“Is this real?”: Assessing the Usability and Accessibility of Augmented Reality with People with Intellectual Disabilities

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Abstract. This paper assesses the perception of Augmented Reality (AR) by People with Intellectual Disabilities (IDs) when using assistive technologies in preparation for a museum visit. We designed and developed an application to test how AR can provide support and is perceived in this context. We organized a user study with 20 participants with IDs, all members of the same association. Three research visits, including focus groups, enabled us to assess the memorability of the contents before introducing AR technology and collect information about users' habits and preferences. Later, we assessed users' perception of AR individually during a test session and conducted a task-oriented hands-on session. Finally, we went to the museum with our users and gathered information about their preferences and choices when using AR in situ, constantly analyzing verbal and non-verbal feedback. We describe all our findings and discuss their implications in terms of guidelines for future design.

Keywords: augmented reality, accessibility, perception, user studies, people with intellectual disabilities

1 Introduction

Technologies such as Augmented Reality (AR) are becoming more popular as compatible devices are widely available, impacting how we can, for instance, learn new content and have fun. Despite its positive impact on engagement and learning, this technology is still not widely investigated with an accessibility focus, considering its benefits and limitations. Methods to produce inclusive and accessible solutions, such as co-design sessions, are time-consuming and require the involvement of different stakeholders and researchers to play various roles.

The complexity of the design process can impact how people with Intellectual Disabilities (IDs) can interact and benefit from AR.

In this work, we assessed the interaction of people with IDs with an AR application for informal learning. During three research visits, we organized focus groups to assess participants' previous knowledge and familiarity with the app's content. Then, we introduced the technology and collected their preferences. Later, we assessed their perception of AR elements with hands-on individual sessions. Finally, we went to the museum with them to contextualize the app and gather their preferences on the medium to be used during a visit.

Participants provided details about the size, color, and description of each 3D content. Participants did not have a precise preference for the realism of the 3D model, suggesting that incredible detail in the 3D model may not be necessary for the success of the AR application. Audio feedback and self-introduction provided a more immersive experience, while labels were less important but still provided an affordance. Some participants encountered issues with the device itself, highlighting the importance of adapting both the application and the device to ensure that software and hardware are accessible to users. Despite these challenges, participants quickly learned how to use AR technology to explore the model and became more confident in their ability to use the technology.

In this study, we contribute to the field of HCI in several ways. To begin, we provide insights into the preferences of users with IDs interacting with AR, in terms of elements that should be considered during the design. Secondly, the study proved the potential of AR applications in engaging users independently in informal learning experiences, by giving them the possibility to interact and explore independently the learning content. Lastly, the involvement of participants in the iterations of the design process proved the importance of co-design practices and highlight the roles they can take. By involving participants with IDs, designers can have access to their unique experiences and needs, thus allowing the development of more accessible and effective solutions.

This paper is organized as follows: In Chapter 2 we provided a background. Further, Chapter 3 introduces the design of our AR prototype. Chapter 4 presents the methodology used in this work. Yet, Chapter 5 shows the results we collected. Chapter 6 presents a discussion focusing on our research questions. Then, Chapter 7 introduces guidelines. Chapter 8, the limitations and future work. Finally, Chapter 9 concludes this paper.

2 Background

2.1 People with IDs and informal learning

ID is a neurodevelopmental disorder characterized by deficits in cognition and adaptive functioning [4]. The severity can vary greatly, with some people experiencing mild challenges and being able to live relatively independently with the right support, while others may need significant and daily assistance [35]. Assistance is needed in the context of formal and informal education, as learning can be difficult for individuals with IDs without accommodations or modifications [48] [29]. This is due in part to limitations in intellectual functions, which may include difficulties with abstract concepts, memory, problem-solving, planning, reasoning and generalization [4] [18].

Museums are regarded as informal learning environments [31]. Informal learning is defined as learning in a socially collaborative context where the learner can choose what and how to learn, with activities focused on meaningful tasks that do not require assessment or have a predetermined goal [13]. Museum participation, in fact, is voluntary, since visitors choose based on their interests [31], but also because visitors can plan their tour, creating a personal agenda [20]. This way, the learning process is connected to self-determination, which is critical for achieving positive learning outcomes [51] [24] and ensuring an improved quality of life and life satisfaction for people with IDs [51]. Furthermore, museums can stimulate involvement in cultural life and promote inclusion [36][40]. As a result, accessibility must be considered to let people with disabilities participate in museum experiences and the resulting informal learning [14] [36]. With this goal in mind, technologies can help to achieve accessibility [14] [42] through inclusive design that is based on real-world testing and application [42], calling for the involvement of the Human-Computer Interaction community.

