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LONG PAPER

Interactive description to enhance accessibility and experience of deaf and hard-of-hearing individuals in museums

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Abstract

Text descriptions in museums provide detailed and rich information about artifacts that broadens museum visitors' knowledge and enriches their experience. However, since deaf and hard-of-hearing (DHH) individuals have low literacy compared to hearing people and communicate through sign language, museum descriptions are considerably limited in delivering a stimulating and informative environment for understanding and enjoying exhibits. To improve DHH individuals' museum experience, we investigated the potential of three interactive description prototypes: *active-linked*, *graph-based*, and *chatbot-based*. A comparative study with 20 DHH participants confirmed that our interaction-based prototypes improve information accessibility and provide an enhanced experience compared to conventional museum descriptions. Most participants preferred the *graph-based* prototype, while post-interviews suggested that each prototype has potential benefits and limitations according to DHH individuals' particular literacy skills and preferences. Text descriptions can be enlivened for DHH visitors by adding a simple interaction functionality, e.g., clicking, which can lead to a better museum experience.

Keywords Museum description · Deaf and hard-of-hearing individuals · Interaction design · Museum experience · Information accessibility

1 Introduction

Museum descriptions (or text) are the most basic means for visitors to access information about various exhibits and serve as a medium that allows for interaction between a visitor and an object [18, 41]. A typical museum description consists of a text supplemented with images or videos. Ranging from simple stories to historical and scientific facts, museum descriptions provide a variety of information on each artifact, often including difficult or professional terms [28]. Although these may be unfamiliar to the average person, visitors can learn new terms by considering the overall context of descriptions and drawing from their prior knowledge; consequently, museum descriptions expand our understanding of exhibits and allow for a rich museum experience [23, 46].

Text descriptions play an important role in shaping visitors' museum experience as they offer detailed explanations about artifacts. Thus, it is essential that the information be presented in a way that is accessible to all visitors. Unfortunately, although museums strive to provide all patrons the same access to rich information and opportunities to expand their knowledge, the current format of museum descriptions considerably limits the museum experience of deaf and hard-of-hearing (DHH) visitors. One of the main challenges DHH visitors face when encountering text descriptions is difficulty reading the text. Generally speaking, they have lower literacy skills than hearing people [15, 16, 33], including problems with reading and understanding text due to unfamiliar syntactic structures or limited vocabulary skills [4, 13, 14, 31]. Due to reading difficulties, many DHH individuals simply visually observe the object or skim descriptions to get a vague idea rather than grasping in-depth information

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or the full back-story contained in museum descriptions; as a result, their museum experience is confined to a limited or shallow level of understanding.

Recently, museums have tried to improve information accessibility for DHH visitors by providing sign language content on digital devices [12, 20, 32, 34, 35, 42], where there exist some issues in exploiting sign language alone. First, cognitive load may occur due to simultaneity [36]. Sign language users who consume all information visually may experience cognitive load due to visual dispersion when understanding descriptions [10]. They must often quickly switch their visual attention between an artifact and sign language while understanding content, which may cause visual dispersion or the omission of some information. Second, sign language content is usually not only costly to produce due to insufficient data [8, 7], but also summarized compared to the original content, so it may not be able to convey the same level of rich information that textual descriptions provide (e.g., acquisition of new terms and a detailed account of artifacts). Moreover, such content is passively provided in a one-way manner, highlighting the need to more actively satisfy the curiosity of DHH visitors inside the museum, e.g., answering any questions they may have on the artifacts [5]. Given that DHH Individuals can use different languages besides sign language [21], museum descriptions need to be studied in various options including text format so that DHH individuals can choose [2]. Thus, there is a need to improve the current textual descriptions to ensure that rich information is provided—even to visitors who have difficulty in understanding texts like DHH visitors. However, to the best of our knowledge, few studies have explored the efficacy, limitations, or potentials of textual descriptions in museums.

To provide better accessibility and improve DHH individuals' experience, we have investigated the potential of interactive museum descriptions that allow people to actively interact with a description system and explore all there is to know about an artifact. After identifying three issues that DHH individuals with low literacy skill encounter in museum descriptions (exploration, construction, and user-inquiry), we propose three interactive museum descriptions: *active-linked*, *graph-based*, and *chatbot-based* prototypes. A comparative study and post-interviews with 20 DHH participants revealed that even textual descriptions, which are most familiar to hearing individuals, could be improved by incorporating some interactive design elements. The potential and limitations of the prototypes are presented to explore the ways in which the interactive museum descriptions could improve the experience of DHH individuals, who have unique needs and preferences.

2 Background work

DHH individuals vary greatly in terms of their communication preferences [16] and reading comprehension ability [15, 47, 50]. Based on educational and cultural factors [50], some DHH individuals are adept readers, but others are not good at reading in general [17]. DHH adults usually report average reading scores between the fifth- and sixth-grade levels [15], which falls well below the standard scores of hearing adults [9]. Many DHH individuals still struggle in comprehending "text" through reading. This presents important challenges, especially in an area where obtaining information by reading is important [16]: **museum descriptions**.

Museum visitors frequently refer to text descriptions to acquire detailed information about artifacts, artworks, etc. As basic museum descriptions are mostly textual in format, this creates a comprehension barrier for many DHH visitors. In an attempt to address this issue, the Smithsonian Museum published 'accessible design guidelines' [45], which highlight that museums must limit sentence length and avoid complex English in text descriptions to facilitate DHH individuals' understanding. Unfortunately, most museum descriptions are designed by and for people who use both spoken and written language; thus, the issue of DHH individuals' information accessibility to museum descriptions persists [20].

When providing textual information to DHH individuals, there are some important considerations to be made. Dostal et al. presented two principles: (1) *Optimize Access* and (2) *Make Content and Thinking Visible* [16]. *Optimize Access* focuses on facilitating communication by inquiring about communication preferences, and *Make Content and Thinking Visible* underscores that making information visible applies to thinking visible. Inui et al. discovered that offering a syntactic and lexical paraphrase of a given text to DHH individuals could support their reading comprehension [24], implying that offering sufficient varieties of leveled text improves their reading ability.

