Engaging Visually Impaired People in Science Museums Through an Immersive Workshop: Practices, Challenges, and Opportunities

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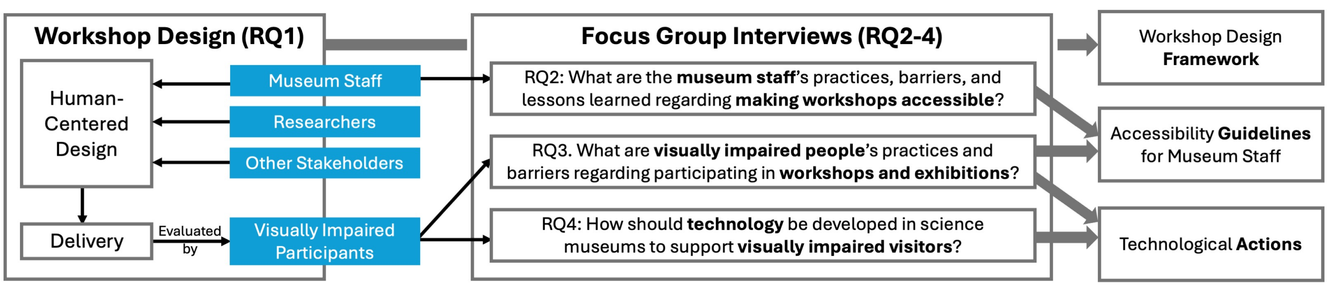

Figure 1: Our approach consists of two parts: (1) Workshop design (addressing RQ1), which followed a Human-Centered Design process involving multiple stakeholders, and was delivered and evaluated by visually impaired participants; and (2) Focus group interviews (addressing RQ2–RQ4) with museum staff and visually impaired workshop participants. Together, they informed a workshop design framework, accessibility guidelines for museum staff, and directions for technological action.

ABSTRACT

As a crucial place for informal learning, science museums feature multimedia exhibitions and themed workshops. However, their accessibility for visually impaired visitors remains underexplored. This study leverages workshops in science museums as a platform to enhance accessibility. We iteratively designed an accessible workshop titled *"Learning by Touch–Life in Space"* in collaboration with diverse stakeholders. Once launched as a recurring museum program, 28 visually impaired participants attended over the course of a year and provided feedback on its accessibility. Additional insights were gathered through focus group interviews with six workshop staff and seven participants, focusing on current practices, accessibility challenges, and technological possibilities for workshops and exhibitions. Our findings contribute: (1) a participatory and adaptive framework for accessible science workshop design; (2) practical accessibility guidelines for museum staff on training, co-development, and content planning; and (3) actions for applying emerging technologies to support flexible, social, and enjoyable science experiences for visually impaired visitors.

Author Version

CCS CONCEPTS

• **Human-centered computing → Empirical studies in accessibility**; *Accessibility design and evaluation methods.*

KEYWORDS

Science Workshop, Exhibition, Accessibility, Blind, Museum staff, Inclusive design, Focus group, Assistive technology

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1 INTRODUCTION

Science museums play a critical role in informally communicating science to the public [15, 31, 36]. They distinguish themselves from traditional museums by offering an abundance of scientific topics [12, 26, 70] and multimedia exhibits for a better understanding of the topics [16, 20, 44]. Although such features have triggered the curiosity of sighted visitors, they have posed broad accessibility barriers to visually impaired people. Prior studies have broadly investigated accessibility in museums in general [22, 68, 109, 110] and art galleries [8, 19, 48, 69], focusing on challenges faced by visually impaired visitors in accessing information, navigating spaces, and understanding artworks. They emphasized the importance of access before, during, and after a visit [22, 110], highlighted the need for assistive technologies [8, 69, 109], and called for collaboration between curators and visually impaired visitors to ensure practical access [19, 48, 68]. However, they often overlook specific context and characteristics of science museums. Investigations into science museum accessibility have been limited, with only a few studies exploring how visually impaired individuals engage with science exhibits [32, 90].

Nevertheless, participatory workshops at science museums provide an agile way to engage in science. Several characteristics have defined the workshops at science museums [41, 50, 59]. First, they have focused themes, narrowing topics like physics, chemistry, or technology into manageable scopes. Second, they include staff-facilitated activities, reducing barriers for participants must overcome on their own. Third, they promote social interaction through group-based discussion, encouraging participants to contribute local knowledge to scientific topics. However, the design of these workshops often fails to consider the needs of visually impaired individuals, limiting their participation and the opportunity for museum staff to gain experience in creating accessible workshops, yet few studies have explored their accessibility despite their potential. Our study addresses this gap by leveraging workshops as platforms for including visually impaired individuals in science museum experiences. These workshops, with their focused format, staff support, and opportunities for social interactions provide an ideal environment for engaging visually impaired participants in science topics. On the designer side, workshops provide a more manageable alternative to broader exhibitions, serving as effective test beds for exploring accessibility challenges. Our study specifically investigates the following research question as a first step:

- RQ1: How can we design an accessible workshop to engage visually impaired people in a specific science topic?

In collaboration with museum staff and various stakeholders, including visually impaired high school students, experts in the workshop's subject area, teachers of visually impaired students (TVIs), and people who are blind or have low vision (BLV), we developed the workshop titled *"Learning by Touch–Life in Space."* The workshop takes up the narrative of traveling to the International Space Station, and it includes tactile explorations, bodily engagement in exhibits, travel through the museum, and a discussion linking space technologies to participants' personal experiences. While space camps have long taught BLV students about space [11, 57, 96], our work builds on these practices with innovations in the museum context: (1) condensing the experience into a 2-hour cohesive narrative using museum resources, (2) developing accessibility and communication skills for museum staff who are not TVIs, and (3) designing for a broader public audience. Our approach addressed the full process, from theme formation to public delivery, and highlighted the value of iterative refinement with stakeholder feedback, tactile prototyping, and live facilitation trials.

The successful deployment of the workshop paved the way for deeper discussions among visually impaired participants and museum staff about accessibility of existing workshops for the general public[1] and exhibitions. The investigation was structured by the following questions:

- RQ2: What are the museum staff's practices, barriers, and lessons learned regarding making workshops accessible?
- RQ3: What are visually impaired people's practices and barriers regarding participating in workshops and exhibitions?

Moreover, the range of barriers and the complexity of the science museum environment cannot be addressed by facilitation alone. Rapid advances in accessibility technology present new opportunities and align well with the innovative nature of science museums. Recent work highlights tools such as audio descriptions [29, 49], conversational agents [1, 2, 84], navigation and mobility support [25, 55, 62], tactile graphics [45, 82, 87], interactive 3D models [86, 99, 113], automatic image recognition [4, 63, 65], and a tool to call museum staff [55]. Despite these innovations, how such technologies can be adapted to science museums remains underexplored, especially from the perspective of potential users. To address this gap, we next identify and evaluate technological opportunities based on accessibility issues surfaced earlier, guided by the following question:

- RQ4: How should technology be developed in science museums to support visually impaired visitors?

Focus group interviews revealed gaps in workshop accessibility. Staff called for clearer guidelines, training, and co-development, while participants expressed both interest and hesitation. The findings underscored the need for direct communication and sustained collaboration between stakeholders. Additional insights pointed to broader challenges in museum engagement, including limited independence, restricted opportunities for exploration, and social barriers to using assistive tools. While supportive technologies have been anticipated, participants emphasized the need for more holistic, enjoyable experiences and technologies that support social dynamics.

Based on the findings, this work presents a preliminary framework for designing accessible science workshops, along with practical guidance for museum staff and strategies for applying emerging technologies. The main contributions of this work are:

[1] We refer to them as "general workshops" in the paper.

- A participatory and adaptive framework for accessible workshop design, including specific strategies to support inclusion and engagement, grounded in the real-world design and deployment of a science workshop.
- Practical guidelines for museum staff to enhance accessibility through training, co-development with the visually impaired community, and accessible content planning.
- Approaches to translating technological opportunities into action, demonstrating how emerging tools can support flexible pacing, social interaction, and enjoyable exploration.

Together, these contributions aim to advance the design of inclusive science museum experiences and foster deeper collaboration between technologists, museum staff, and the visually impaired community.

2 BACKGROUND AND RELATED WORKS

2.1 Science Learning for Visually Impaired People

Every child should be entitled to education, irrespective of disabilities [115]. Science education is crucial because it enhances children's knowledge, stimulates curiosity, and aids in developing personal and social skills [83]. While the educational goals of visually impaired children align with those of sighted peers [40], science learning often relies on visual aids and hands-on activities, posing challenges for visually impaired people, who require tailored support to address specific needs [34, 115]. Educational tools should cater to their perceptual needs, incorporating tactile graphics, models, real objects, and accessible science equipment to facilitate active participation [83, 104]. Educational settings must be encouraging, adaptable to learner pace, and attentive to psychological and social needs [34, 101]. Unfortunately, there is often a lack of comprehensive support systems for visually impaired students in inclusive science classes, resulting in lower STEM involvement [13, 103] and a high possibility of lagging behind their sighted peers [60].