2.2 AR for learning

AR is a rapidly growing field that is changing how people interact with the virtual and real world. It superimposes virtual information onto the real world, creating an immersive and interactive experience [2]. With the increasing availability of devices, AR is quickly gaining popularity [23] and has the potential to revolutionize a wide range of industries, including education [2]. In the field of education, AR has the potential to enhance the learning experience [41] [16]. Several studies have explored the benefits of AR in education and the results are positive [22] [2]. AR has been shown to increase motivation [47] and engagement [26] among students, as it presents virtual content in a realistic setting that makes learning more interactive and enjoyable. Because of this, its application has the potential to support individuals with IDs in their learning and development [6]. As previously stated, individuals with IDs may encounter obstacles with traditional learning methods [48] [29], and with AR they are able to experience virtual content in a way that is more accessible and engaging [12] [30]. This can increase their motivation and engagement in learning, and reduce their dependence on caregivers [27]. With AR, individuals with IDs are able to independently explore educational material, allowing them to take control of their own learning process and develop new skills [27], making this technology suitable for informal learning contexts. Indeed, AR interventions seem to be the most effective when conducted in informal learning settings as part of informal activities [22].

In recent years, various AR solutions for individuals with disabilities, particularly visually-impaired individuals, have been developed. These can aid in developing important life skills such as ironing, making the bed [10], using ATMs

[28], shopping for groceries [52], and even playing games [5]. Additionally, AR has been proven effective in improving literacy [32] [3] and numeracy skills [15] [30] [39], as well as in improving learning outcomes in other school subjects, such as scientific knowledge [38]. AR applications can be standalone or enhanced by incorporating other sensory stimuli, such as tactile [33] and olfactory feedback [37].

2.3 Accessible AR in museums

Accessible AR has been widely adopted in museums because of its *authenticity*, referring to its promise of meaningful experiences, *multisensory affordances*, which refer to its ability to provide multiple sensory modalities, *connectivity*, alluding to its ability to connect quickly with and within an environment, and *exploration* [43]. Some AR applications specifically designed for visually-impaired individuals enhance their museum experience by providing spoken descriptions of artworks [1]. The integration of AR technology not only makes the descriptions more interactive, but also empowers visually-impaired visitors to experience the art independently. In some cases, AR is combined with physical objects to offer a multi-sensory experience, further enhancing the overall experience [33] [37]. Hard-of-hearing individuals can also benefit from AR application, which fosters a more direct and authentic interaction with the artwork, promoting independent exploration and enjoyment of cultural heritage [7]. For individuals with IDs, museum AR applications provide assisted navigation [21] and a more interactive approach to cultural heritage, allowing for a more direct experience [49].

2.4 Designing accessible AR

The development of accessible and inclusive AR is essential for ensuring that everyone, regardless of their abilities, can enjoy the benefits that AR has to offer. One of the key considerations in creating accessible AR content is to follow accessibility guidelines such as the W3C Accessibility Guidelines (WCAG) [50]. These guidelines provide a framework for ensuring that digital content is designed in a way that is usable by as many people as possible, including those with disabilities. Indeed, accessibility features play a crucial role in learning and comprehension, both for individuals with disabilities and for everyone else. Visual accessibility, for example, can be achieved through the use of easy-to-read texts [19], which use simple language and short sentences, or Augmentative and Alternative Communication (AAC) [8] that uses pictograms. Auditory feedback, such as text-to-speech (TTS) technology [11], can also be used to make AR content more accessible. TTS technology is particularly valuable for non-literate individuals with IDs, but further research is needed to fully understand its impact on reading proficiency and comprehension [45].

Aside from following accessibility guidelines, it is critical to include people with disabilities in the design process in order to create truly accessible and inclusive AR content. Ongoing research is exploring methods for working and co-designing with individuals with intellectual disabilities (IDs) through focus groups, co-design, and active support [17] [9]. Participatory design helps to ensure that AR technology is designed with the needs of people with disabilities in mind, and that it can be used to improve their learning and development [44]. However, when developing AR applications, the majority of researchers still involve people with IDs as passive subjects [43], posing doubts on those applications efficacy.

3 Designing AIMuseum: the AR prototype

The development of AIMuseum aimed to provide a solution for people with disabilities to access and interact with cultural environments with ease [25]. In this paper, we are describing how we evaluated the usability of AIMuseum – the AR app – and discussing the implications of our findings.