Numerous other works have studied tools that can boost DHH individuals' reading comprehension [1, 2, 3, 6, 25, 27, 29]. Alonzo *et al.* examined the benefits of automatic text simplification (ATS) for DHH individuals and found that they perceived benefits from and preferred a system with on-demand lexical simplification [2]. Kushalnagar *et al.* simplified cancer and health-related texts using MOSES, a text simplification program, and confirmed the benefit of text simplification through an experiment on 36 DHH students [29]. Gennari and Mich evaluated whether another text simplification tool (LODE) could improve DHH children's reading comprehension and found that appropriate illustrations make the text easier

to understand; by enriching the stories with static and/or animated drawings, they significantly improve text readability [19]. Chung *et al.* proposed a news display system for DHH individuals that automatically converts complex sentences in a given news article into simple sentences and illustrates the relationships among them via a graphical representation. Their research demonstrated the potential of (1) Identifying subordinate and embedded clauses in complex sentences, (2) Relocating them for better readability, and (3) Displaying the clauses' relationships with a graphical representation, which subsequently allowed readers to have a better understanding of the text [11].

Although reading text remains a challenge for DHH individuals with low literacy skills, these studies showed that text accessibility can be improved by determining how to adapt its presentation, suggesting museum descriptions can also be improved in this regard. With this context, we explore three research questions in this study:

- RQ1: What difficulties do DHH individuals have when they encounter textual descriptions in museums?
- RQ2: Does the interaction help DHH individuals have a better experience with museum descriptions?
- RQ3: What are the potential and limitations of interactive museum descriptions?

3 Methods

3.1 Prototypes

Based on prior studies for DHH individuals [2, 3, 1, 4, 5, 12, 14, 20, 30, 35, 22, 49], we focused on three issues DHH individuals may face when they encounter textual descriptions of museum artifacts:

- *Exploration* DHH individuals want to explore more information in addition to the basic description of an artifact. Many studies have shown that deaf people report a more positive museum experience when they can explore and interact with more information on their own [5, 12, 20, 30, 35]. Accordingly, providing supplemental visual materials and explanations, e.g., definitions, examples, and related stories, would be helpful for their understanding and exploration [22, 49];
- *Construction* DHH individuals often have difficulty understanding complex and long sentences due to low literacy skills [21]. Prior research has revealed that the main factors of poor comprehension are syntactic structure and difficult vocabulary [2, 1, 3, 4, 14]. Museum descriptions are generally composed of complex syntactic structures and unfamiliar terminology; thus, their format may be unsuitable to effectively convey information to DHH individuals who have not skilled at reading;
- *User-inquiry* DHH individuals want to ask questions and receive adequate feedback when they become curious about an artifact in the course of a museum tour [5, 20], but sign language interpreters, who explain exhibits to DHH people and facilitate communication between hearing people (e.g., curators) and DHH visitors, are not always available in museums [5].

Taking the above issues into account, we prototyped four description styles to explain artifacts in museums as shown in Fig. 1: *common*, *active-linked*, *graph-based*, and *chatbot-based* styles. Table 1 summarizes the characteristics of the four prototypes described in what follows:

- *Common prototype* As a baseline, the ***common*** prototype provides conventional descriptions commonly available in museums; the description consists of many complete sentences;
- *Active-linked prototype* Researchers found that on-demand text buttons like pop-ups (text boxes appear above the words when hovering the mouse) help reading understanding rather than unconditionally replacing complex museum descriptions with a simplified version [2]. Referred to these works, the ***active-linked*** prototype is an improved version of the common prototype that allows users to explore information up to one additional level depth (shallow exploration). In the *active-linked* prototype, some difficult or professional words, e.g., "maguri" and "reverse inlay technique," are color-highlighted so that additional information pops up when users click the colored words. Strategic highlighting of words or phrases can enhance the reading experience of DHH [26];
- *Graph-based prototype* As a prototype of a simplified construction rather long sentences, we adopted the "knowledge graph." Knowledge graph presents related information in a hierarchical connection [43] and can reduce the need to read the entire descriptions [44]. We refer to the third prototype as ***graph-based***, where the keywords (nodes) are hierarchically connected to each other. In terms of construction, it initially displays only several keyword nodes instead of presenting all descriptive sentences at once. It can then be expanded with more details if users click on the nodes (keypoint-based construction). Unlike the *active-linked* prototype's single-level exploration, the *graph-based* prototype enables a deeper level of exploration by progressively expanding the graph according to users' interests (progressive