Beyond education in classes, informal science learning plays a significant role, especially for children under 14 who are forming engagement or interest in science [81]. Investigative and hands-on workshops are crucial for them to develop interest and engagement with science [81, 104]. Teaching visually impaired students the abstract concept of space has a long history, often facilitated through space camps. These informal learning opportunities provide (1) real-world experiences, such as using telescopes and space shuttles [11, 57], (2) 3D models and tactile materials [10, 39, 91, 108], and (3) hands-on interaction with assistive tools, such as LabQuest, JAWS, and Text-to-speech [57, 96, 107].

While science camps offer valuable opportunities [10, 104] for visually impaired children, they are limited in frequency and typically focus on younger age groups. From a design perspective, such programs are usually developed by well-resourced institutions and accessibility specialists such as TVIs. The development processes behind these activities are rarely documented or shared, making it difficult for other institutions to adapt or learn from their methodologies. For adults, opportunities for informal and lifelong science learning are also necessary for enhancing science literacy [18, 42] and empowerment [73]. Science museums play an important role in providing informal learning opportunities to all citizens [18, 54, 59], yet they often fall short in providing accessible experiences to visually impaired visitors.

Our research addresses this gap by exploring the practices and processes in designing an accessible science museum workshop. In doing so, we aim to develop scalable and transferable strategies that support inclusive informal learning for a broader age range, including both children and adults.

2.2 Science Museums Characteristics, Accessibility, and Research Gaps

Science museums are crucial places for communicating science informally to the public. Different from conventional museums that preserve and showcase collections of art and artifacts [27, 74], science museums foster public engagement with science through innovative exhibits that span static, dynamic, and hands-on experiences [16, 20, 44] while integrating cutting-edge technologies [44, 112]. While such features enhance public engagement [20, 24, 95], they can exclude visually impaired visitors unless they are adapted for sensory, physical, and cognitive accessibility [35, 97, 111, 112].

Beyond exhibitions, science museums feature participatory workshops across domains, such as physics and chemistry [6, 28, 41, 50, 59]. These themed workshops can deepen domain-specific awareness and interest [6, 18, 42], catalyze social interactions among diverse stakeholders in forming opinions [18, 41, 59], and bring local knowledge to scientific developments [18, 30]. However, they often neglect the needs of visually impaired individuals. The activities mostly available to individuals with disabilities have been conventional exhibition tours modified for their disability rather than for their interests [117].

The pressing need for more inclusive science museums arises not only from legal mandates [66, 92] but also from the recognition that individuals with disabilities can offer unique insights to shape the future of science, technology, and society [5, 51, 71]. Accessibility research has largely investigated collection-type museums [109, 110] or art galleries [8, 69]. Vas et al. proposed frameworks for accessibility throughout a visit to a museum, aiming to enhance sensory, intellectual, and physical accessibility [111]. Sylaiou et al. conducted a survey on technology-based assistive tools for visually impaired visitors to cultural heritage sites, identifying a number of research opportunities aimed at multimodal access [105]. Focusing on art museums and galleries, Li et al. investigated blind people's experience and proposed design considerations for presenting art content and fostering social communication [69]. Butler et al. developed and evaluated accessible gallery experiences, providing insights into resource adaptation, interpretation, experience, and programming from the viewpoints of BLV visitors and museum staff [19]. Huang et al. examined the difficulties curators face in employing assistive technologies, highlighting the lack of standards and the need for comprehensive approaches that include stakeholders like curators, artists, and accessibility experts [48]. Nevertheless, a small amount of research has focused on science museums. When Rocha et al. investigated science museum accessibility in Latin America, they identified significant gaps in physical, attitudinal, and communicational conditions, suggesting that implementation lags behind the awareness of accessibility [32, 90]. However, earlier work neither investigated the design of accessible workshops nor proposed methods to address accessibility gaps specifically in science museums, underlining the need for ongoing dialogue among stakeholders to enhance accessibility in science museums.

On the one hand, we draw on key accessibility insights from prior work on museums to inform science museum workshop design. These include the importance of providing rich tactile interactions to support non-visual exploration [85, 110], addressing the challenges of limited institutional resources [19, 48], and designing for sustained engagement [19, 110]. On the other hand, we extend these findings by examining science museums' specific affordances and constraints, using workshops and exhibitions to bridge accessibility gaps and contextualize inclusive design approaches.

2.3 Technology Support for Museums

Technology advances have improved the lives of visually impaired individuals. Museums can benefit from relevant applications that aid navigation, information provision, and communication during all phases of a visit.

Before visits, screen readers enable the visually impaired to access web information on mobile devices, including image descriptions with rich presentations [65, 67, 77]. Accessible maps aid pre-visit spatial learning, with 3D maps preferred over tactile graphics for clarity [46, 47]. Interactive maps, using physical buttons [46], touch screens [38, 113], or computer vision [100] to enable audio-tactile interaction, support autonomous exploration and construction of a mental map before the visit. Furthermore, stackable maps [78, 93, 113] allow learning external structures and floor layouts to build a three-dimensional mental map before the visit.

For on-site navigation, mobile applications, smart canes, and robotics have been developed to guide visually impaired users to their destinations and help them avoid obstacles [58, 61, 72]. These innovations have been adapted for museums to facilitate wayfinding among exhibits and improve autonomy [9, 55, 75].

For information provision, accessible audio guides such as Open Art [52] and Navilens[2] offer interfaces for selecting accessible audio descriptions of artifacts. Interactive systems like MusA provide detailed artwork descriptions through touch interfaces on smartphones [3]. To support learning about exhibits, tactile graphics on swell paper [79, 118] and 3D printed models [7, 89, 116] have been developed. Race et al. further identified that while most museums were producing low-fidelity touch objects, accessibility experts preferred high-fidelity ones [85]. Although 3D printed models with braille labels have been proposed [76], considering space limitations and varied braille literacy [80], interactive 3D models with audio labels have emerged as more effective in enhancing engagement and enabling independent learning. Tools like Markit and Talkit allow creation and interaction with audio-annotated 3D models [98, 99]. Hierarchical explorations guide users through complex structures via audio feedback [86, 114]. Additionally, a multi-sensory experience featuring haptic, olfactory, auditory, and thermal elements was proposed to enhance engagement with visual art [21].

Communicating science should go beyond receiving information; it involves inquiry and sharing the public's local knowledge [18]. Technologies facilitating communication include VizWiz [14] and conversational crowd assistants [64], enabling visitors to ask questions and receive instant human answers. Conversational agents have also been proposed to facilitate inquiries while touching 3D models [88]. Kayukawa et al. introduced a communication tool on navigation robots, allowing users to request information from museum staff directly [55]. Furthermore, advances in large language models and Visual Question Answering now allow chatbots to respond to inquiries about images[3] and videos [102], greatly enhancing the accessibility of visual contents.

Despite their potential, these technologies remain underexplored in the context of informal learning at science museums. Our work investigates the possibilities to meaningfully integrate technological advances in museum accessibility and science communication into science museum settings to support non-visual exploration, enhance visitor engagement, and accommodate diverse access needs.

3 DESIGN OF AN IMMERSIVE WORKSHOP FOR VISUALLY IMPAIRED PEOPLE

We conducted a year-long, iterative design process using a Research Through Design approach [37, 119], engaging a range of stakeholders to develop an accessible museum workshop for visually impaired visitors. The workshop was envisioned as a recurring program designed to welcome several participants each time across a wide age range, from school children to adults. The core design team included four science museum staff members and two accessibility researchers. Among the museum staff, two specialized in museum management, while the other two focused on workshop design and facilitation. The researchers contributed expertise in developing accessible artifacts and technologies for people with visual impairment.

3.1 Study Method

The design process adhered to the three-phase framework of Human-Centered Design (HCD) [94] utilized IDEO' HCI toolkit: Inspiration, Ideation, and Implementation [106]. It followed a multi-phase participatory design (PD) approach, where distinct stakeholder groups contributed at different stages yet iteratively informed one another's work, a configuration documented in recent PD studies [33, 56]. As summarized in Figure 2, the three phases consisted of:

- Inspiration: Understanding user needs and design opportunities through observation and discussions with a group of TVIs and students.
- Ideation: Collaboratively forming the narrative and materials with space science experts and TVIs, some of whom had lived experience of blindness.
- Implementation: Refining facilitation methods and communication strategies with visually impaired museum visitors.