The application was built using the Unity game engine and the C# programming language, and utilized the Vuforia API. We used QR codes as markers in our application, as they are easily recognizable, even in low light conditions, due to their black and white design. The QR codes were optimized for our needs based on preliminary testing, and the size and quality were adjusted accordingly. Additionally, we integrated a Screen Reader accessibility feature, using a UI Accessibility Plugin for Unity.

We engaged with educators to fit the AIMuseum experience with the learning objectives of the participants and the contents of the local museum. As a result, the application displays natural science content, focusing on dinosaurs, crocodiles, wolves, and deer. Each item was represented by a 3D model, a descriptive label, and audio feedback that provided a self-description (Fig. 1). Except for the dinosaur fossil, all of the selected animals were present in the museum as taxidermied specimens.

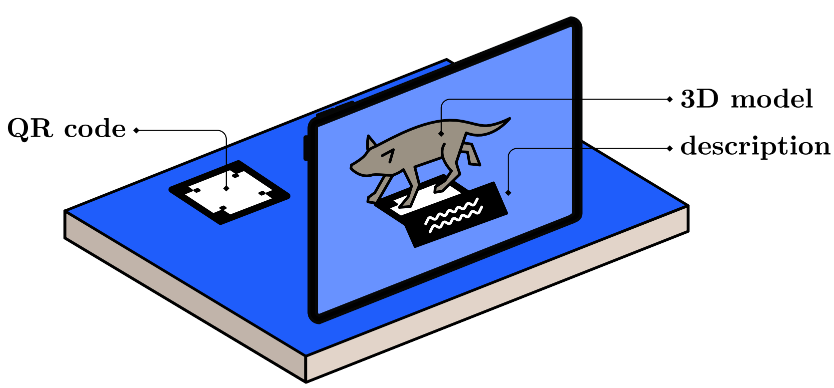

Fig. 1: Illustration of how the AIMuseum application works: it reads a QR code and generates a 3D model and description of the museum content.

To improve accessibility, the main menu includes a quick tutorial to help participants to use the application, and the possibility to change settings. Users can configure the text-to-speech volume and language, and the descriptive text font size.

When the app is launched, the user simply needs to point their device at a QR code to get information about the animal. The application will scan the code and provide further information, in this case, a brief description of the animal. The user can hear this information if the screen reader is turned on.

We evaluated several characteristics together with the participants in an iterative process for each feature. In particular, we considered the 3D model realism, size, and texture; textual description size, color, and background; voice (text-to-speech) regarding gender, tone, speed, and type.

4 Methodology

4.1 Rationale and research questions

This paper assesses the accessibility of AR by people with IDs when using assistive technologies before, during, and after a museum visit - an informal learning domain. While most AR research for IDs has focused on formal education, little is known about its effectiveness in informal settings such as museums.

The research consists of a user study that seeks to understand how people with IDs interact with AR and how they make sense of the information that it provides in the context of informal learning. We conducted three research visits (RV I, RV II, and RV III) to ANFFAS, an association that works with people with IDs in Trieste, Italy. There, we investigated the following research questions:

- **RQ1:** Which AR elements define the user's experience, and what characteristics of those elements are critical?
- **RQ2:** How simple is learning and remembering how to interact with AR?
- **RQ3:** What roles do participants play in the co-design of an AR application?

4.2 Procedure overview

To develop the procedure, we collaborated with ANFFAS. The research fit in with their daily learning activities and with their visits of museums and art galleries. The study was made possible by an agreement between the participant's association and the research organizations involved. With the participants' and/or guardians' consent, we did not store any sensitive information, only audio and video for data analysis.

Over three visits, lasting a total of nine days, we engaged with individuals with mild to severe IDs to understand their needs and preferences for an AR application. We used a combination of activities and focus groups to gather their feedback and improving the app between visits (Fig. 2).