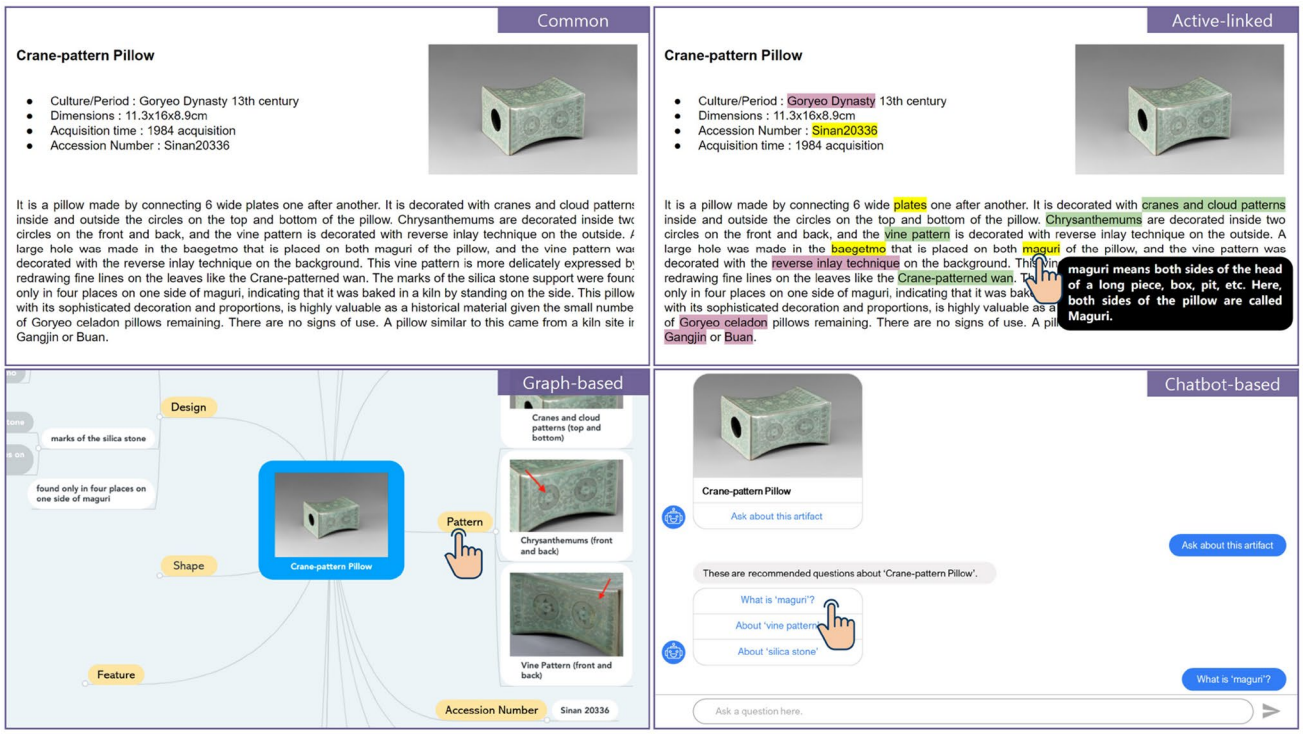

Fig. 1 Four prototypes of description styles about a target artifact (e.g., Crane-pattern pillow)

Table 1 A summary of prototypes across three design dimensions

Dimension	Common	Active-linked	Graph-based	Chatbot-based
Exploration	No	Shallow	Progressive	Hybrid
Construction	Sentence-based	Sentence-based	Keypoint-based	Keypoint-based
User-inquiry	Disable	Disable	Disable	Enable

exploration). We implemented the *graph-based* prototype using Mindmeister[1];

- *Chatbot-based prototype* Chatbots have been widely used as a solution for promptly handling user-inquiry [48, 48]. In prior works, most chatbots for DHH individuals were designed to use mainly their voice or gestures to communicate, not text [38, 40]. To figure out the potential of chatbot with text-based interaction for DHH individuals, our ***chatbot-based*** prototype provides a basic museum chatbot with buttons and an input textbox. It initially provides a few candidate question buttons (e.g., FAQs) on a target artifact rather than displaying all of the descriptions at once (keypoint-based construction). However, there are fewer explorable topics (buttons) compared to the *graph-based* prototype. Users can get some answers by selecting a candidate question, but they mostly acquire more detailed information by typing their own questions. The *chatbot-based* prototype provides corresponding answers according to the user's interests and preferences (hybrid exploration). Notably, this is the only one of the three prototypes that allow users to ask their own questions (enable user-inquiry). To ensure the quality of the chatbot system remained constant (e.g., avoiding misunderstanding an input question), we employed a Wizard-of-Oz approach utilizing real-time human responses. We implemented the *chatbot-based* prototype using Chatfuel[2].

3.2 Materials

3.2.1 Artifacts and descriptions

For this study, we first evaluated the difficulty level of descriptions of ten representative artifacts displayed

[1] https://www.mindmeister.com/.

[2] https://chatfuel.com/.

Table 2 Number of explorable items in three prototypes

Interaction style	Exploration level	Description 1 (101)	Description 2 (84)	Description 3 (84)	Description 4 (103)	Average
Active-linked	Level 1 (max)	14	19	21	17	17.8
Graph-based	Level 1	15	14	13	13	13.8
	Level 2	8	12	8	13	10.3
	Level 3 (max)	9	12	10	13	11.0
Chatbot-based	Level 1	6	6	6	6	6.0

Numbers in parentheses of columns indicate the total number of words in the description. Note that the *chatbot-based* prototype can only provide answers that are found in the description of the *graph-based* prototype

Table 3 Interaction metrics and questions for subjective evaluation

Metric	Survey question
Understanding	This prototype made it easy for me to understand the description.
Desire to explore	I want to know more about artifacts when I use this prototype.
Feedback	This prototype answered what I was curious about.
Usability	This prototype was easy to use.
Interesting	This prototype was interesting.

in the Asian Ceramic Gallery of the Gwangju National Museum in Korea. Ten DHH individuals (not participants in the main study) assessed the difficulty level of the ten descriptions, and four descriptions similar in level and length were finally selected and used in this study. The length of the four descriptions ranged from 84 to 103 words ($M = 93$), and 8 to 10 difficult words were included in each description. All descriptions were customized for each prototype. The number of explorable items (colored words in the *active-linked*, nodes in the *graph-based*, and candidate questions of the *chatbot-based*) are presented in Table 2. The *common* prototype, as a baseline, provides no explorable items. The *chatbot-based* prototype was designed to provide six candidate questions and users may ask a question to obtain more information. However, the chatbot can only answer questions based on the same information provided in the *graph-based* prototype.

3.2.2 Subjective evaluation questions

To measure the experience of DHH individuals with each prototype, five interaction metrics were considered (see Table 3). *Understanding* indicates how well participants can understand an artifact through a prototype. *Desire to Explore* indicates how much the prototype triggers their motivation to explore and know more about the target artifact and *Feedback* indicates if the prototype provides sufficient information to satisfy their curiosity. *Usability* and *Interesting* examine how easy and interesting the prototype is for DHH participants to use, respectively. All questions consist of a 7-point Likert-type scale of agreement ranging from 1 = "Strongly disagree" to 7 = "Strongly agree."