[2]https://www.navilens.com/

[3]https://www.bemyeyes.com/blog/introducing-be-my-eyes-virtual-volunteer

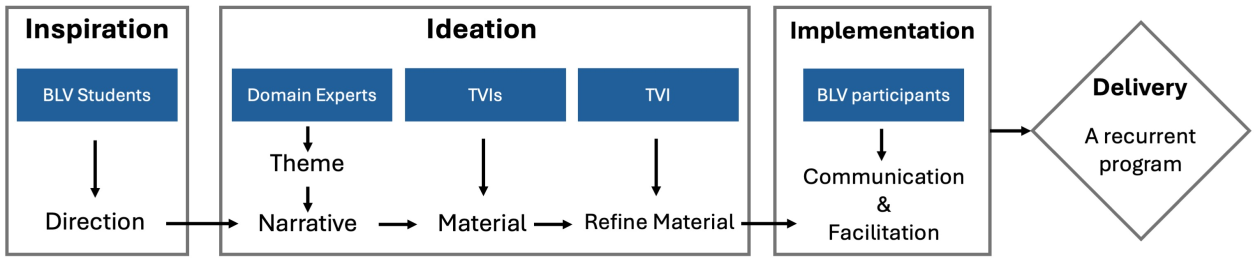

Figure 2: Overview of the process and design iterations. The blue boxes highlight our collaborators at each phase, and the arrows below summarize the outcomes of each step toward the development of the workshop through participatory and iterative engagement.

3.2 Inspiration: Understanding Context and Needs within Available Resources

The museum where the design took place features a wide range of science-themed exhibitions. Initially, a school for visually impaired students organized a visit for their high school students (five legally blind, ten with low vision) due to their interest in scientific topics. This visit was positioned as a contextual inquiry into how visually impaired people explore, interpret, and connect with science exhibitions in situ. The visit included three parts: (1) a guided tour led by museum staff, highlighting existing accessible features such as tactile models and verbal explanations; (2) an independent museum exploration phase; and (3) a facilitated group discussion involving students, teachers, and design team members. This final participatory reflection surfaced three fundamental needs:

- Cognitive Load and Depth Preference: The museum's broad range of topics was overwhelming. They preferred a focused, in-depth exploration of a single theme (e.g., space, biology) rather than a shallow survey of multiple topics.
- Value of Tactile Interaction: Tactile exhibits were valued as the most effective way to "get closer to" and "form a mental image of" abstract scientific concepts. Conversely, exhibits presented behind glass were viewed as inaccessible and disappointing.
- Desire for Continuity and Immersion: Rather than isolated facts or disconnected information, participants expressed a desire for coherent, immersive experiences that enabled them to visualize and internalize scientific content as a complete narrative.

Due to practical constraints related to available resources, namely, the physical infrastructure, existing exhibitions, and staff expertise within the museum, the design team took the lead in narrowing the focus into exhibitions that foster tactile and embodied engagement. Specifically, the team selected the "International Space Station (ISS)" exhibition as the basis for the workshop. This exhibit includes a full-scale replica module featuring a tilted floor, airflow simulation, exposed equipment, and two immersive chambers that are typically inaccessible to touch. Its existing tactile and spatial affordances, combined with its potential for multisensory storytelling, made it a strong candidate for delivering a high-quality, engaging experience.

3.3 Ideation: Co-Creating the Theme, Narrative, and Materials

This phase focused on collaboratively shaping the content and tactile materials for the workshop, with participatory input from domain experts and TVIs.

3.3.1 Developing the Theme and Narrative with Domain Experts. We conducted two structured brainstorming sessions with four museum experts in space science. In the first session (75 minutes), experts individually generated ideas using sticky notes (45 min), followed by a group discussion and thematic clustering (30 min). Starting from the museum's existing ISS exhibition, ideas were grouped into four categories:

- **Experiencing Life Inside the ISS:** Participants can explore typically inaccessible areas like the bedroom and restroom, simulate gravity shifts on a tilted floor, and navigate using walls and handles.
- **Exploring the Space Environment:** Tactile access to the ISS exterior allows participants to feel spacewalk. Simulations could be designed to give a sense of the spatial distances and perspectives, like viewing Earth from space.
- **Tactile Interaction with Models and Graphics:** Creating models and tactile graphics related to the ISS can help visualize abstract concepts and structures that are too big to touch.
- **Active Participation Workshops:** Group discussions that invite participants to reflect on the space theme can encourage engagement, understanding, and opinion formation.

In the second session (60 minutes), participants refined these ideas into a cohesive narrative: *"Learning by Touch—Life in Space."* The workshop was divided into three segments: tactile introduction, simulated expedition, and reflective discussion. We structured the experience into seven sequential steps:

(1) **Space Overview:** Introduing the vastness of space and the distances between Earth and the ISS, helping participants visualize the concept of space.
(2) **ISS Exploration:** Participants delved into the overall picture and details of the ISS, the largest man-made structure in space.

(3) **Journey of a Rocket:** We depicted a rocket's journey, detailing its departure from Earth, docking with the ISS, and its return.
(4) **Virtual Space Travel:** The participants were guided to walk through the Oval Bridge, a walkway encircling the Geo-Cosmos exhibit, which mimics the Earth as seen from space.
(5) **ISS Module Externals:** Participants explored a replica of the ISS module in the exhibition, engaging in a tactile exploration of its exterior.
(6) **ISS Module Internals:** The journey culminated in an immersive experience inside the ISS module, where participants could interact with the environment as if they were onboard.
(7) **Reflective Group Discussion:** Encouraging participants to reflect on the experience, linking their own lives to the theme with a question: "If you were going to the space station, what essentials would you take?"

3.3.2 Co-Designing Materials with TVIs. Based on the workshop narrative, we developed tactile artifacts for each step, prioritizing fabrication over interactive technologies due to (1) museum constraints on electronic deployment, (2) limited workshop time for technology onboarding, and (3) the need for robust, cost-effective materials suitable for long-term use. The materials included:

- Tactile Map (Step 1): A raised-line map of Japan with concentric circles to show distances to space (100 km) and the ISS (408 km), as shown in Figure 3.
- 3D Printed ISS Model (Step 2): Adapted from a public 3D model[4] with simplified details and thickened panels for durability. A magnet was added to enable simulated shuttle docking.
- 3D Printed Falcon 9 Rocket Model (Step 3): Segmented a public 3D model[5] into Stage 1, Stage 2, and the Crew Dragon's trunk and capsule, all magnetically connected for easy assembly and docking simulation.
- 3D Printed Oval Bridge Model (Step 4): Illustrated the bridge's circular, ascending path around the Geo-Cosmos display.
- 3D Printed ISS Exhibition Model (Step 5): Depicted the module's exterior and cutaway interior, helping participants grasp the full layout of the life-size exhibit.

To further develop the materials, we conducted a two-hour session with four TVIs (one blind, three sighted from different disciplines). The session included 30 minutes on Steps 1–3 in a side room, 30 minutes exploring Steps 4–6 inside the museum, and a 60-minute feedback discussion. TVIs found the small-scale models (Steps 4 and 5) effective for visualizing the full-scale exhibits, while also identifying three key areas for improvement.

- Connecting Concepts to Familiar References: The tactile map (Step 1) lacked dimensionality. Suggestions included using a basketball as a scale model of Earth and referencing familiar classroom props (e.g., a bath mat for texture) to anchor abstract concepts. These insights informed updates to Steps 1 and 5.
- Encouraging Independent, Hands-On Interaction: The modularity of the rocket model and the docking process was praised for enabling self-directed learning. TVIs recommended extending this approach to other steps, prompting revisions to Steps 2 and 3 to support independent manipulation.
- Full-Body Engagement: TVIs noted participants should be encouraged to explore with their entire body: tapping ceilings with white canes, gripping wall handles, and entering enclosed chambers. These ideas informed refinements to Step 6.

In response, we implemented the following changes:

- Earth and Space Analogy (Step 1): Using a basketball to represent Earth's scale, with 1.5 mm for space and 7 mm for the ISS above the fingertip.
- Hands-on Technical Operations (Steps 2–3): Added magnets to the ISS model for separating modules. Updated the rocket with movable legs to allow participants to simulate vertical landing themselves.
- Material Representation (Step 5): Introduced an aluminum bowl to simulate the ISS's surface texture.
- Spatial Immersion (Step 6): Encouraged full-body interaction, including touching ceilings with canes, gripping handles, and entering replica chambers.

These refinements reflect an iterative design process grounded in TVI expertise, emphasizing the value of analogies, active engagement, and embodied learning for enhancing spatial and conceptual understanding in BLV-friendly museum settings.

3.3.3 Further Refinement with a Former TVI. To further improve our materials, we conducted a two-hour visit to a Hands-on Teaching Materials Library operated by a former TVI. The session included: (1) a 30-minute tour of the library's tactile teaching tools, (2) a 30-minute presentation of our workshop materials, and (3) a 45-minute co-reflection on possible refinements.

The library featured a range of tactile resources, from low-fidelity graphics to detailed 3D models. Two key strategies emerged from the discussion:

- Human-Scale Analogies: Emphasizing familiar body-sized references to anchor abstract concepts.
- Multi-Fidelity Modeling: Supporting layered understanding through sequential tactile formats, such as a simplified 3D overview, followed by detailed relief, and ending with a take-home graphic.