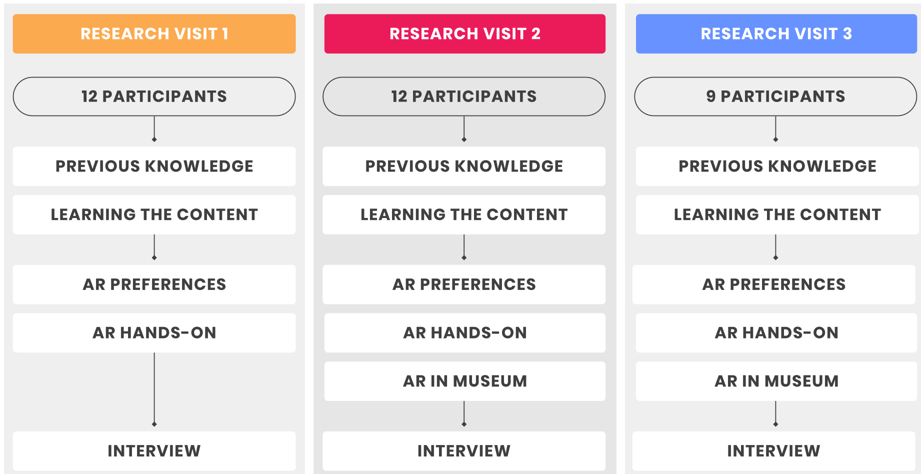

Fig. 2: The procedure of the three research visits presented in this paper.

Our visits started with focus groups to get to know the participants and understand their prior knowledge about the animals we planned to introduce. The group discussed the animals through written responses or drawings, based on the participant's abilities, and we reviewed the key details about each animal with an easy-to-read text. We used easy-to-read guidelines also in the context of interviews and oral communications [34]. During the study, we asked questions to assess their technology habits and preferences.

On each visit we evaluated the AR app with the participants, first introducing AIMuseum at the association. On the first visit, due to COVID-19 restrictions, participants couldn't go to the museum. Without directly interacting with the device, we showed them how AIMuseum worked and we asked them about the size and color of the text, and about the audio feedback parameters, such as the voice's tone, speed, and type (human or synthesized). We also asked about their preferred interaction method. A few participants did a hands-on pilot test. During the second and third visits, all participants directly interacted with the app on a tablet and gave their thoughts on what they saw and heard. On the second visit, we also presented 3D models with different textures, ranging from realistic to minimal, to gather their preferences.

On the second and third visits, participants were given the opportunity to explore AIMuseum in the museum we collaborated with – The Civic Museum of Natural History of Trieste, Italy. Participants were given 10 minutes to freely use the app, while looking at the full-size animal model provided by the museum. To better understand their preferred method of learning about the animals, we offered three options during the second visit (easy-to-read text, AAC text, and AIMuseum), and five methods during the third visit (easy-to-read text, AAC text, AIMuseum, tablet with ACCESS+, an accessible app for museums [46], and a multisensory experiences box).

Finally, after each user evaluation session, we conducted individual interviews with each participant to assess retention and gather additional feedback. Participants were asked to recall their experiences and share their likes and dislikes.

We collected the data using annotations, pictures, and video recordings. The data were analyzed by the researchers to identify emerging themes to be discussed. We used a Miro board to map the results and clustered themes in different and relevant categories for each research visit.

4.3 Participants

This study involved 20 participants who were all members of the ANFFAS association in Trieste, Italy. The participants are all adults, ranging from 21 to 63 years old, with 13 women and 7 men (Table 1). Only 5 participants attended all research visits.

Table 1: Participants' demographic and diagnostic information.

PID	Gender	Age	Research Visit	Presence	Context	Official Diagnosis
P1	Female	21	I, II and III	In Person	Association and Museum	Moderate Intellectual Disability
P2	Female	44	I, II and III	In Person	Association	Moderate Intellectual Disability
P3	Female	63	I, II and III	In Person	Association and Museum	Mild Intellectual Disability and Down Syndrome
P4	Male	32	I, II and III	In Person	Association and Museum	Moderate Intellectual Disability
P5	Male	49	I, II and III	In Person	Association and Museum	Mild Intellectual Disability
P6	Female	51	I	Hybrid	Association	Moderate Intellectual Disability
P7	Female	34	I	Online	Association	Mild Intellectual Disability
P8	Female	45	I	In Person	Association	Moderate Intellectual Disability and Down Syndrome
P9	Male	63	I	In Person	Association	Mild Intellectual Disability
P10	Male	28	I	In Person	Association	Severe Intellectual Disability
P11	Female	23	I and II	In Person	Association and Museum	Mild Intellectual Disability
P12	Female	55	I and III	Hybrid	Association	Moderate Intellectual Disability
P13	Female	22	II	In Person	Association	Mild Intellectual Disability
P14	Male	21	II	In Person	Association	Severe Intellectual Disability
P15	Female	47	II and III	In Person	Association and Museum	Severe Intellectual Disability
P16	Female	55	II and III	In Person	Association and Museum	Moderate Intellectual Disability
P17	Male	58	II and III	In Person	Association and Museum	Moderate Intellectual Disability and Low Vision
P18	Male	50	II and III	In Person	Association and Museum	Mild Intellectual Disability
P19	Female	53	III	In Person	Association and Museum	Moderate Intellectual Disability and Down Syndrome
P20	Female	55	III	In Person	Association and Museum	Moderate Intellectual Disability

