# Designing Near-surface AR Interaction for Social Learning of Group Visitors

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**Abstract**

Smartphones enhance museum experiences by providing educational and entertaining content, but their use can also divert attention away from physical exhibits, a key component of visitor engagement. To address this challenge, we introduce near-surface AR interaction (NAI), which utilizes a "magic lens" effect to overlay digital content when a mobile device is placed on the surface of an exhibit. This study investigates the impact of NAI on social interactions and learning experiences in museum settings. Through a controlled experiment, we compared NAI with conventional mobile interaction (CMI) among adult-adult and parent-child dyads. By analyzing recorded dialogues, we found that the spatial configuration of NAI significantly increased conversational engagement and enhanced collaborative learning. These findings highlight how spatially-aware AR interactions can mitigate the isolating effects of mobile screens and foster richer social experiences in museums. This research contributes to the design and evaluation of AR-based interactive systems for cultural heritage and educational environments.

**Keywords**

Near-surface AR interaction, museum, interactive exhibit, visiting experience

## 1. Introduction

Since the early 2000s, museums have increasingly incorporated mobile devices (e.g., PDAs and PMPs) to enrich visitor experiences by providing supplementary digital content alongside physical exhibits. With the widespread adoption of smartphones, visitors can now access such information seamlessly while moving through exhibitions, using either museum-provided devices or their own [1]. This transition has been associated with several benefits, including improved access to high-quality interpretive information [2, 3], support for multi-sensory engagement [4], and enhanced immersion within exhibition environments [5, 6].

Despite these benefits, mobile interaction also introduces well-documented challenges. A prominent concern is the "lure of the screen," in which visitors attend primarily to on-screen content, potentially diverting attention from physical exhibits and reducing social engagement [7]. This is consequential because museum experiences often involve meaning-making through direct, embodied engagement with artifacts and installations [8]. Moreover, museum visits are frequently social rather than solitary, motivating prior efforts to foster visitor-to-visitor interaction [9]. When attention is predominantly directed toward personal screens, however, engagement may shift toward digital overlays at the expense of shared noticing and discussion around physical exhibits, potentially weakening social and immersive aspects of the visit.

To mitigate these issues, museums and science centers have increasingly explored Augmented Reality (AR) approaches. Mobile AR is particularly practical, as it allows visitors to access augmented information while maintaining visual access to exhibits and the surrounding environment. However, conventional mobile AR typically requires visitors to hold devices at a distance and interact via screen-based touch input, which can reproduce the same separation between visitors and physical exhibits.

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Recent work has therefore investigated interaction techniques that more directly couple digital content with physical artifacts. Yi et al. [10, 11] proposed near-surface AR interaction (NAI), in which a mobile device is placed directly on the exhibit surface so that augmented content appears spatially aligned with the exhibit itself. This configuration allows visitors to engage with the exhibit and the digital overlay within a unified spatial frame. Prior studies further suggest that NAI can increase visitor interest and encourage more frequent physical interaction with exhibits.

While existing research has primarily emphasized individual engagement, we hypothesize that reconfiguring the spatial relationship among exhibit, device, and visitor may also influence social interaction. This hypothesis is consistent with Morrison et al. [12], who reported that "magic lens" interactions with physical artifacts (e.g., paper maps) supported richer social interaction by establishing a shared visual reference. Their findings imply that proximity-based mobile interactions may facilitate co-attention, shared viewing, and conversation among visitors.

Building on these insights, this study examines how NAI affects visitor social interaction in a museum environment. Specifically, we investigate whether altering the spatial configuration between exhibit, device, and visitor changes conversational engagement and collaborative behaviors. To this end, we designed a controlled exhibition incorporating NAI and conducted an experiment to analyze visitor conversations and social behaviors. By clarifying how spatial interaction design shapes social learning, this work contributes to ongoing discussions on improving museum experiences through AR-based interactive systems.

## 2. Related Works

### 2.1. Social Learning in Museum Context

Group visiting is a defining characteristic of museum experiences. Visitors commonly attend museums in socially meaningful configurations—such as parents with children, classmates on field trips, or adults visiting with partners—and these relationships shape how exhibits are experienced and interpreted. Falk and Dierking [13] emphasize that museum visiting is situated within a sociocultural context, where interactions among companions (and with other visitors) substantially influence learning and meaning-making. Building on this view, Perry [14] conceptualizes engagement in museums as comprising physical, emotional, intellectual, and social dimensions, highlighting social engagement as particularly consequential in informal learning settings.