These strategies highlighted the importance of scaffolding learning through tactile exploration that progresses from macro to micro, and from orientation to memorability. Based on these insights, we implemented three refinements:

- Laser-Cut ISS Silhouette (Step 2): Introduced before the 3D model to provide an accessible spatial overview.
- Scale Reference Figure (Step 2): A small human figure was added to clarify proportion.
- Gift for Memory Reinforcement (Step 6): A pocket-sized 2D ISS silhouette was provided to support post-visit memory retention.

These refinements further supported tactile orientation, scale comprehension, and lasting engagement.

[4]https://www.thingiverse.com/thing:4203169
[5]https://www.thingiverse.com/thing:4503875

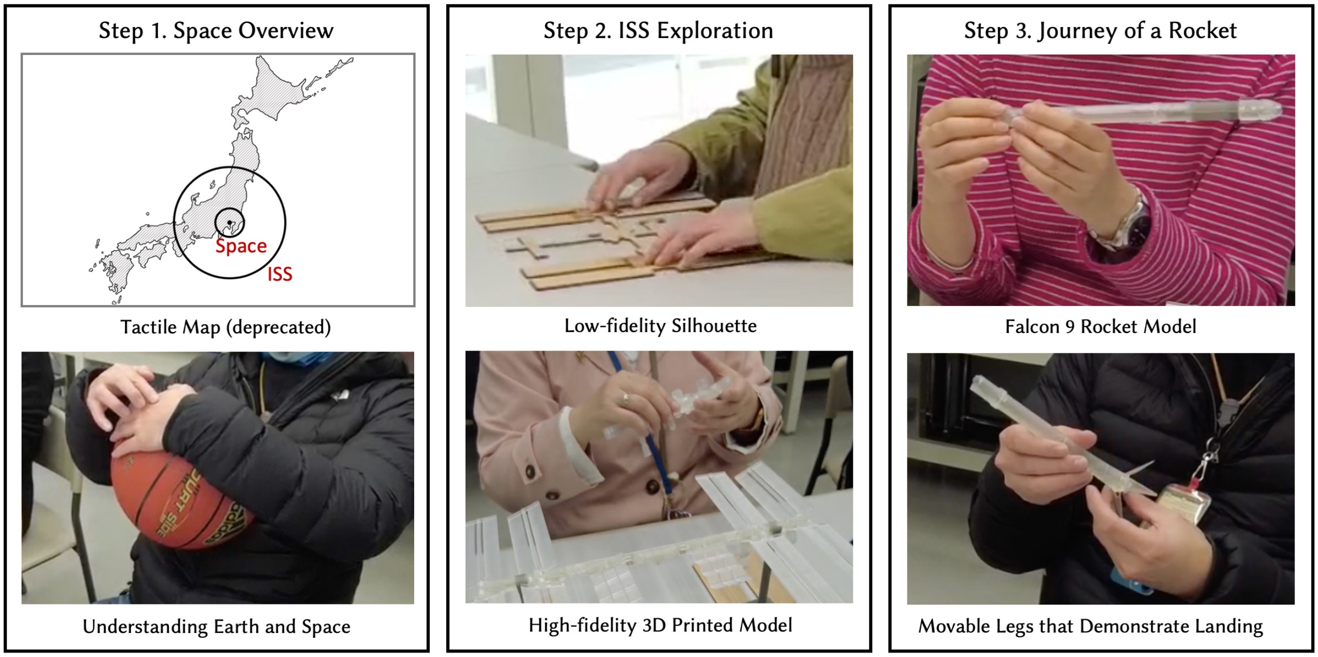

Figure 3: Workshop's first stage in an adjoining room to give an overview. It includes steps 1 to 3, involving tactile objects.

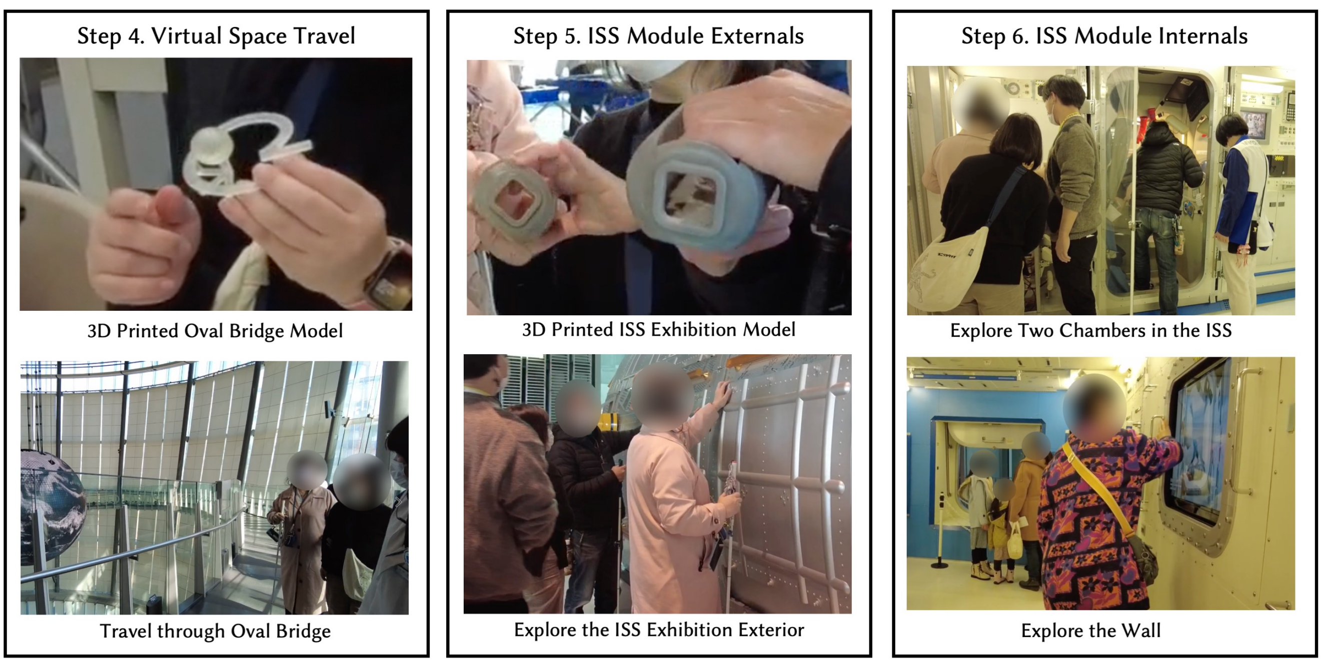

Figure 4: Workshop's second stage on the exhibition floor. It includes steps 4 to 6, simulating a space expedition.

3.4 Implementation: Refining Facilitation and Communication

This phase focused on translating the co-designed materials and narrative into a live workshop format and refining facilitation strategies through real-user evaluations. During co-design sessions with TVIs (Section 3.3.2), two pedagogical approaches were emphasized: top-down (overview to detail) and bottom-up (assembling to form a whole). While bottom-up supports exploration, the top-down method was recommended for its clarity and efficiency in group settings. TVIs also emphasized the importance of pacing, pausing for questions, and accommodating different exploration speeds. Following these insights, we adopted a top-down facilitation structure to support consistent communication, while encouraging spontaneous discussion and regular check-ins with participants. We invited five participants, four totally blind and one with low vision, to experience and improve the refined tour. They were recruited via an e-newsletter for people with visual impairments and compensated with $75 plus travel expenses for their time. Two two-hour sessions (a group of 3 and 2 respectively) were conducted, each facilitated by two museum staff. Feedback confirmed the effectiveness of the updated materials (e.g., the basketball analogy), and surfaced three areas for improvement:

- Visual contrast (Steps 2–3): The low-vision participant struggled to distinguish translucent models from the tabletop. We resolved this with a black tablecloth for contrast.
- Group coordination (Step 6): Simultaneous tactile exploration proved challenging. We responded by dividing participants into subgroups, each guided individually through different module sections. The exhibit was reserved exclusively for 30 minutes.
- Sensory stimulation (Step 7): To enrich group discussion, facilitators used sensory props and shared examples (e.g., space food or meaningful objects) to lead discussion and prompt responses.

The final workshop lasted two hours and was designed for up to three participants: 35 minutes in an adjoining room (Steps 1–3, as shown in Figure 3), 60 minutes in the museum (Steps 4–6, as shown in Figure 4), and 25 minutes for group reflection (Step 7). It was open to participants with visual impairments from grade 4 and above, with a child-friendly version offered periodically using simpler language and a slower pace.

3.5 *In-Situ* Evaluation

The workshop, announced on the museum's homepage and through the e-newsletter for people with visual impairments, was held free of charge ten times over a year. A total of 28 BLV participants attended, each accompanied by a sighted companion (not counted as participants), with up to 3 participants per session. When applications exceeded capacity, participants were selected by lottery. Among the attendees, 22 were totally blind (including three children) and six were legally blind (including one child).

3.5.1 Methodology and Data Analysis. After each workshop, participants took a 5-10 minute interview, which included a 5-point Likert scale evaluation on understandability and satisfaction as well as comments on accessibility (noted manually by staff due to privacy constraints on recording).