Prior to the in-person visits, the researchers met with the participants via video call to get to know them and make them feel at ease with the research goal and process. Following that, participants and their legal guardians were asked to give permission to take part in the study. During the visits, we emphasized that they could opt-out at any time, and we reiterated the study's goal. The activities were kept short and breaks were included to ensure their comfort. The researchers were able to provide adequate time between sessions thanks to the assistance of educators who knew the participants.

At the first research visit, 12 participants were present. P8 and P9, who had recently recovered from COVID-19, joined online from a separate room. P7 attended fully online and was shown how AR works through a video call. P6, P7, and P11 also contributed with drawings during the first research visit. During the second research visit, 6 new participants joined and 6 participants from the previous visit were not available. Out of the 12 participants present, 9 went to the museum visit. Finally, on the third research visit, 18 participants previously attended one or both of our sessions, while 2 new participants joined. All of the 12 participants also went to the museum with us.

5 Results

5.1 User evaluation at the association

Previous knowledge and learning the content. On the first steps of each research visit – previous knowledge and learning the content – we made our participants free to express their ideas in the best suitable way, by writing, drawing, or simply speaking out loud (Fig. 3). Everyone was encouraged to participate. Each correct answer was followed by positive feedback from the educator, stimulating participants to keep engaged.

(a) Group discussion (b) Dinosaur content drawings

Fig. 3: Conducting the previous knowledge and learning the content sessions.

We used the whiteboard to put participants' contributions related to questions such as: What do you remember about the animal?; What characteristics did it have?; Where does it live? The questions slightly changed to adapt to users' needs and museum content. During the activity, the researchers were helping the educator and familiarizing themselves with the participants, including the analysis of their roles and contribution to the group discussion. Personality and abilities played an important role in participants' discussions: verbal and talkative participants always wanted to contribute. The educator managed the participation to achieve everyone's full potential, with collaboration from everyone and scaffolding whenever needed (prompting questions and fading when they achieved the goal).

First steps. Most participants interacted with AR for the first time and needed help to start the activity. P2 looked at the screen and, when she started touching the tablet, said: "Help, how do I do it?" On the other hand, P1 was so happy and proud of knowing how to complete tasks and interact with the device and the application. She also remembered details of the interface in the following RVs, including the label and its volume icon. Besides, some participants such as P1 demonstrated great independence during our sessions: "And we can start, so I will start now."

Emotions. We noticed several verbal and non-verbal emotional expressions during our work, from surprise to indifference, happiness to fear. The contents, mainly concerning the dinosaur and the crocodile, were not the most helpful in avoiding making some participants afraid. When we asked P2 if she was scared, she said: "A bit. I mean, almost not, because the crocodile is far away." P5 said when the audio played: "Wow, how do you do this?." This magical feedback was met with fun and engagement. On the other hand, some participants were puzzled, confused, or afraid of the content. The more they got comfortable with the application and us, the more they participated.

P16 recognized the crocodile and made a disgusted face saying: "I won't touch it; it's disgusting; I don't like crocodiles." When we asked if she would have preferred to see a dog, she answered: "Yes, a dog yes, but not a crocodile." In the case of P1, the fear was also mixed with surprise and amusement: "Oh gosh, amazing! But it made me a bit scared!" P18 was nervous during our AR evaluation session; he held the tablet and shook his hands. We believe this is because he feared dropping and ruining the device.

Interaction. We noticed difficulties related to dimensions and distances in AR. We asked participants to zoom in on some characteristics of the animal, such as teeth, legs, and tail. Participants brought the smartphone closer to themselves rather than the animal. Likewise, when asked to zoom out, the same issue arose. When using the phone to explore the virtual object, we noted a problem with rotating the device. The difficulty increased for P9, who is in a wheelchair with reduced space for mobility. Another challenge of using the smartphone is related to the position of participants' fingers, as sometimes they unconsciously block the camera and missed the AR experience.

