostering a shift towards a more sustainable future. Creating public spaces as eco-didactic forums that highlights the consequences of the environmental crisis and propose sustainable solutions has the potential to enhance environmental awareness and encourage eco-action.

Our hypothesis points that Artificial Intelligence (AI) can enhance engagement and learning experiences in interactive eco-didactic public installations, potentially leading to eco-action. Our investigation into existing installations at the Biosphere environmental museum in Montreal revealed a limitation in entertainment and aesthetic values, a gap we believe utilization of AI and mixed-media components can meet. Studies exploring AI's role in interactive art and entertainment highlight numerous opportunities for increased audience engagement. AI enables audiences to become creators through generative capabilities, deepening their involvement in the experience. We believe this multisensorial approach could effectively promote environmental learning in the public realm. Moreover, the widespread interest in AI technologies presents opportunities to reach broader audiences and generate increased attention. Harnessing the power of AI for a greater cause -shaping the future of our planet- appears inevitable in our technology-driven world.

Nevertheless, the current limitations of the AI technologies include flaws, biases, lack of regulation, most notably, high energy consumption. It is crucial to acknowledge and address these limitations while actively seeking improved solutions. As we consider future research directions, a pivotal question emerges: How can we enhance intelligent engagement to foster methods that raise ecological awareness in a sustainable and energy-efficient manner? Delving deeper into this realm, our objective is to uncover new insights, advance understanding, and contribute to the development of innovative approaches that leverage AI technology to create engaging and environmentally conscious educational experiences.

Author Contributions

Conceptualization: B.O. and C.C.; methodology: B.O. and C.C.; validation: B.O. and C.C.; formal analysis: B.O. and C.C.; data curation: B.O. and C.C.; writing and original draft preparation: B.O.; writing, review, and editing: C.C; visualization, B.O.; supervision, C.C; project administration, C.C.; funding acquisition, C.C.

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Appendix 1

The layout sketch and photographs of the exhibition titled This is not umbrella, Biosphere, Montreal.

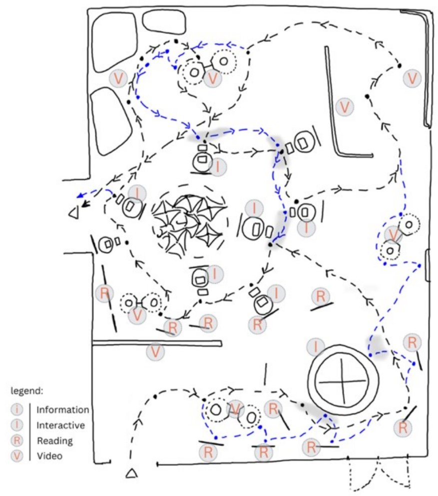

Figure 1. Layout sketch of the exhibition area, "This is not an umbrella" at Biosphere. Sketch: Olgen, 2023.

Figure 2. Exhibition areas of "This is not an umbrella" at Biosphere. Images: Olgen, 2023.

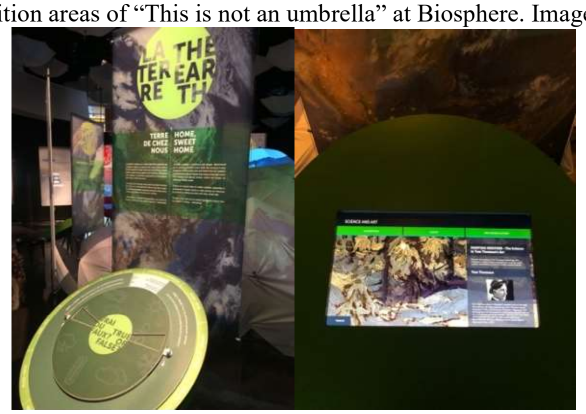

Figure 3. Analog and digital interactive installations at "This is not an umbrella" at Biosphere. Images: Olgen, 2023.

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Appendix 2

The layout sketch and photographs of the exhibition titled Eco Lab, Biosphere, Montreal.

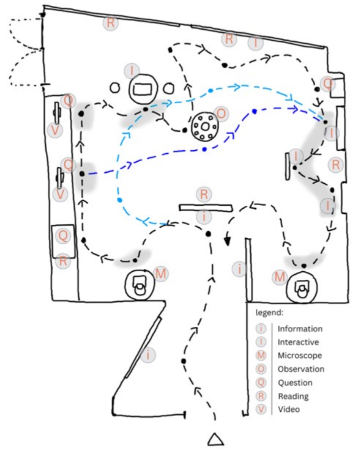

Figure 1. Layout sketch of the exhibition area, “Eco Lab” at Biosphere. Sketch: Olgen, 2023.

Figure 2. Mixed-media interactive installations at “Eco Lab” at Biosphere. Image: Olgen, 2023.