Thematic analysis [17] was used to analyze the data. Two coders independently processed the transcripts and developed codes using open coding [23], and the codes were discussed with the rest of the research team to reach a consensus. Finally, the research team performed affinity diagramming [43] to cluster the codes and identify themes, which were initially developed by one researcher and later refined collectively.

3.5.2 Findings. Overall, participants found the tour highly understandable and satisfying. Specifically, 75% (N=21) reported the tour as very easy to understand, 21.43% (N=6) as easy, and 3.57% (N=1) as difficult. Regarding satisfaction, 71.43% (N=20) were very satisfied, 25% (N=7) satisfied, and 3.57% (N=1) neutral. Moreover, five themes were identified from participant comments. Three of them illustrated the strength of the workshop while the other two highlighted future directions. To distinguish participants from later sections, the participants were labeled with W.

Effectiveness of Communication Through Tactile Experience. In the evaluation, eleven participants expressed enjoyment of all activities and the flow. Eight participants highlighted the effective combination of tactile materials and the actual exhibition for building a clear image:

> *"I was able to discover things from different angles. The 2D silhouette, 3D printed models and the real thing helped me to build a clear image. My sighted companion also enjoyed it so much."*[6] W16

Another eight participants favored the detailed exploration within the exhibition's two chambers:

> *"The two exhibit rooms were narrow but filled with touchable objects. They gave me totally distinct impressions!"* W5

Four participants praised the 3D printed models for their clear depiction and interactivity, such as disassembling parts and docking:

> *"I was grateful to touch the models, learn their scale, shape, and structure, and detach the magnet-connected parts."* W17

Participants also enjoyed various activities, such as group interactions (W12, W15, W17), touching space food (W5, W20), and using a basketball to learn about space (W1).

Four participants highlighted that the theme was suitable for an accessible workshop, since previously they could only learn it from video and textual material:

> *"When it comes to understanding the universe, there used to be only video and text available. It's a fascinating topic and I appreciate the opportunity to learn by touching."* W6

However, three participants wished for more time inside the ISS exhibition for a thorough exploration:

> *"I noticed there are other things in the exhibition like a monitor showing videos. But I didn't get enough time to learn about it."* W28

W3 also hoped for more confirmation of the correctly touched place, since currently they have to guess whether they touched the right place.

Supporting Engagement of Science and Technology. Workshops at the science museum aim to enhance public engagement in science and technology, which encompasses awareness, understanding, and forming personal opinions [18]. In this workshop, nine participants discovered inspiring aspects previously unknown to them. Five were particularly impressed by the use of Velcro tape inside the ISS:

> *"When I found out that Velcro is used on the ISS, it made perfect sense to me. I believe it would be beneficial to apply this technique to the lives of visually impaired individuals because it is often challenging to locate things. Sometimes, items can fall over without any notice."* W22

[6] All comments are translated from the participants' native language.

Three participants provided thoughts on the ISS's international collaboration:

> *"Although the ISS is composed of modules from different countries, it operates without borders. It is a remarkable feat of international cooperation."* W2

Additionally, two participants' comments touched on the practical challenges in space, like using the restroom, and the sustainability of reusable rockets.

A Welcoming Attitude. Five participants commented that it was their first time attending such a workshop, and it became a valuable experience. Four participants highlighted the staff's welcoming attitude and attentive service. Three participants reported the value of accessing exhibits that were usually inaccessible for touch:

> *"It was amazing to have the opportunity to touch exhibits like the two chambers inside the ISS, which are typically locked. I am extremely grateful for this service."* W6

Future Direction: Broadening Accessibility. Despite receiving brief descriptions, five participants pointed out that the Geocosmos exhibition, a dynamic visualization of the Earth on a spherical display they encountered in step 4, was accessible. They suggested multimodal and interactive improvements, including adding sound effects to simulate wind and clouds (W3), incorporating directional wind feedback (W6), implementing detailed audio descriptions for the display's current content (W13), and updating information received while traveling (W10).

Five participants also called for more customized explanations. Two participants found the explanation too simple, while two others felt the pace was too fast. W9, an elementary school student who rated the workshop "hard to understand", commented that repeated visits might improve understandability. W14 further suggested take-home materials summarizing the tour and museum highlights.

The tour raised interest in other museum exhibitions, with six participants eager to explore more. However, they noted that these additional exhibitions lacked accessibility features, pointing to a broader need for inclusive design across all museum exhibitions.

Future Direction: More Modalities and Themes. Participants also proposed ideas to expand the modalities. Four participants hoped for a more embodied experience: entering the sleeping bag (W2, W16), wearing a space suit (W7), and trying out the anti-slip socks (W17). Sensory additions were also proposed, like the ISS's ambient sounds and smells (W10) and tasting space food (W15). Additionally, there was a desire for simulations of gravity-less ISS activities, like workouts (W2) or eating meals (W24).

Interest was also expressed in expanding the range of topics. Six participants suggested delving deeper into space exploration, like the solar system (W10) and planets (W12), with others seeking topics beyond their reach, like the ocean (W6, W12, W26), or timely science and tech trends, such as AI (W15) and autonomous vehicles (W28).

4 FOCUS GROUP WITH MUSEUM STAFF

Science workshops facilitate informal learning and communication. While one accessible workshop was developed, many others targeting the general public remain inaccessible to BLV visitors. To identify challenges and opportunities for broader accessibility (RQ2), we conducted a focus group with museum staff members. We asked about: (1) their current practices and challenges in developing accessibility skills, (2) what they learned from this workshop and how that knowledge might transfer to other workshops, and (3) their strategies for communicating scientific content in the accessible workshop. The focus group format encouraged staff to share knowledge and build on each other's ideas, providing a more comprehensive perspective.

4.1 Participants, Procedure, and Data Analysis

We recruited six participants who participated in the *"Learning by Touch–Life in Space"* workshop. Four (S1–S4) were staff members who designed the workshop. S5 and S6 joined after its deployment, and S3–S6 acted as facilitators during the workshop. All of them had experience in designing workshops for the general public.

The focus group lasted approximately one hour and was recorded in video and audio. Thematic analysis was used on the data to identify themes, following the process outlined in Section 3.5.1. The following subsection highlights three key themes that were identified.

4.2 Practices, Barriers, and Lessons Learned for Broadening Accessible Workshops

4.2.1 Developing Communication Skills. Five staff members (S2–S6) acknowledged that specialized skills in accessibility were needed in addition to mastering the content—skills that are not as easily learned as subject matter expertise:

> *"We had no prior experience with accessibility. Learning was a hands-on, iterative process that involved co-designing with many stakeholders. We gradually accumulated experience along with the development of the workshop."* S4

Both facilitators who were not part of the original design team (S5, S6) emphasized the importance of developing a manual to support newcomers in understanding the fundamentals of accessibility within this context. They suggested it should outline the "what," "why," and a simple version of the "how" of communicating scientific concepts to visually impaired audiences. However, they recognized the limitations of such a resource, noting that real-world practice was essential for a full understanding:

> *"The manual is a starting point. I think it is a source that gives you the initial confidence. But it's the practical sessions that build competence."* S6

Two staff members (S3, S6) also emphasized the importance of personalized accommodation, noting that its nuances are best understood through direct experience. Direct engagement with participants–deciding when to provide verbal guidance, when to offer physical assistance, and how much detail to include–demanded in-the-moment judgment:

> *"Every interaction with a participant is unique. While the manual provides a framework, tailoring the approach to each participant is the key."* S3

Their comments underscored the dynamic nature of accessibility in the workshop. Staff should navigate between structured guidance and the fluidity required by personal interaction to provide an adaptable learning experience.

4.2.2 Creating Channels for Improving Accessibility Together. The museum's staff (S2, S3, S4) recognized the challenge of promoting science workshops for the general public as accessible without the rigorous iterations of design and evaluation. S2 noted that while audio-based workshops such as talk-based events could be more friendly to visually impaired people, the inherently visual nature of science concepts still posed an accessibility barrier. As a result, they were reluctant to advertise these programs as accessible.

Despite this, there were sparse instances where people with disabilities independently reached out to attend workshops. For example, S4 recalled a "strawberry tasting" workshop that a visually impaired person attended after confirming minimal reliance on visual elements, resulting in positive feedback. Similarly, S5 described a hands-on biology experiment that was accommodated for a hard-of-hearing visitor, with accessibility support discussed in advance and feedback reflected after the workshop. Staff (S1, S3–S6) recognized that beyond purposely-built accessible programs, these cases were also crucial for understanding and improving accessibility. They emphasized the importance of creating channels to involve diverse participants, collaborate with them, and progress together:

> *"Of course, it is never 100%, but we strive to offer as many options as possible. Having a dedicated channel to discuss both successes and failures with participants can help us move forward together."* S5

Staff (S2–S5) also highlighted that integrating alternative sensory experiences and materials were essential to enhance accessibility while maintaining the interactive nature of science workshops. Using a typical biology experiment that required visual observation as an example, suggestions included using odor changes instead of visual cues (S4), accessible equipment to aid in tactile operations (S2), and providing additional materials they could recap beyond verbal explanations (S5). Crucially, they (S3–S5) stressed the essential role of visually impaired individuals in co-designing these adaptations. However, finding collaborators with both lived experience and science expertise remains a challenge:

> *"The current situation is that there are extremely few visually impaired people specializing in science and engineering."* S3

In summary, staff underscored the value of dialogue with the visually impaired community and the need for flexible, adaptive strategies to make science workshops more inclusive.