The device's size plays an important role. In the experiment we ran during the second research visit, we used a tablet to provide a bigger screen size and avoid the fingers easily being placed over the cameras. Both devices have pros and cons since a tablet is heavier and harder to hold. It is also essential to have a QR code well positioned to avoid confusion. P17 was, on both research visits, swiping the QR code on the tablet instead of holding the device. Similar to what we do when swiping a card for payment. The QR code was also associated with previous experiences: P3 associated the QR code with a COVID-19 pass and P2 with a photocopy.

Feedback provided by participants on the overall experience proved meaningful too. P7 said, “It’s a good idea for someone who can’t read” and P3 was surprised, “Let’s say it must be screen magic.”

Audio: gender, speed, type and content. During all research visits, we associated each QR code with a 3D model, a label providing its description, and audio feedback with a self-introduction of the content with different parameters, changing the gender to man/woman, the speed to faster/slower, and the type to synthesized/humanized. The dinosaurs said, “Hi, I am a dinosaur” (brown) or “Hi, I am another type of dinosaur” (white), while the crocodiles “Hi, I am the Nile crocodile, and I live in some regions of Africa” (realistic texture) and “Hi, I am another type of crocodile” (light green). We chose to have the animals self-introduce themselves to evaluate the participants’ approval of text-to-speech technology and provide an alternative way to understand the text for non-literate participants.

In general, they appreciated having the audio feedback. When we asked, “What would you do if a digital dinosaur/crocodile talked to you?”, P2 said, “I would say: Hi, I’m P2”; P4 said, “Oh gosh, no”; P5 said “Makes me a bit scared. If it is a cute animal, ok, but a big one, no”; and P10 said, “It is weird, but I like when it talks.” When we tested the voice with different parameters, gender was indifferent to 72% of the participants, while 28% preferred a masculine voice. Most participants could notice when we changed the voice. 28% of the participants preferred a faster, 14% a slower voice, and 58% were indifferent about this aspect. The voice type seems not to get a consensus: 44% preferred a synthesized voice, 28% a humanized voice, and 28% were indifferent. When we asked specifically about the voices, we heard from P3 that “The voices were slow, they were not the clearest, but I could understand the words”, and from P15, “The voices were so sweet.”

Content: size, labels, and appearance. We asked our participants about the size of the 3D objects, comparing across versions, with one about 25% smaller than the other. Almost all of the participants noticed the first one was bigger. Specifically, P2 said, “Yes, I noticed the difference. That other one was big, and this one was small”, and made gestures with her hands to represent the size. When we asked what size they preferred, 28% of the participants were indifferent, while 44% preferred the bigger version and 28% the smaller.

We designed some 3D models with different colors. The dinosaur was available in white or brown, while the crocodile was in light green or with a realistic texture (Fig. 4). Analyzing the results of the first research visit, we found out that 72% preferred the brown dinosaur, while 14% picked the entire white, and 14% did not have any preference. P12 said she saw a plastic dinosaur, referring to the white version.

For the crocodile model, we first introduced the realistic texture (Fig. 4b) and later the light green color (Fig. 4a). After that, we asked if the second crocodile was different and how. 75% of the participants associated the first one with the real one, 17% thought the second was real, and 8% did not have an answer. P10 said "The last one was fake."

5.2 User evaluation at the museum

(a) Light green crocodile (b) Realistically textured crocodile

Fig. 4: Museum visit: participants interacting with the content 3D model.

We focused on participants' preferences when learning about the museum content during the museum visits (Table 1).

On the second research visit, we asked them to choose between AAC text, easy-to-read text, and AIMuseum. AIMuseum was chosen as the first choice by 4 participants. When it was not the first choice, it was the second choice of 4 other participants. It is also important to mention that the AAC text was the primary choice of the other 5 participants. The easy-to-read text was not the first choice of any of the participants. Only P16 didn't choose the tablet between the main choices. She said she had never used a tablet before and disliked technology. This participant often avoided our proposed activities, so we respected her decision to do not proceed with a specific session.

On the third research visit, we asked about their preferences between AAC text, easy-to-read text, AIMuseum, a multisensory experience box, and ACCESS+. All participants chose a high-tech solution as their first choice: 8 chose AR, and 4 chose ACCESS+. AIMuseum was the second choice for 2 participants, third choice for one, and last choice for one. One participant chose a low-tech solution as their first two choices.

5.3 Interviews

We interviewed participants individually after each user evaluation at the association and museum. We applied this method to analyze the retention from each activity, reinforcing what they remembered right after leaving the testing room and expressing their preferences.