Reflecting this emphasis, approaches to assessing museum learning have expanded beyond classroom-style pre- and post-tests toward observational measures that capture social processes as they unfold. In this line of work, visitors' talk has been treated as a central indicator of learning-relevant engagement. Allen's coding scheme [15], which categorizes utterances into perceptual, conceptual, affective, connecting, and strategic talk, has been widely adopted to analyze visitor interactions and learning in museums and related informal environments. Prior studies have applied this scheme to examine learning outcomes and engagement in science education settings [16] as well as behavioral indicators of engagement in museums and zoos [17]. Consistent with this tradition, our study focuses on visitors' conversational interaction as a primary lens on social learning, complemented by analyses of embodied behaviors such as touching exhibits, gestures, and interpersonal proximity.

### 2.2. Mobile Spatial Interaction in Museum Context

Mobile spatial interaction has been studied as a means to connect the physical context of exhibitions—such as visitors' locations, movement paths, and exhibit-specific sites—with digital content that supports interpretation and engagement. By coupling information with physical context through mobile devices, museums can provide visitors with convenient access to high-quality interpretive resources. Technologies such as QR codes and RFID/NFC enable digital content to be anchored to specific places or objects, supporting efficient delivery of large volumes of information [18, 3, 2]. Prior work has further argued that using smartphones as tangible probes—through pointing or touching to retrieve exhibit-related content—can be more intuitive and may better support learning than purely menu-driven access [19, 20]. Beyond location-triggered information delivery, systems that sense visitors' movement and provide situated content accordingly have also been explored [21, 22, 23, 24].

Mobile AR has become a prominent approach within this broader area, presenting digital information as if it were spatially aligned with physical exhibits when viewed through a device screen [25, 26, 27]. A substantial body of work has demonstrated the potential of AR to support learning and engagement in educational contexts [28, 29], and this potential is particularly relevant for museums as open-ended learning environments [30]. Nevertheless, mobile spatial interaction can also introduce attentional trade-offs. Prior studies note that mobile screens may draw visitors' attention away from exhibits and promote individualized viewing, potentially separating visitors from companions as well as from the physical artifacts [7]. Conventional mobile AR shares this limitation, as it typically requires visitors to interact through a handheld screen at some distance from the exhibit, reinforcing screen-centered engagement.

### 2.3. Near-surface AR Interaction in Museum Context

The notion of integrating digital information with physical space through handheld devices can be traced to Fitzmaurice's early work on situated information spaces and spatially aware palmtops [31]. Since then, researchers have explored interaction techniques that treat mobile devices as tangible viewers over physical surfaces, often framed as near-surface augmentations [32, 33, 34, 35] or spatially aware handhelds [36, 37, 38, 39, 40, 41]. These techniques are closely related to "magic lens" and "peephole" paradigms, enabling users to reveal, filter, or manipulate information by positioning a device over a localized region of a larger information space.

Within this lineage, near-surface AR refers to interactions in which a mobile device is placed on, or held extremely close to, a target surface such that the system can estimate the device's position and orientation relative to that surface and render spatially aligned visual augmentation on the screen. This typically requires device-side spatial awareness to robustly track the relative pose between the device and the physical surface. Prior work has demonstrated the usability of near-surface interactions for tasks such as search and navigation on large workspaces [42, 43]. Leigh et al. [33] further explored near-surface scenarios across multi-device settings and validated their practicality. Importantly, near-surface interaction has also been applied to non-digital artifacts. For example, Xu et al. [35] presented a near-surface augmented reading system that overlays contextual information on printed text, and earlier work demonstrated point-and-click interaction between a PDA and a paper map [44]. Coconu et al. [32] similarly implemented tangible navigation on paper maps using neARtracker [36].

Extending these approaches to museum contexts, Yi et al. [45, 10] proposed near-surface AR systems designed for practical exhibit interaction. They argue that near-surface AR can strengthen hands-on engagement by encouraging direct physical interaction with exhibits while providing access to digital content [11]. Because the device is positioned directly above the exhibit surface, visitors may more readily shift attention between the artifact and the augmentation. This configuration has been suggested as a way to retain the benefits of mobile information delivery while reducing the disconnection often associated with screen-centered museum interaction.