3.2.3 Post-interview

At the end of the experiment, post-interviews were conducted to understand participants' experience of the four museum description types and obtain their feedback. First, in order to understand the difficulties they experience when exploring museums, we asked how they feel when they encounter conventional museum descriptions as well as their usual viewing styles. Next, we asked them to rank the four prototypes in order of preference from most to least and inquired as to the reason for their ordering. Finally, they were asked to provide any suggestions for a new textual interaction design and what other functions would be needed to enhance their museum experience.

3.3 Experiment

3.3.1 Procedure

A within-subject study was conducted where participants experienced all four prototypes. The data collection procedure was as follows. First, after receiving an overview of the study, each participant signed a consent form and responded to demographic questions. Then they tested the four prototypes according to a balanced Latin-Squares design, while the four artifacts were presented in the same order. Prior to

using each prototype, participants watched a brief video that explained its use and functions and then explored one of the artifacts with it. Then, the participants responded to subjective questions. After examining all four prototypes, we conducted post-interviews to collect opinions and feedback for our further understanding, and the participants were asked to order the prototypes by preference. To ensure clear communication with participants, a sign language interpreter was present during all study procedures; that is, the study was conducted through communication among the researcher, the sign language interpreter, and a participant. The materials used in this study included a tablet PC (to present the prototypes), the survey paper, and an interview sheet. The tablet PC screen was recorded to observe participants' interaction procedure while using the prototypes. The study took approximately one hour and participants were compensated with 40K KRW ($34 USD) for their participation. All ethical and experimental procedures and protocols in this study were approved by the Institutional Review Board (IRB) of the Gwangju Institute of Science and Technology.

3.3.2 Participants

Twenty participants identified as deaf or hard-of-hearing were recruited from a community rehabilitation center. Their average age was 47.35 ($SD = 14.51$), and the group comprised 11 females and nine males. All participants self-identified as having severe deafness and the average age of hearing loss occurred was 3 years old ($SD = 2.52$). Their preferred languages included sign language (all participants), spoken language (2), and writing (2). When asked whether they had received any reading education, 16 participants answered "Yes" and four answered "No." The earliest age and latest age of receiving reading education were 4 and 22, respectively ($M = 9.75$, $SD = 4.15$). Additionally, in their assessment of the difficulty of the description immediately after experiencing the common prototype, nine participants identified it as hard, nine identified it as normal, and two identified it as easy.

4 Results

4.1 What difficulties do DHH individuals have when they encounter textual descriptions in museums? (RQ1)

4.1.1 Barriers to accessing information due to low literacy skills

Although many of them lacked background knowledge and educational experience about history, DHH participants had a great desire to learn historical stories and details. However, many participants reported significant difficulty understanding museum descriptions consisting of long and complex sentences with difficult and unfamiliar vocabularies. When facing such difficult descriptions, four of the 20 participants (P3, P7, P14, and P15) responded that they tried to search the Web for more information to understand the artifact and its description, but the other participants stated they were more apt to give up and move on the next object. Many avoided asking questions (even when they were deeply curious about a particular artifact) because it was too inconvenient for them to communicate with others, e.g., people who verbally explain about the museum artifacts. In this situation, they refrain from seeking further knowledge unless there is a sign language interpreter, which is uncommon in most museums.

> *"Because there were many words that I didn't know and it's hard to understand the description of the artifacts, I could not know what the contents are, so I just skipped it. It doesn't interest me because I cannot know the story about the artifact. It's too boring to read everything, and there are too many difficult Chinese characters and terminology."* – P4

> *"I want to tell my friend about the old history that happened in my neighborhood, but even if I want to know about the history, I can't. It's frustrating that I can't tell my friend."*– P16

> *"When a description is provided with sign language, I can understand, my curiosity grows, and communication about artifacts occurs. However, when the description provided is a long sentence, it is incomprehensible and not accessible."*– P19

> *"I was frustrated that there was no solution when I wanted to know additional information."*– P2

4.1.2 Need for individual and active touring

Most DHH participants have visited museums as part of a group tour with a sign language interpreter who interprets descriptions of the exhibits. Many participants stated that a group tour with other DHH visitors to a museum is time-consuming and expensive because they can only visit when an interpreter becomes available and must wait for all other DHH visitors to finish viewing each artifact. Some participants responded that they would like to explore the museum freely as individuals rather than as a group. With respect to interaction, they want contents they can react to, experiences they can participate in, and active interaction rather than one-sided and passive touring, even when a sign language interpreter is present. Some participants strongly expressed

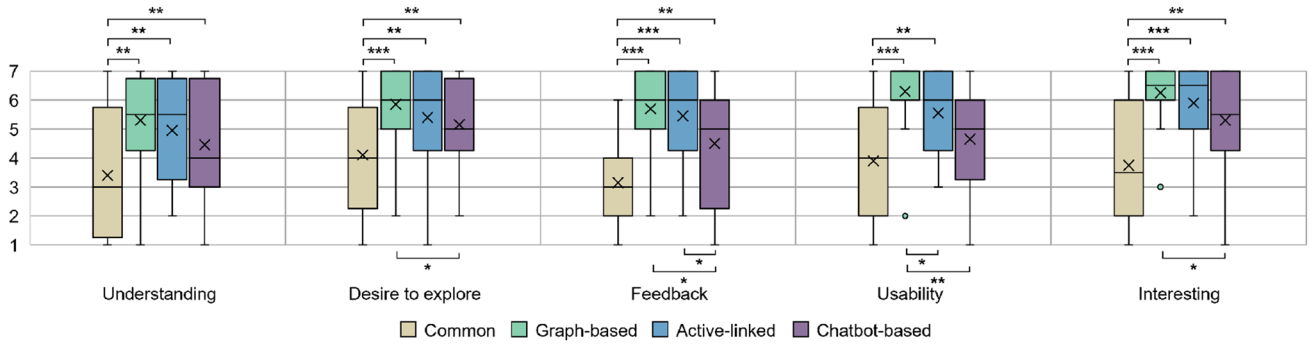

Fig. 2 Comparison of participants' responses to interaction metrics by prototype with significant pairwise differences (*$p < 0.05$, **$p < 0.01$, and ***$p < 0.001$)

the preference for active touring in which they personally search for information and enjoy the museum independently.