On the first research visit to the institution, the educator asked our participants what the researchers showed them, and she provided more specific questions to trigger their memory if needed. Most of the participants could remember details of the dinosaurs. P12 said, "It was a plastic dinosaur", while P1 mentioned she saw "drawings with writings; they look like pictures made on a large white sheet; there was a dinosaur, you could see the body, the legs, the tail." P5 mentioned the dinosaur self-introducing was weird; it reminded him of 3D movies.

On the second research visit, questions were more specific about the crocodile model: What did the researcher show you?; What was the shape and color of the object?; Did the voice change, and what was the voice saying?; Did the text change, and what was written?; Could you interact with the application alone or did you need help?; Have you already seen any other animals with the researcher using the tablet? [to understand if they remembered the previous experience]; What did you like? What did you not like?. All of them could remind a crocodile as the animal they interacted with. Most of them also gave details about the 3D model: size, color, and voice. The label was not perceived as important; some participants could not read it. 7 participants could remember correctly details and order of interaction related to shape and color – surprising information given the complexity of the question. Most could also remember the sentences introduced with the audio.

When we asked if they needed help, most said they needed help to hold or control the tablet. P3 said, "I knew how to do it alone, but sometimes I needed help." We were also interested to know if they had a previous similar experience, and more than half of the participants could remember interacting with AR in our previous session. Most participants mentioned adjectives such as fun and beautiful to describe what they liked about the experience; on the other hand, about what they didn't like, most participants couldn't mention anything specific, while P1 mentioned the woman's voice and P11 the colors.

On the third research visit, we provided more general questions and questioned their level of independence: What did you do?; Did you have to do something by yourself?; Were you able to use the tablet alone?; What animals did you see?; Did you hear any noises?; and What was the experience like?. Ten participants answered the questions related to their experience interacting with the tablet. P1 said, "I had to see the wolf and the big reindeer. You had to move the tablet over the writing on top of the black thing called a QR code." And P18 mentioned, "It is a little scary because seeing it so big made me a bit tense. It was a surprise to see the animal." 4 participants mentioned that the interaction was easy and they could do it alone; 3 said it was difficult, and 2 needed help. P4 and P12 explained it was hard to focus on the QR code, and the content was "disappearing or running away"; they lost track of the tag and asked for help. Most participants were already familiar with the researchers; this time, some of them also mentioned having a lot of fun – highlighting the importance of the connection between researchers and participants.

During the museum visits, they had a follow-up individual interview to elicit extra feedback. We asked the 12 participants about what they experienced and which were their favorites. In particular, they recalled their interaction with the animal displayed by AIMuseum while mentioning the nearby stuffed animal, thus making the connection between virtual and real objects.

6 Discussion

It is important to emphasize the different roles each participant can play. Our 20 participants contributed differently to our co-design sessions; we could associate them as informants, evaluators, or designers. The emotions and contributions of stakeholders play an important role in any research involving people with IDs. This study could have different outcomes for diverse marginalized and under-studied communities.

6.1 3D models are the pivot point of the interaction

Most of the participants could provide details about the size, color, and voices of each 3D content. Most participants preferred realistic or colorful textures for the AR interaction. The size of the 3D content is also not a consensus – participants tended to favor the bigger versions, however, a bigger device, such as a tablet, could make them feel scared. This suggests that the interaction with the 3D models is the main touchpoint of the experience, prompting participants to engage with the digital content. However, despite the importance of the model, participants did not have a precise preference for the realism of the 3D model. This implies that incredible detail in the 3D model may not be necessary for the success of the AR application. Instead, the main goal of the AR app should be to provide an enhanced way of looking at the models, as visitors are often unable to freely move around items in the museum. It's also worth noting that the taxidermied animals in the museum can provide the necessary detail, while the AR app can focus on enhancing the experience by enabling visitors to interact with the models in new ways.

By providing audio feedback and self-introduction by the models, the AR app can provide a more immersive experience, catering to visitors who are non-literate or prefer audio feedback. Gender is not essential for audio content inside an AR application; the regular pace is preferred rather than a faster or slower speech speed; and audio type is not a consensus – we could go either with a human or synthesized voice. Lastly, the labels did not appear as important; participants were more interested in the 3D model characteristics. However, while the audio feedback was the preferred method of receiving information about the models, the label still provided an affordance that showed there was additional content beyond just the 3D model. Even though it was not as preferred as the audio feedback, having the label as a visual cue likely helped participants fully engage with the experience.