4.2.3 Empowering Visually Impaired People's Voice. In striving to enhance public engagement, two workshop facilitators (S3, S6) acknowledged they faced challenges in facilitating multi-way communication with visually impaired participants, namely reinforcing participants' voices and sharing views with each other. One-way communication dominated, with participants mainly being guided rather than engaging in dialogue. Yet in the discussion section of the workshop, there were a few moments when multi-way communication emerged, fostering exchanges of personal stories linked to scientific themes. As S3 reflected:

> *"This interaction is the essence of what we aim for–participants actively sharing and responding to each other's insights."* S3

Another goal of science communication is to form opinions and provide local knowledge to the development of science and technologies [18]. Staff (S3, S4) recognized that while the current workshop could not directly shape scientific research, it served as a bridge between experts' knowledge and participants' lives, spurring the formation of initial opinions:

> *"The workshops sparked dialogues on common experiences between astronauts and visually impaired individuals, such as navigating daily tasks with limited resources. These conversations could inspire innovative solutions when these groups exchange ideas."* S4

In conclusion, science museum workshops should be not only accessible learning platforms but also springboards for visually impaired individuals to connect with and contribute to the scientific community. Although still in an early stages, fostering spaces where participants' voices are heard and valued can lay the foundation for inclusive dialogue and collaborative innovation in science and technology.

5 FOCUS GROUPS WITH WORKSHOP PARTICIPANTS

Among participants who joined the workshop, seven agreed to participate in the focus group interviews about the science museum workshop and exhibition accessibility. The focus group interview was structured into three 30-minute sections: (1) Their experiences with science workshops and the challenges encountered (RQ3). (2) Their experiences and challenges with museum exhibitions (RQ3). (3) Based on identified challenges in earlier sections, the researchers presented emerging technologies surfaced in Section 2.3, and collected participants' experiences, opinions, and design considerations for their use in science museums (RQ4). The technologies were introduced through verbal explanations, and participants were encouraged to ask questions to ensure clear understanding before providing feedback. The focus group format was chosen to support idea sharing across experience levels, allowing participants to build on each other's insights and suggest new directions. Notably, two children actively contributed their thoughts. Each participant was compensated $40 for their time.

5.1 Participants, Procedure and Data Analysis

The focus group interview was conducted over Zoom[7] in two sessions, each facilitated by the same two researchers and recorded in both video and audio. The first session included participants P1 to P3 along with the guardians of P1 and P2, while the second session involved participants P4 to P6. The demographics of the participants are presented in Table 1.

Thematic analysis was used on the transcribed data to identify themes, following the process outlined in Section 3.5.1. The key themes identified are presented as subsection headings in the following sections.

5.2 Practices and Difficulties with General Science Workshops

5.2.1 Interest Despite Limited Experience. Beyond the *"Learning by Touch–Life in Space"* tour, only two participants (P5, P7) had joined science workshops for the visually impaired, with none attending

[7] https://zoom.us/

Table 1: Participants' demographic information, experience with science museums and workshops, and motivations for attending the workshop. Motivation was selected from 1. being interested in the topic and 2. because it is marked accessible. *P1 and P2 were accompanied by their guardians during the study, who were not counted as participants.

ID	Age/ Gender	Blind Since	Science Museum Experience	Science Workshop Experience	Motivation: Topic/ Accessibility
P1*	11/F	0	Yes	No	Both
P2*	11/F	0	No	No	Accessibility
P3	34/M	15	Yes	No	Both
P4	43/M	22	Yes	No	Both
P5	23/F	20	Yes	Yes	Both
P6	36/F	0	Yes	No	Topic
P7	23/F	8	Yes	Yes	Topic

museum workshops for the general public. However, three participants (P4, P6, P7) were open to attending these science workshops if the topics interested them, despite potential accessibility challenges. P7 further pointed out that some workshops intended for visually impaired individuals were not completely accessible:

> *"I will go even if it's not advertised for visually impaired people. I will contact [the organizers] in advance to confirm the facilities. Even when it is promoted 'for visually impaired people,' the accessibility of the workshop can fall short, only offering limited tactile experiences."* P7

5.2.2 Workshop Accommodation. Four participants (P1 – P3, P5) expressed concerns about attending public science workshops, highlighting accessibility barriers. Most activities primarily cater to sighted attendees, and converting these visual experiences to auditory ones can be confusing (P2, P3, P5) or quickly tiresome (P1):

> *"When explanations are lengthy, I tend to lose interest."* P1

Additionally, participants valued the ability to independently obtain information through touch, such as using tactile objects or Braille materials (P1, P2, P5). However, the time and extra help needed to digest information would result in a different pace from others:

> *"Usually, the pace is faster with sighted people. It would be good if you could proceed slowly and step by step, making sure we understand before going too far."* P1

5.2.3 Pre-Workshop Information. Two participants (P3, P5) were hesitant to be the only or first visually impaired attendees at a workshop. Advance reassurances, such as publicly shared comments from visually impaired individuals who had participated, would make attending less daunting:

> *"Reading the blog of how other blind people have enjoyed it would lower the mental barrier to participation."* P3

One participant interested in public science workshops expressed a lack of information received:

> *"I've never attended because I didn't know what workshops intended for everybody were available. Maybe if I only tried harder, I could get some information that's not disability-related but interest-related via SNS."* P6

5.3 Practices and Difficulties with Science Museum Exhibitions

5.3.1 Biased and Insufficient Verbal Explanations. Participants (P1–P4 and P7) observed that accessing information from verbal explanations, either through pre-recorded audio descriptions or by a guide, was dominant in science museums, but it could lead to an unenjoyable experience in multiple ways. Descriptions from a guide person could carry their biases and interpretations, making the receiver's understanding subjective (P1, P2, P4, P7):

> *"When I'm guided by someone, the information I receive is often influenced by that person's bias and opinion. I may only get their perspective on a topic, which can make my understanding of it less objective."* P7

Participants stressed that pre-recorded descriptions could be insufficient for creating an image (P1–P3). Such descriptions often drew comparisons to other objects and concepts, but these references could be unfamiliar or difficult to comprehend (P1, P2):

> *"For things behind the glass, the description usually says 'it is like so and so,' but if you have never touched that 'so and so,' you can't imagine what it is. It is better to touch it directly."* P2

Moreover, the fixed-length audio description, while detailed, demanded significant time and cognitive load:

> *"The prepared audio description wants to teach me from zero to 100 percent, but that is painful. Most of the time, I only want a simple scan-through, like window shopping. I only want to hear the details about things that interest me."* P3

Participants desired a tool that could aid objective, multi-perspective, and flexible comprehension in science museums.

5.3.2 Challenges of Overview and Independent Exploration. Participants (P1–P3, P5–P7) highlighted the daunting challenges of independently exploring exhibition floors despite their strong desire. They identified two main challenges: obtaining a comprehensive overview and navigating freely to desired exhibits. Participants (P4–P7) struggled to gain an overview of the exhibition, making it difficult to choose the exhibits they were interested in:

> *"Sighted visitors quickly scan and select interests; however, it's difficult for us to grasp all of the options quickly."* P7

Additionally, P2 and P7 mentioned that reliance on others for guidance limited their autonomy, forcing them to follow the pace and preferences of companions:

> *"Currently, someone else often decides what I learn about, providing only secondhand information and restricting my understanding of the exhibition."* P7

5.3.3 Inadequate Tactile Experiences. Participants (P5–P7) highlighted the essential need for tactile experiences in exhibitions, emphasizing direct interactions from different perspectives. They noted that even though many science museums offer life-sized exhibitions that they could touch, they might fail to convey an overview for a comprehensive understanding:

> *"Touching real or life-sized replicas is valuable to learning actual sizes. But without small-scale models like that used in the workshop, I couldn't use touch to learn the whole picture."* P7

Moreover, P1 noted that tactile experiences are often limited, covering only parts of one exhibition, which hinders a comprehensive understanding of the exhibition's concept:

> *"It was nice to touch the model, but there is a lot more information. By just touching one thing, I still don't know what that exhibition was about."* P1

This highlights the need for more extensive tactile integrations to improve accessibility and comprehension.