## 3. Exhibition Design for User Study

As depicted in Figure 1, near-surface AR interaction (NAI) forms a different spatial configuration from conventional mobile interactions (CMI) such as QR codes, RFID, and mobile AR. In CMI, visitors typically view mobile screens individually, whereas NAI reduces the distance between exhibit–visitor and visitor–visitor by placing the device directly on the exhibit surface, making the screen more shareable. Inspired by Morrison et al. [12], who showed that combining physical artifacts with magic lens interaction diversifies social interaction, we hypothesized that applying NAI in exhibitions would positively influence visitors' social interactions and collaboration, leading to improved learning experiences.

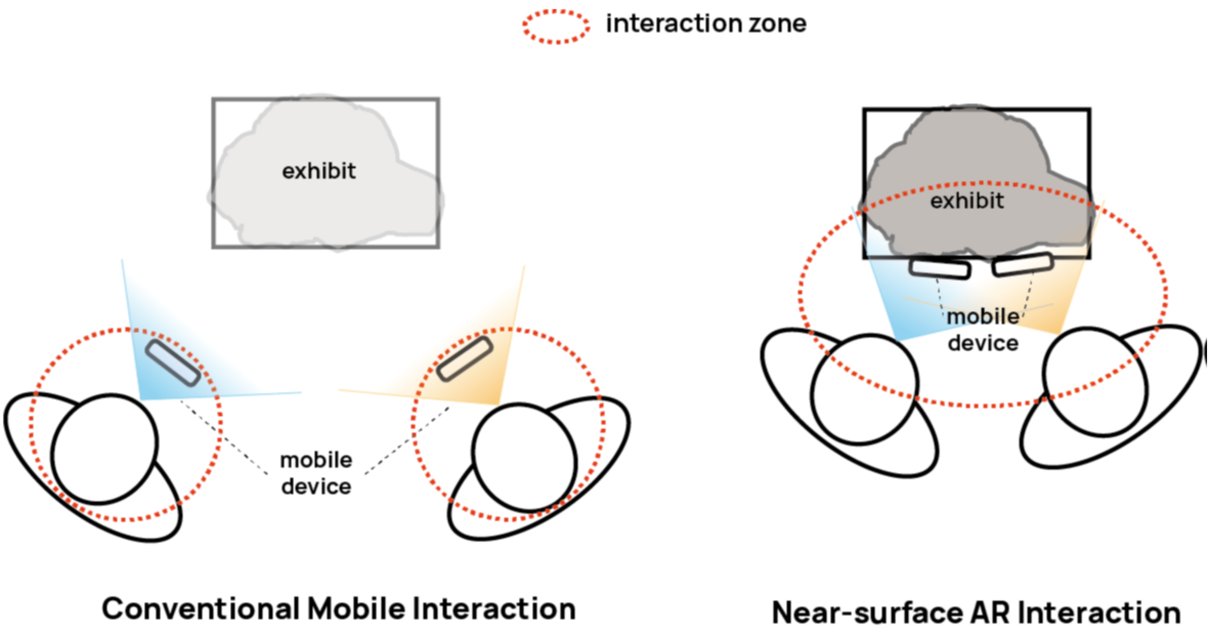


**Figure 1:** Relative configuration of an exhibit, a mobile device, and a visitor in conventional mobile interaction and near-surface AR interaction.

To conduct a controlled comparative study, we organized the exhibition content in consultation with professional curators and directors from the National Science Museum in Daejeon, South Korea. To minimize environmental variability and ensure safety during COVID-19, the exhibition was constructed in an in-lab exhibition hall.

The exhibition theme was "The world of bees," a common science museum topic suitable for NAI. The space (6.5m × 8.2m) consisted of 11 sections (Figure 2), covering bee types, anatomy, growth process, and characteristics. Five sections were panel-based, one was hands-on, two presented video materials, and three incorporated NAI. Physical exhibits were constructed using low-poly cardboard papercraft to balance production cost and visual clarity.

The experiment examined how NAI's spatial formation among visitors, exhibits, and devices influenced social interaction compared to CMI. The goal was not to compare AR technologies per se, but to isolate the effect of spatial proximity on social behavior.

### 3.1. Exhibits with Near-surface AR Interaction

We implemented NAI using the WonderScope module [45], a compact smartphone attachment that detects RFID tags and overlays digital content onto physical exhibits with geometric registration. When placed on an exhibit's RFID tag, the device displays corresponding visuals and audio, aligning digital content with the exhibit surface.

Three sections (Sections 3, 6, and 11 in Figure 2) incorporated NAI and were interspersed among general exhibits to enable natural comparison of visitor behavior.