> *"Five to ten DHH individuals usually gather together to watch with a docent and a sign language interpreter. The group tour is expensive and time-consuming."*– P13

> *"To be honest, I can only passively acquire the given information when I am provided with a description through a sign language interpreter....I wish there were a system that can respond immediately when DHH individuals are curious or want to know more about something."*– P19

> *"It is hard to enjoy it freely because there is a limit to group tours. I want to tour the exhibits alone."*– P16

> *"It is not fun because there is nothing that I can react to."* – P11

4.1.3 Negative emotions due to limited information accessibility and museum experience

Most participants felt frustrated, alienated, bored, and even fearful when they run into complicated descriptions; many thought the museum should have been more considerate of their needs. They also expressed a strong sense of discontent with their inability to comprehend the provided description since they failed to access the desired information. Some participants even thought that this situation was inevitable due to personal limitations, saying:

> *"It is my fault that I cannot understand because I am not good at understanding sentences."*– P15

> *"It is because I am not good at studying."*– P13

> *"That's just my luck. I gave up."*– P12

4.2 Does the interaction help DHH individuals have a better experience with museum descriptions? (RQ2)

Figure 2 shows the mean score and distribution of interaction metrics by the prototype. To check the reliability of the participants' responses, we first calculated Cronbach's alpha, which showed strong reliability for all subjective questions ($\alpha = .89$). We conducted a Friedman test for all four prototypes and Wilcoxon signed-rank tests for post-hoc pairwise comparison. The Friedman test indicated a significant difference for all interaction metrics (*Understanding* $\chi^2 = 14.946$, $p = .002$; *DesireToExplore* $\chi^2 = 25.757$, $p = .000$; *Feedback* $\chi^2 = 26.860$, $p = .000$; *Usability* $\chi^2 = 23.800$, $p = .000$; *Interesting* $\chi^2 = 25.447$, $p = .000$). The post hoc pairwise comparison using Wilcoxon signed-rank tests mostly revealed significant differences in the comparison of the *common* and other prototypes for every metric (see Fig. 2).

Subjective scores for all interaction metrics were high in the order of *graph-based*, *active-linked*, *chatbot-based*, and *common* prototype. In particular, the *graph-based* prototype had the highest scores for all metrics. Post-interviews with our participants revealed that compared to the *common* prototype, most participants were more satisfied with the three other prototypes' capacity to satiate their curiosity by providing feedback, e.g., definitions of unfamiliar words. They were also pleased that they were able to acquire in-depth information through additional visual images and relevant information provided for the artifacts.

Understanding is the most fundamental step in the museum experience since a good understanding about the exhibited artifacts often leads visitors to a better experience of museum contents. Regarding the current description of museums, DHH participants found it difficult to understand without additional explanation and images (mean score: 3.4). In contrast, they responded that the *graph-based* (mean score: 5.3) and *active-linked* (mean score: 5.0) prototypes

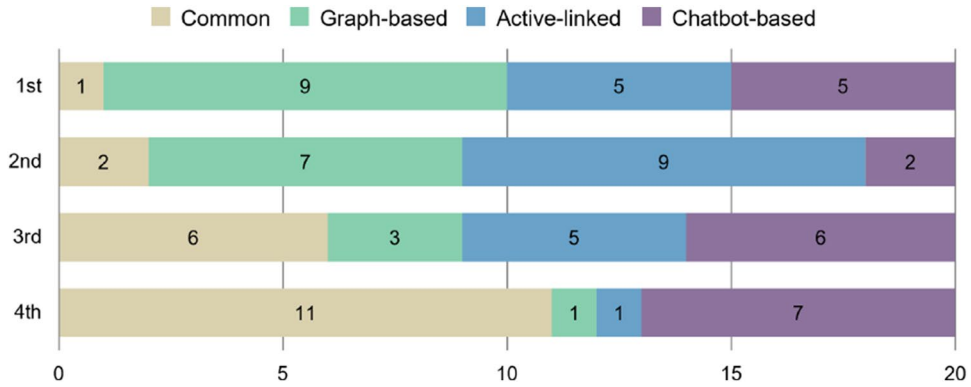

Fig. 3 Preference ranking for the prototypes

substantially helped them comprehend the description of a target artifact with additional information including images that could be easily accessed by clicking colored words or nodes: *"I was able to satiate my curiosity because there was an explanation of the word."* (P5) and *"It was nice to have a lot of pictures related to this artifact"* (P8). For the *chatbot-based* prototype (mean score: 4.5), only a few individuals were satisfied with typing custom queries to support their further understanding of artifacts.

Desire to explore indicates whether a prototype may trigger the desire of users to know more about an artifact while experiencing it, and ***Feedback*** conveys if it provides a proper answer to their curiosity. With the *common* prototype, participants had questions and wanted to find out more while reading the description, but they were frustrated that there was no pathway to acquire further information on the description (*DesireToExplore*: 4.1; *Feedback*: 3.2). On the other hand, they evaluated that the *graph-based* (*DesireToExplore*: 5.9; *Feedback*: 5.7) and *active-linked* (*DesireToExplore*: 5.4; *Feedback*: 5.5) prototypes strongly motivated their exploration desire and provided appropriate feedback. Particularly, the majority of participants (17 out of 20) had a strong desire to explore and progressively opened 73% of nodes in Level 1 and 49% of nodes in Levels 2 & 3 in the *graph-based* prototype. Similarly, 15 out of 20 participants demonstrated an eagerness to explore by clicking 71% of color-highlighted keywords of the *active-linked* prototype. The nodes of the *graph-based* and the color-highlighted keywords in the *active-linked* appear to have significantly positively impacted their desire to explore by offering supplemental materials according to their interest: *"The information in the graph is connected to each other, and it was nice to be able to see them by opening [the nodes]"* (P17) and *"The words were colored so I could enter according to my curiosity"* (P1 and P18).