5.3.4 Limited Multi-Sensory Alternatives for Dynamic and Interactive Exhibits. Interactive installations and dynamic visualizations in science museums often fail to accommodate visually impaired visitors due to their heavy reliance on visual elements (P1, P4, P5, P7). Participants (P1, P5) noted difficulties with the pace of interactive games despite audio support being offered:

> *"The train driving simulator was difficult. I could hear how fast it was, and I got support from my family, but every step of my maneuvers was late. I wonder if it could be made easier for visually impaired people."* P5

Two participants (P5, P7) highlighted similar issues with dynamic displays like the Geo Cosmos, expressing a desire for more immersive experiences that could convey data, movement, and spatial concepts:

> *"I was told that the Geo Cosmos was a symbolic exhibition that shows the earth and cloud movement, but how? I cannot imagine it at all. It would be amazing if I could experience such dynamic content."* P7

Participants (P3, P4) also suggested enhancing interactive content with tactile elements to aid understanding:

> *" I wonder if there's a physical alternative that can be manipulated in the same way as actions performed in a game on the screen."* P3

5.4 Technologies to Support Accessible Experiences

Based on the challenges identified in Section 5.3, we proposed emerging technologies and solicited participants' experiences, opinions, and design considerations for their use in a science museum context.

5.4.1 Conversational Agent for Information. We introduced the idea of a Conversational Agent, such as ChatGPT[8], to address biases in human interpretation and the inflexibility, comprehension difficulties, and pacing issues associated with traditional audio guides. Most participants acknowledged the benefits, noting that frequent interactions with a machine felt less burdensome than interacting with a person (P2, P3, P4, P7), and the system allowed for independence and flexibility (P1, P6). Moreover, the active inquiry style made a deeper impression than passive listening (P3). However, concerns were raised about the systems' inability to consider contextual information, as experienced by participants with Siri (P5, P6):

> *"I only want to ask AI about simple things. I'm still not very confident about AI's performance. Humans can respond based on the context and surrounding circumstances."* P5

Additionally, P3 and P7 suggested that for independent exploration, such systems should be integrated with navigation and mobility assistance. For group visits, further investigation is needed to determine how users can interact with it smoothly in the social context:

> *"AI conversation is best used with mobility assistance for independent exploration. If I am with someone, constantly talking on the phone while neglecting them makes me feel uncomfortable. It can create friction with a companion."* P3

5.4.2 Maps and Mobility Assistance for Exploration. We then discussed the use of tactile and 3D maps to obtain an overview. Participants (P4–P6) found traditional tactile maps difficult to understand and ineffective for navigation. P4 preferred a precise navigation guide to describe a sequence of points of interest (POIs) rather than a vague overview, since she struggled with distinguishing lines and routes on tactile maps. We proposed 3D maps with audio explanations [46, 113], and two participants (P4, P6) mentioned that if the tactile experience could be augmented with interactive explanations, it could help form a pre-visit mental link to the actual site and enhance anticipation for the museum visit:

> *"Instead of simply putting the map and the audio guide together, it would be great to allow self-led, self-paced, touch-based exploration. I could link the map information with the actual experience, making the visit more enjoyable."* P4

Next, we proposed a navigation robot [55] to aid independent movement within the museum. Overall, participants thought it beneficial (P1–P3, P7). Specifically, P3, who had previously interacted with such a robot, noted that it greatly reduced the cognitive load of navigating:

> *"When I walk, I have to pay attention to the sounds around me, which disrupts my memory of conversations and exhibits. But when I was led by a robot, it was easier to talk with others while walking."* P3

However, P3 raised concerns about the social perception of using such a device and its impact on the user's experience. Three participants (P1–P3) preferred a design that did not draw too much attention. P1 suggested that the robot could generally blend in but should be able to indicate its function during specific occasions or when necessary. P4 emphasized the importance of the robot providing information about the surroundings to ensure a seamless experience comparable to that provided by a human guide:

> *"The main point is what you feel, find, and learn while traveling, not just about moving to a destination. I wish I could enjoy receiving information about my surroundings while moving, like what a guide can offer."* P4

5.4.3 Recognizing and Interacting with the Exhibits. Finally, we explored the potential of image recognition and captions to enhance exhibit accessibility. While using smartphones to access information

[8]https://chat.openai.com/

is common (P2) and considered a low-cost solution (P3), they (P1–P3) expressed concerns that this approach prioritizes utility over enjoyment. P2 highlighted the difficulty of framing images for totally blind individuals. P1 worried about the time-consuming nature of the technology, deeming it unsuitable for group tours that require keeping pace with others. Participants craved more direct, enjoyable interactions with exhibits:

> *"I really think theme parks and science museums are spaces for an enjoyable experience. Sighted people can enjoy them easily. If I must overcome many difficulties using technology in the science museum, rather than enjoying the exhibitions directly, I prefer having a guide person or just not coming."* P3

We further inquired about direct interactive methods, such as interactive 3D models [99, 114] that recognize touch and provide audio descriptions. Although none had prior experience, all participants were enthusiastic about such technology. They valued the independent exploration it could enable (P2, P6), considered it a fun experience (P3, P4), and appreciated the direct interaction without the mediation of other guides or machines (P2, P5, P3). However, P7 preferred only brief explanations to avoid detracting from the tactile experience. P1 emphasized the need for a seamless experience where information is accessible regardless of where one touches:

> *"Overall, I think it would be nice to get feedback no matter where you touch it. Otherwise, figuring out where to touch could be a problem."* P1

6 DISCUSSION

This section reflects on our design process and its broader implications for improving accessibility in science museums. We articulate our methodological contributions, draw practical insights for museum staff, and propose technology directions grounded in our study. By situating our findings within existing literature, we aim to contribute both theoretically and practically to accessible design in informal science education.

6.1 A Participatory and Adaptive Framework for Accessible Workshop Design

Our workshop used a participatory, iterative process involving visually impaired individuals and TVIs. Feedback from 28 attendees highlighted the workshop's clarity, accessibility, and welcoming atmosphere, with tactile materials supporting clearer understanding and engagement. These responses underscored the value of collaborative design, adaptive communication, and creative use of museum resources. Unlike prior work that focused on final outcomes of science camps [11, 57, 96] or designing artifacts for existing exhibitions [19], our Research through Design approach encompassed the full process from theme formation to public delivery. Based on this experience, we propose a four-stage adaptive framework that emphasizes flexibility, stakeholder involvement, and iterative learning, while acknowledging practical constraints and areas for future improvement.

6.1.1 Grounding Inspiration through Stakeholder Engagement. Our process began with a visit from TVIs and BLV students, which revealed accessibility gaps and inspired a bottom-up design approach. Stakeholders were encouraged to explore both accessible and inaccessible areas of the museum, helping them identify limitations and envision improvements. This stage highlights the importance of exposure to the full experience, including challenges, as a catalyst for co-creation. It supports situating the design process in users' lived experiences, even when they are unfamiliar with the environment. However, the final workshop theme was selected by the design team rather than co-framed with participants, due to limited time and participants' unfamiliarity with the museum's affordance. In the future, more detailed tactile previews or guided walkthroughs could empower participants to shape the thematic direction based on their own interests and interpretations of the museum's potential.

6.1.2 Collaborative Theme, Narrative, and Content Development. The workshop's theme, narrative, and materials were co-developed with experts, museum staff, and TVIs including one who is blind, to address both educational and sensory needs. The use of story-based narrative helped participants follow a coherent sequence of events, making abstract science concepts more relatable and memorable. Paired with tactile objects, the narrative structure supported active exploration and deeper engagement. We prioritized robust, low-tech materials such as 3D models and commercial objects to ensure accessibility, feasibility, and replicability within institutional resources and staffing capacity. Although most narrative content was drafted by sighted domain experts, direct BLV involvement at this ideation stage is critical: lived-experience perspectives surface assumptions that sighted designers may overlook and ensure that the theme and activities resonate with BLV visitors. In our case, we struggled to recruit contributors who combined both lived experience and prior museum familiarity. We also chose not to prototype emerging technologies at this stage, concentrating first on a stable set of tactile materials. Future design should address these gaps by partnering with BLV community organizations early in ideation and, where resources allow, co-prototyping interactive or experimental tools from the outset.

6.1.3 Iterative Validation of Facilitation and Communication. We conducted small-scale walkthroughs and trials with visually impaired participants to refine materials, clarify explanations, and improve facilitation strategies. This phase enabled rapid adjustments that strengthened both content and delivery, while underscoring the importance of incorporating participatory feedback into facilitation design to ensure sessions were responsive, engaging, and well-paced. However, the limited scale of this validation may not capture the full diversity of communication styles and preferences within the broader BLV community. Future efforts should involve participants with varying degrees of vision and technological familiarity to further adapt facilitation practices.

6.1.4 Public Deployment and Institutional Feedback Loops. Through close collaboration with museum staff, the final workshop was adopted as a recurring public program, validating the design under real-world conditions and enabling broader institutional learning. Public deployment became a dual learning opportunity: BLV participants engaged in science communication, and staff gained hands-on experience with accessibility practices. The recurring nature of the workshop created a feedback loop that fostered ongoing reflection, surfaced new thematic possibilities, and laid the groundwork for future accessibility initiatives.

However, sustaining such programs requires more than initial training. Continued support and embedded accessibility practices are essential for long-term success. Future efforts should explore mechanisms to formalize these practices and share accessibility knowledge across teams.