#### Internal anatomy of bees

A large panel (1.3m × 1.2m) displayed a bee image. When participants placed the device on RFID tags positioned on the panel, anatomical overlays appeared on the smartphone screen aligned with the bee image (Figure 3). As users moved the device, internal organs were visualized, and brief functional descriptions appeared when targeting specific features. Users could filter digestive, nervous, and circulatory systems using on-screen buttons. This content enabled participants to explore internal structures and understand anatomical relationships, such as honey storage and the connection between the stinger and digestive system.


**Figure 2:** "The world of bees" exhibition setup for the experiment. The highlighted three sections are the exhibits with the NAI device.


**Figure 3:** "Internal anatomy of bees" content shows a bee's anatomy and its physiological functions. (a) The panel of the exhibit. (b) Exploring the internal organs using the device. (c) Selecting an organ system.

### The growth process of bees from a larva to an adult

This exhibit consisted of hexagonal hive cells representing developmental stages (Figure 4). Eggs and adult bees were visible as physical models, while larva and pupa stages were sealed to prompt exploration. By placing the device on RFID tags, participants viewed 3D models of each stage accompanied by brief explanations. Moving the device enabled inspection of metamorphosis inside the cell, supporting understanding of life cycle transitions.

### What is inside the bee hive?

At the center of the exhibition, a large oval beehive model (130cm diameter × 180cm height) constructed from cardboard invited exploration (Figure 5). Two RFID tags were attached on opposite sides. When activated, the device displayed internal honeycomb structures aligned with the surface. Participants could move the device along the hive to observe cells where eggs are laid, larvae develop, and honey is stored and matured. This section allowed participants to explore hive organization and functional roles through spatially aligned visualization.

**Figure 4:** "The growth process of bees from a larva to an adult" content shows developmental changes. (a) Physical exhibit. (b) Participant interaction. (c) Screen visualization.

**Figure 5:** "What is inside the bee hive?" content shows internal hive cells and their functions. (a) Physical structure. (b) Interaction. (c) Screen visualization.

# 4. User Study

## 4.1. Experimental Setup and Procedure

The comparative study aimed to identify cues for social learning by examining participants' conversations and behaviors during an exhibition visit. To isolate the effect of spatial formation, we designed a control condition that differed from the near-surface AR interaction (NAI) condition only in the navigation method used to explore the information space. The control condition was based on conventional mobile interactions (CMI), which commonly underpin QR-code-, RFID-, and mobile-AR-based experiences: visitors first recognize an exhibit via a marker or tag and then navigate or manipulate digital information through touch-based on-screen interactions.

In the CMI condition, participants used a smartphone equipped with the same WonderScope module and accessed the same information space by touching and swiping on the screen. Participants in both conditions followed an identical procedure until placing the device on the RFID tags attached to the exhibits; thereafter, only the navigation method differed. Whereas participants in the NAI condition explored the situated information space by moving the device along the exhibit surface, participants in the CMI condition explored the corresponding content through on-screen gestures. The two conditions shared the same smartphone–module configuration and identical application GUI settings, with one exception in the bee anatomy content (Figure 6). Because the anatomical illustration exceeded the smartphone's display size, we provided an additional minimap in the CMI condition to indicate which region of the bee's body was currently shown. This design enabled us to attribute observed behavioral differences primarily to variations in spatial formation rather than differences in content or interface structure. To avoid carryover effects associated with experiencing identical content multiple times, the study adopted a between-subjects design.

Participants were recruited through announcements at the National Science Museum and posts on the institution's online community. The sample consisted of dyads, including parent–child pairs and pairs of close friends who had previously visited exhibitions together. Upon arrival, participants received a brief explanation of the study and completed a consent form for data collection. Each dyad was


**Figure 6:** Interaction method in each condition for the bee exhibition. Both conditions followed the same procedure until RFID tag recognition; only the method for navigating the information space differed.