However, despite the fact that the *chatbot-based* prototype can provide additional information like *graph-based* and *active-linked* prototypes, this prototype seems to have been rated by participants as less satisfactory in satiating their curiosity with adequate feedback related to their interests (*DesireToExplore*: 5.2; *Feedback*: 4.5). One possible reason is that they did not know what questions to ask. The *chatbot-based* prototype provided six candidate questions, but these were insufficient to reflect all participants' interests. Another explanation is that it is difficult to communicate with the chatbot in an interrogative sentence format. We observed that most DHH participants just asked one question or refrained from asking at all because they were hesitant to type their query as a sentence. As a result, they soon ceased exploration to find more information.

Usability and **Interesting** show how convenient a prototype is to use and how interesting it is to explore information, respectively. The *graph-based* (*Usability*: 6.3; *Interesting*: 6.3) and *active-linked* (*Usability*: 5.6; *Interesting*: 5.9) prototypes are fairly easy to use and interesting, even though they only provide a very simple interaction functionality, i.e., clicking: *"It's fun to click"* (P11) and *"It was pleasurable to visit the nodes"* (P14). It would appear that the simple act of clicking precisely meets the need of users to explore an area of their specific interest instead of being informed of all contents: *"It's nice to be able to click and see only what I am curious about, not the sentences"* (P14). Most participants were interested in the *chatbot-based* prototype (*Interesting*: 5.3), but, as previously mentioned, many participants had a bad experience of formulating and typing their own input queries (*Usability*: 4.7). In fact, many museums are introducing chatbot services in order to help visitors ask questions about the artifacts and the museums, but this result signifies that the user-inquiry functionality has to be designed carefully for DHH individuals. For the *common* prototype, they evaluated that it was the least useful and the most boring since they only passively received information without any interaction (*Usability*: 3.9; *Interesting*: 3.8).

4.3 Potential and limitations of interaction styles (RQ3)

From the previous section (RQ2), we found that the *graph-based* prototype showed positive interaction results for DHH participants in all interaction metrics. However, in terms of

preference, we observed that it does not address the needs of all participants. As shown in Fig. 3, there were different preferences for each prototype. The *graph-based* prototype was the most preferred prototype, followed by *active-linked* and *chatbot-based*, with the *common* prototype ranking last. A total of nine of the 20 participants reported *graph-based* as the first preferred type, while more than half of the participants (11 of the 20 participants) reported *common* as the least preferred type. *Active-linked* was observed to have the same popularity as *graph-based* overall, but participants slightly preferred *graph-based* over *active-linked* as the first preference. Contrary to our expectations, the *chatbot-based* prototype showed a greater degree of preference compared to the other types, where the participants either greatly liked or disliked it.

4.3.1 Graph-based—Just display key points and I will explore by myself.

A total of 16 out of 20 participants had a positive experience with the *graph-based* prototype (ranking it first or second most preferable) since it is visually concise and the connection between presented facts is clear.

> *"I liked that it was not a sentence, and I liked the way that I could target information I was curious about by simply clicking on it. [The graph-based prototype] is an easy way for DHH individuals to find information."* – P14

The graph structure seems to appeal to DHH individuals who have a sense of repulsion to sentences; the content is summarized rather than presented in many sentences at once and the connectivity between information is visually mapped based on keywords. Regarding this aspect, the sign language interpreter who participated in this study also commented:

> *"[The graph-based prototype] may be easier for DHH people to understand because the graph structure seems to be similar to the structure of expressing sign language sentences (a way of expressing and arranging relationships between words)".*

Some participants (P11, P13, P18, P19, and P20) were highly interested in the interaction method itself that unfolds information progressively when clicked, reporting: "*Clicking (interaction) is fun, and expanding an idea when clicked is fun*" (P13). They also evaluated such methods positively because they could acquire in-depth information through expanding interaction. Those who favored the *graph-based* prototype explored nodes at a much deeper level than those who did not (47% vs. 6%).

> *"It was great to see more and more information spread out and expand about one aspect. In this way, it was possible to acquire in-depth information."*– P19

> *"It was good to expand, and it was fun and good to be able to dive deeper if you had any questions."*– P18

Since DHH individuals are reluctant to read long sentences where all information is presented at once in a line-by-line format, it would be advisable to display key content instead so that they can actively explore by themselves whenever they so desire, i.e., when they are curious. From this point of view, the *graph-based* prototype helped promote DHH individuals active exploration.

> *"To be honest, I can only passively acquire the given information when I am provided with a description through a sign language interpreter, but in the case of the graph style, it is good that I can acquire information actively. If this type were provided in the museum, I would use it again."*– P19

However, there were some participants who evaluated this prototype negatively (P1, P7, P10, and P16). One participant felt the graph format was rather complicated. Other participants pointed out that the contextual information of the existing description was lost in the graph because it was a summary of relationships only.

> *"It was complicated and made me dizzy. I don't know what it's trying to say"* – P7

> *"[The active-linked prototype] was easier to understand as additional information came out in the common description, but I didn't feel that the information was connected here (in the graph)."* – P1

4.3.2 Active-linked—Keep original context, just add more on it.

A total of 14 of the 20 participants selected the *active-linked* prototype as their first or second preferred style. Participants favoring this type responded extremely positively to the color highlighting of some words.