6.2 Interacting with AR is easy to learn and easy to remember

The study involved participants interacting with AR technology in three separate sessions over the course of a year. While not all participants were involved in every session, the majority participated in at least two sessions. The sessions were conducted months apart, allowing researchers to observe how well participants retained their ability to interact with the AR application.

The most common difficulty encountered by participants was related to movement around the model. Specifically, participants needed to move the tablet closer to the QR code to make the model appear larger on the screen. However, many participants believed they needed to move the tablet closer to their face to better see the model. This counterintuitive perception, which differs from their prior experiences of looking at images, is probably caused by the novelty of the encounter. In addition, some participants had issues with the device itself. For some, the smartphone was too small, making it easy to accidentally block the camera with their fingers. Conversely, the tablet was sometimes too heavy, requiring two hands to use. This shows the importance of adapting both the application and the device to ensure that software and hardware are accessible to users.

Despite these challenges, participants quickly learned how to use AR technology to explore the model. Over time, they required less help and became more confident in their ability to use the technology. Participants remembered how the QR code and the device interacted, allowing them to recall how to use the technology easily. Although some participants required a brief recap on how to explore the model (P3: "I knew how to do it alone, but sometimes I needed help"), it did not negatively impact their experience. AR technology is a usable and friendly tool for providing content in a new way. It does not need prolonged use too; it has the potential to be a powerful tool for engaging users and enhancing their learning experience.

6.3 Participants can act as informants, evaluators and designers

Collaboration and participation are critical components in developing usable and effective solutions, especially when designing for marginalized and understudied communities. Inclusive design practices aim to involve all stakeholders in the design process to ensure that the resulting solutions are usable and meet the needs of all users.

The value of the participation of people with IDs is significant. As demonstrated by the results of the co-design sessions undertaken in this study, these individuals have unique insights into their experiences and needs, which can inform the design of solutions that are more accessible and effective. Additionally, the active participation of users with intellectual disabilities in the design process can help break down stereotypes and misconceptions about this community and empower them to shape their own experiences actively.

In the context of usability, during the co-design of this study, participants took on spontaneously different roles, such as informants, evaluators, and designers. As informants, participants provided valuable insights and feedback that can inform the design process. As evaluators, participants assessed the usability and effectiveness of the solution, identifying potential issues and areas for improvement. As designers, they were involved in the actual design process, providing input and ideas that shaped the solution through its iterations.

7 Guidelines

From the analysis and discussion of our data, we can extract a few guidelines to address the usability of AR-inclusive applications (G1 to G4) and guide their co-design (G5 to G8) with people with IDs. In order to enhance the usability of inclusive AR applications:

- **G1**: Prepare QR-codes with different colors and sizes
- **G2**: Provide devices with different weights and screen sizes to accommodate participant's needs
- **G3**: Include AAC, text-to-speech, and easy-to-read texts or other strategies to facilitate participant's comprehension and involvement (e.g. Task Analysis)
- **G4**: Give choice to express the participants' creativity in their own way

When designing AR-inclusive applications for and with ID participants:

- **G5**: Encourage different forms of expression and respect the pace and time for each participant to contribute and feel part of the process.
- **G6**: Prepare different questions and materials to adapt to participants' needs
- **G7**: Provide open questions to avoid the yes/no answer
- **G8**: Get to know your participants; they need to be comfortable before they can fully collaborate with you

This is not meant to be a complete list but just an initial step toward defining a flexible framework for designing inclusive applications.

8 Limitations and Future Work

The limitations of this work are primarily related to the context. At the association, we did not have a specific room to conduct the assessments, and we had to consider the influence of museums not being familiar places for the participants. Most participants could read and write, but not all of them. This impacted the interaction with labels and their preference for easy-to-read or AAC texts. Also, familiarity with technology was decisive in evaluating individual experiences. In future works, we plan to combine gamification with AR technology, helping participants to discover new content.

9 Conclusions

Our participants' rich feedback and insights were essential to co-design more inclusive and accessible technologies. We extracted guidelines based on our findings to be shared with other researchers.

This research opens the possibility of designing new AR applications for museums and suggests different factors influencing how people with IDs use AR. Working with individuals who have IDs is both incredibly gratifying and demanding. To ensure their comfort at all times, we concentrated on their needs and adjusted the study as necessary.

Finally, it is essential to recall that the participants have different diagnoses on the spectrum of IDs and can also have other conditions, some not even mentioned because it was out of the scope of this work. Thus, we need to learn with and from them, respecting and understanding their contribution.

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