6.1.5 Additional Design Strategies. In addition to our overarching framework, we propose three design strategies that proved effective in our workshop and may be applicable in other science museum contexts. First, a coherent narrative helped participants follow the logic of scientific phenomena, providing conceptual scaffolding that made abstract content more relatable. It further extended the findings of art galleries that tactile materials often lack contextual continuity [19]. Second, offering tactile materials with multiple levels of fidelity enhanced understanding. While prior work [85] emphasizes high-fidelity models, we found that simplified forms aided initial orientation, while detailed or removable components encouraged deeper exploration and storytelling. Third, active communication and social interaction played a key role. While social aspects are also found in art-focused tactile experiences [69], science learning especially benefits from multiple-way communications. Encouraging participants to ask and generate questions fostered scientific literacy, peer learning, and a greater sense of agency.

6.2 Practical Guidelines for Museum Staff to Advance Accessibility

Our findings from two focus groups reveal both a clear interest from visually impaired visitors in attending science workshops and a willingness among museum staff to make those experiences accessible. However, significant barriers remain on both sides. Visually impaired visitors emphasized the need for multimodal access beyond verbal explanation, flexible pacing, and reassurance in unfamiliar group settings. Staff, meanwhile, pointed out limited institutional resources, lack of training, and uncertainty around promoting general programs as accessible. Based on these insights, we propose the following practical guidelines to support more inclusive science workshop practices.

6.2.1 Establish Co-Design as a Core Practice. Accessibility should be embedded from the start of the design process, not added later. Both participants and staff emphasized the value of involving visually impaired individuals as collaborators rather than testers. This aligns with existing calls for multi-stakeholder collaboration [48], and was reinforced by staff who viewed co-design as essential to building inclusive experiences. Museums should form cross-functional teams that include people with lived experience and subject expertise. When these qualities are not present in a single individual, partnerships with external organizations can help identify co-design collaborators.

6.2.2 Build Staff Capacity through Practice, Reflection, and Institutional Support. Staff emphasized that accessibility cannot be fully learned through manuals alone; it should be developed through hands-on experience and collective learning. To support this, museums, as institutions, should create opportunities for peer learning, such as allowing new staff to observe experienced facilitators during accessible programs. Regular team reflections, where staff share challenges and insights across departments, can help surface practical strategies and foster shared responsibility. Developing reusable toolkits, such as tactile models, communication templates, or adaptation guides, can make accessibility practices more sustainable and scalable across topics.

6.2.3 Design for Flexible Engagement and Pacing. Participants consistently expressed a need for science workshops to accommodate varied learning paces and offer alternatives to purely verbal explanations, which can become tiring or difficult to follow. Museums should prioritize multimodal access by integrating tactile materials, verbal narration, and where possible, Braille or haptic alternatives. Facilitation should include natural pauses that allow for individual inquiry and understanding, with clear communication about when and how support will be offered. To accommodate mixed-ability groups, key elements of the workshop, such as model handling or narrative explanation, should be designed to be modular and adaptable. Additionally, exploring pacing aids or collaborative technologies may also help visually impaired participants to engage more comfortably in group settings.

6.2.4 Reduce Social Barriers Through Visibility and Inclusive Communication. Participants expressed hesitation about attending public workshops due to uncertainty and the fear of being the only attendee with access needs. To reduce this barrier, museums should share social narratives, such as blog posts or social media, from past participants to normalize inclusion and highlight real experiences. Staff also reported uncertainty about when and how to promote programs as accessible. Clear, transparent communication about available access features, along with an open invitation to request accommodations, can build trust and encourage participation. These small yet visible practices help signal that disabled visitors are welcome and expected in public science programming.

6.3 Translating Technology Opportunities into Actions

While the final section of our focus group (Section 5.4) examined user responses to specific technologies, here we synthesize insights across them to identify three cross-cutting actionable directions. Rather than mapping one-to-one with individual technologies, these directions reflect recurring themes in participants' enthusiasm and concerns—specifically, the need for tangible interaction, seamless social integration, and emotionally engaging experiences. Each direction aims to translate accessibility research into meaningful, visitor-centered experiences in science museums.

6.3.1 Emphasize Tangibility in Making Dynamic Content Accessible. Participants repeatedly expressed that visual-first exhibits, such as simulations, interactive displays, and videos, often excluded them entirely, even when paired with audio descriptions. These verbal alternatives were seen as cognitively demanding, overly interpretive, and lacking contextual clarity (Section 5.4.1). In contrast, participants strongly favored tactile materials and emphasized that combining high- and low-fidelity models could help scaffold both overview and detail (Section 5.4.3). This underscores the importance of designing tactile representations not only of objects but also of movement, scale, and scientific processes.

To address this, we recommend science museum accessibility broadly adopt and expand research on physical, touch-based interaction with dynamic content. This includes (1) interactive 3D models that respond to touch with contextual audio feedback, (2) small-scale tactile representations of large or abstract exhibits (e.g., earth systems, physics simulations), and (3) physical interfaces that simulate input/output behaviors of digital displays or games. Such technologies should be co-designed with visually impaired people, ensuring they align with real-world learning strategies and foster independent inquiry. The goal is not to simplify content but to transform it into an accessible, embodied experience.

6.3.2 Design for Shared Use and Social Inclusion. While tools like AI image descriptor[9] and navigation systems [55] can promote independence, participants emphasized the need for designs that also support socially inclusive use (Sections 5.4.1 and 5.4.2). Extended smartphone or voice interactions, for instance, can feel isolating in group settings (Section 5.4.1). Since social interaction is key to science museum enjoyment, tools that overlook this dynamic may unintentionally exclude users.

To address this, technologies should be designed for flexible, shared use by both visually impaired and sighted visitors. Tools should activate only when needed and integrate naturally into the flow of the visit. Navigation robots, for example, should offer contextual guidance that is non-intrusive to the group dynamics. Conversational agents could also be embedded into shared interfaces, facilitating inclusive discussion rather than isolating one-on-one exchanges. These design choices help reduce social separation and ensure that accessibility tools support both individual autonomy and collaborative discovery.

6.3.3 Enhance Enjoyment through Multisensory Interaction and Pacing Control. Participants viewed enjoyment not as a bonus but as essential to engagement. Many accessible systems were seen as overly functional, lacking opportunities for curiosity, play, or emotional connection (Section 5.4.3). Audio guides, in particular, were often rigid, lacking pacing flexibility and user control (Section 5.3.1). Some participants wished for casual "window-shopping" modes (Section 5.3.1), while others preferred in-depth exploration (Section 5.3.2), but few technologies offered that range of interaction.

To meet these needs, technologies should support multisensory, self-directed interaction with adjustable pacing. Rather than delivering fixed-length content, systems should offer layered, on-demand information. Tactile interfaces enriched with spatialized audio or haptic feedback can create more immersive and enjoyable experiences—especially when paired with narrative or game-like elements.

In addition, full-body engagement through virtual or mixed reality also offers a promising direction. Research shows that combining auditory, tactile, and kinesthetic feedback allows visually impaired users to build spatial understanding while enjoying freedom of movement [53]. Systems that allow users to walk through and interact with virtual representations, such as the Geo Cosmos (Figure 4. Step 4 bottom), by augmenting directional audio, vibration, and object-based cues, can support rich, embodied learning experiences. These approaches not only make scientific concepts more intuitive but also enhance enjoyment through physicality, autonomy, and playful exploration.

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6.4 Limitations and Future Work

This study focused on accessibility in science museums, from workshops to exhibitions, marking an initial exploration of their unique characteristics and needs. A major limitation was the reliance on focus group discussions with a small group of visually impaired participants (N=7), limiting the breadth of our findings. Although we might have identified a small portion of accessibility needs, we believe these to be the most prominent ones. While our results align with some known accessibility needs, they also reveal specific requirements in science museums, such as in science communication, group learning, and social interaction aspects. Another limitation was that the experiences of individuals with low vision were underrepresented. While the design phase of the workshop included a participant with low vision, the final workshop primarily attracted blind participants, likely due to our e-newsletter's reach. Future workshops should actively engage more people with low vision, and we plan to update and refine our findings with the low-vision community. Accordingly, we consider our work a contribution to shaping research directions rather than providing definitive design guidelines. Moving forward, our study lays the groundwork for advancing accessible technology designs and further explorations to enhance real-world science museum accessibility.

7 CONCLUSION

We designed an accessible workshop for visually impaired people at a science museum and facilitated focus group interviews among seven participants and six staff members. Our design approach investigated the process of making a specific science theme accessible and could be applicable to various science topics. The focus group interviews focused on the challenges of generalizing accessibility across general workshops and explored technological opportunities within science museums. The findings align with the broader literature on museum accessibility and offer contextual suggestions for enhancing informal learning and engagement, particularly in science museums. This work sets the stage for future initiatives, proposing practical directions for practices and technologies to ensure that workshops and exhibitions are inclusive for all visitors.

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