> *"It was good and helpful to provide additional information by categorizing it by color. Adding color rather than plain black text made it easier to access information.*" – P1

> *"Deaf people really like things with color. It feels like suggesting something I don't know, and it's easy to understand when I check it. I've never seen such a method before, but it's so nice. In particular, deaf people are really weak when it comes to text. If sign language is added here, there is nothing more to ask for."*– P14

As seen above, some preferred to add an exploration function while preserving the existing description itself. There were many opinions that it is better to be provided the option to click and explore additional information when curiosity arises while reading the context of an existing description.

> *"It was good because I gain additional information while reading intuitively."* – P6

> *"[Using the active-linked prototype,] the description was easy to understand because it was connected to the original sentence. I can click on it only when I don't know the meaning of a word or I am curious about it."* – P12

> *"It was more difficult than the graph style, but it was good to know the knowledge about difficult-to-find words right away.*" P14 (who selected the *active-linked* as the 2nd preference)

Conversely, those who exhibit a strong sense of reluctance to sentences had a negative experience with the *active-linked* prototype. These individuals preferred the keyword-based construction such as *graph-based* and *chatbot-based* rather than the sentence-based style (*common* and *active-linked*). P13 even stated that because the *active-linked* prototype displayed many sentences from the beginning, it was a little different from the *common* prototype.

> *"It was good to get pictures when I clicked buttons, but it was difficult to understand because of many sentences. I wanted to know in-depth, even if I got only one new fact, but it was hard to understand because the information was presented in complex and long sentences."*– P19

Some participants reported that the depth of exploration was shallow and could not satisfy their curiosity. This indicates that DHH individuals may want to actively explore information at a deeper level. In particular, participants (P2, P4, P5, and P15) who demonstrated a low preference for the *active-linked* prototype, preferred the types that could be explored deeply such as *graph-based* and *chatbot-based*. These individuals' average usage time in the *active-linked* prototype (137 s) was lower than the average time for all participants (145 s), but their time spent exploring the *graph-based* prototype (219 s) was higher than the average time for all participants (195 s).

> *"The active-linked button alone did not satisfy my curiosity. My curiosity hasn' been satiated much with this type."* – P19

> *"With this style, I discovered some new information such as the fact that the ship was sunk in Sinan, but I couldn't find any other information."*– P18

4.3.3 Chatbot-based—Immediate answer to my pressing questions.

Although many participants found it difficult to use the *chatbot-based* prototype, there were seven participants who selected this type as their first choice. These individuals expressed that they felt more freedom in being able to ask questions directly compared to the other types, dependent on context and exploration. Except for P10, who was 71 years old, six enjoyed interacting with the chatbot enough to spend approximately twice as much time as those who did not prefer this prototype (5.7 min vs. 3 min).

> *"The chatbot was fun to interact with as it gave answers that directly satisfied my curiosity, but the second (graph-based) doesn't have that aspect."* – P2

> *"It was the easiest to use because it gave feedback right away. It's nice to be able to focus on finding only what you're interested in. The rest [other types] are limited in that they provide set information."* – P4

> *"It was cool to be able to ask questions right away when I don't understand something. When will chatbot be launched in Gwangju National Museum? I want to use it soon."*– P15

A few participants responded positively to the candidate question buttons. Because DHH individuals did not know what sorts of questions to ask due to limited knowledge of history, they found the buttons more useful to obtain information. In general, the *chatbot-based* prototype was preferred by young people (P1, P2, P4, and P5 were all individuals in their 20s) as well as by people who were not burdened with writing sentences.

Even though the *chatbot-based* prototype provides a key-point-based construction, e.g., candidate questions, similar to the *graph-based*, the rest of the participants found it difficult to interact with. Unanswered queries could be answered only by typing questions due to the limited number of buttons implemented in the *chatbot-based* prototype. However, many participants simply pressed the candidate question buttons and very few typed a question directly (the average number of direct questions was 1). Owing to the difficulty of formulating sentences, many felt uncomfortable interacting with the chatbot. Notably, if they do not use the user-inquiry function and simply press the buttons, the *chatbot-based* prototype may be a little different from the *graph-based* or *active-linked* types.

> *"It was difficult because I was not familiar with chatbots. It is burdensome to have to type something in a full sentence."*– P20

> *"I think it would be difficult for DHH individuals to use a chatbot because they have difficulty writing sen-*

tences. Still, it's good to ask questions about topics I don't understand. However, this style feels similar to the graph-based style in that I get feedback when I press a button. Both the graph and the chatbot felt similar to me." – P14

In other words, unless DHH individuals can use the 'direct question' function, which is the advantage of chatbots, there is no advantage to the *chatbot-based* for them compared to the other prototypes. Thus, researchers seeking to provide a *chatbot-based* description may need to focus more on tailoring the specifics of the recommendation function to adapt to DHH individuals' needs.

4.3.4 Common (conventional) – That's why it is common.

There was one person who preferred the *common* prototype. He expressed confidence in writing and reading sentences to the extent that writing is one of his preferred languages. He also stated that he disliked unfamiliar and complicated things and felt that the existing description was sufficient for him.

"I liked the general description and its simplicity. I don't really have any questions, and it's the type I've seen a lot in museums." – P7

Thus, it would appear that those possessing strong literacy skills who can obtain enough information with the existing description would be sufficiently satisfied with the *common* description style.

5 Discussion

The results collected and analyzed in the present study allow us to extend the discussion beyond a simple comparison of the museum description styles. In what follows, we discuss implications and suggestions for enhancing the museum experience of DHH individuals based on their present museum experience and the results of our study.

5.1 Potentials of text description styles for DHH individuals

Our results show that besides sign language content, the text-based description commonly seen in museums and familiar to hearing individuals can be improved in terms of the level of information accessibility and exhibit interaction. Although they are interested in museum touring and historical knowledge, poor information accessibility limits them from receiving rich information and achieving a satisfying museum experience. As the majority of DHH individuals have a lower degree of literacy compared to hearing people, providing some additional visual materials and explanations to supplement the common description made them feel more satisfied and cared for as museum visitors. However, in addition to these supplements, the method of provision is also an important aspect to consider when moving forward in attempts to enhance DHH individuals' museum experiences.

5.2 Text descriptions are as important as sign language descriptions

When we asked the participants to suggest a new description style during post-interviews, most expressed a strong desire to receive additional sign language content, as expected. However, they also said that sign language alone may be insufficient in conveying descriptions. Sign language varies from country to country, but only approximately 4.5% of the words in the Standard Korean Language Dictionary appear in the Korean Sign Language Dictionary. Unregistered words are often expressed in fingerspelling (words spelled in a sign language representation of the alphabet) or combinations of several words. It was confirmed that the museum's sign language descriptions expressed single Korean words in protracted fingerspelling or were truncated by excluding complex information from the original description. As a result, not all information from the original descriptions may have been included in the sign language content. This, in turn, suggests that sign language alone may be insufficient in providing a fully satisfying museum experience.

Numerous participants felt that it is more useful to provide both sign language and text when explaining museum contents rather than to provide only sign language descriptions. For example, P4 stated, *"It is difficult to distinguish the meaning of sign language because there are many identical words. Sign language consists of short words, so text must be provided as well to facilitate clear understanding."* P13 added, *"If a sign language video is provided, it is easy to understand, but if I watch only sign language, I usually miss the content. Sign language has no word order, so having the text together helps improve comprehension."*

There was also an opinion that participants should be able to select the format they find most useful. Our results showed that although they share the common attribute of "deafness", participants were diverse in terms of literacy skills, preferred language, curiosity, interest, and desire to explore. Therefore, we need to respond to their various attributes and preferences, present them with different types of content, and allow them autonomy to select the description method that works best for them. The concept of providing autonomy is aligned with a prior study that suggested autonomy should be ensured [2].

"Sign language and text should be provided together, but I wish I could choose. I hope that deaf people who need sign language will receive sign language and deaf people who prefer text will receive text so that they can see the description. The best and most flexible method would be to provide both options and allow the viewer to select what works best for him/her. Neither option is complete, so the text and sign language should be provided at the same time." – P14

5.3 Shifting from passive touring to active touring

Our results showed that the interaction of DHH individuals with museum descriptions was improved compared to the common description style by merely adding a simple and small interaction such as click or touch. Although it was a minor change to add a small interactive element to the common text, it significantly increased participant satisfaction. As indicated by the answers to RQ1, since DHH individuals desire active and explorative touring rather than passive one-way information consumption, museums are advised to provide interactive content. In addition to a sign language, it is possible to attract DHH individuals' interaction through content that can work well for both DHH and hearing individuals.

5.4 High demands for personal touring

As mentioned, DHH individuals had no choice but to schedule a group tour with other deaf people accompanied by sign language interpretation when visiting a museum. Therefore, support for individual and active touring for DHH individuals is necessary. Recently, museums have been offering personalized touring using personal devices, commonly referred to as "Bring Your Own Device" tours [39]. If researchers want to create museum content for diverse target audiences, especially DHH visitors, they may consider the various description styles evaluated in our study as potential design considerations.

6 Limitations and future work

Our study has several limitations. First, we observed that sign language is effective in conveying information to DHH individuals, but we focused on the potential of "text" descriptions as the modality by which DHH individuals obtain information. Reflecting on the interview results that indicate that DHH individuals desire information conveyed in both text and sign language and prefer to be able to choose between text, sign language, or both modes when obtaining information, the future extension of current prototypes with sign language would be optimal. In this regard, the characteristics of the particular sign language used must be considered, since sign languages vary by country and region.

Second, although we aimed to recruit a balanced age population, the majority of DHH participants (11 out of 20) were in their 40s and 50s. Because there is a difference between the education level of young and middle-age DHH individuals, our participants may not be generalizable to all DHH individuals. Subjective evaluation scores and preferences between description styles will slightly differ when balancing the age population of the participants. Future work should pay more attention to DHH individuals' demographics, especially balancing age populations and education levels.

Third, we intended to conduct this study in an actual museum, but due to the COVID-19 restrictions we were unable to use actual museum facilities. Thus, future studies should conduct experiments in museums to better understand the usage aspects of each descriptive style of DHH individuals in real-world situations.

Fourth, our study focused on a small sample of only four artifacts. Thus, the findings should be verified by applying them to other artifacts with different levels of descriptions throughout the museum. We also need to ensure that our findings can be applied in other domains (e.g., art museums, science museums, etc.) besides history museums. Through future works we can apply our results to various domains to validate their veracity.

Finally, our study was evaluated focusing DHH visitors with low literacy levels. However, considering that text descriptions are common in museums and more familiar to hearing visitors, our approach can also be applied to hearing people. Therefore, future research must validate and further develop how our approach affects the museum experience of various visitor groups (e.g., hearing people and people with cognitive deficits or learning difficulties).

7 Conclusion

Museum text descriptions have the potential to expand visitors' experience of artifacts through detailed and rich information, but accessibility and experience have been considerably limited for DHH visitors with low reading ability. This paper proposed three interactive description methods designed under the considerations of exploration, construction, and user-inquiry. We observed the strong potential of the *graph-based* description style in museums for DHH visitors, which allows them to explore descriptions according to their interests (progressive exploration) and presents concise visuals rather than overwhelming users with all explanations at once (keypoint-based construction). According to the various preferences of DHH participants, the *active-linked* and *chatbot-based* styles also significantly improved their

experience compared to the conventional description. The *chatbot-based* style showed potential in terms of interesting interaction, but it requires a careful design to ensure usability for DHH individuals. The post-interview reflects the various needs and preferences of DHH individuals in museums, such as individual and active touring and a high preference for color highlights. Although this study focused on DHH individuals, our approach is not limited to DHH visitors. Considering that textual description is the most basic form of description in museums, our approach can be applied to a general audience to provide an accessible and rich experience in museums. We hope our approach and insights could be beneficial for future works studying museum contents for DHH visitors, and more generally, for various groups of visitors.

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Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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