**Table 1**
Coding scheme with five categories for understanding learning talk in museum exhibitions [15].

| Categories | Subcategories | Definition | Example |
|---|---|---|---|
| Perceptual | Identification, Naming, Feature, Quotation | All kinds of talk drawing attention to stimulus from surrounding exhibits. | "Oh, there is the honey pocket", "It looks fluff..." |
| Conceptual | Simple Inference, Complex Inference, Prediction, Metacognition | Cognitive interpretations of whatever about the exhibit and the surroundings. | "Are they die after sting?", "So...they actually chew the honey." |
| Connecting | Life-connection, Knowledge-connection, Inter-exhibit connection | Any kind of talk making specific connections between exhibits and some other knowledge or experience of visitors. | "Oh, I heard about that...", "I've never been stung by them" |
| Strategic | Use, Meta-performance | Discussion of how to use exhibits and the surroundings. | "Why dont you see it carefully?", "Where is the another sticker?" |
| Affective | Pleasure, Displeasure, Intrigue, Surprise | All expressions of feeling about the exhibits. | "It's so cute!", "It's little bit disgusting..." |

randomly assigned to either the NAI or CMI condition and was provided with a smartphone equipped with WonderScope. After receiving instructions on device use, participants were asked to explore the exhibition freely, moving through the space at their own pace and using the device at RFID-enabled exhibits. As shown in Figure 2, cameras installed at both ends of the exhibition hall captured where participants stopped and how they moved. In parallel, the smartphones recorded participants' verbal interactions. A researcher also remained in the space to observe participants and take field notes. After participants indicated that they had sufficiently viewed the exhibition, they returned the devices and completed a short questionnaire regarding their exhibit preferences.

### 4.2. Participants

A total of 24 dyads consented to data collection and participated in the experiment. For parent–child dyads (Adult–Child; AC), children were required to be at least seven years old to ensure they could independently hold and operate a smartphone with the WonderScope module. For adult dyads (Adult–Adult; AA), recruitment was restricted to pairs who had previously visited exhibitions together, as familiarity was considered important for eliciting naturalistic, exhibition-related conversation.

The NAI condition included 6 AC dyads comprising adults (3 males; Age $M = 40.0$, $SD = 5.7$) and children (4 males; Age $M = 9.0$, $SD = 1.7$), as well as 6 AA dyads (6 males; Age $M = 24.8$, $SD = 0.8$). The CMI condition included 6 AC dyads comprising adults (4 males; Age $M = 43.0$, $SD = 3.8$) and children (3 males; Age $M = 8.7$, $SD = 1.4$), and 6 AA dyads (8 males; Age $M = 27.8$, $SD = 3.0$).

### 4.3. Measures and Analysis

#### a) Conversation Analysis

From entry to exit, participants moved freely through the exhibition while carrying the provided smartphone with WonderScope and used it at RFID-enabled exhibits (Sections 3, 6, and 11). Cameras installed at both ends of the exhibition space recorded participants' locations and observable behaviors, while the smartphones captured audio of both members' verbal interactions. We synchronized the video and audio recordings to annotate each utterance with the speaker identity, spatial location, and the exhibit-related topic under discussion.

Utterances were first filtered to remove speech unrelated to the exhibition and then segmented into idea units. To reduce redundancy, we merged echoes, defined as repeated expressions or immediate repetitions prompted by a companion. Two coders subsequently classified all segmented utterances using Allen's learning talk scheme for museum settings (Table 1), which captures visitor responses to stimuli in the exhibition environment. Inter-coder reliability indicated an almost perfect level of agreement (Cohen's $\kappa = 0.89$). For subsequent analyses, we used the coded dataset produced by the primary coder.

Although the learning talk scheme is commonly summarized using category proportions, we conducted statistical comparisons on the absolute frequencies of coded utterances to obtain a more sensitive measure of conversational differences. We measured (1) the total viewing time for the full exhibition and (2) the time spent using the WonderScope device at the three RFID-enabled exhibits (Sections 3, 6, and 11 in Figure 2). Because visit duration varied across dyads, we normalized conversational activity by dividing each dyad's number of utterances by device-use time, yielding an utterance rate. This analysis allowed us to compare conditions in terms of how long participants engaged with exhibits, how extensively they used the device, and how actively they communicated with their companion. We then performed a two-way ANOVA to test for differences as a function of interaction method (NAI vs. CMI) and dyad relationship (AC vs. AA).

#### b) Behavioral Observation and Preference Survey

A researcher remained in the exhibition hall to observe participants and take field notes throughout each session. We examined these notes alongside the video recordings to derive ancillary observations that could contextualize the conversation analysis results, with particular attention to nonverbal social behaviors and any notable usability or engagement issues when interacting with RFID-enabled exhibits. After completing the visit, participants reported which of the three device-enabled exhibits they preferred most.

## 5. Result

#### a) View Time

Participants spent approximately 10–12 minutes viewing the entire exhibition and used the provided device for nearly half of that duration in both conditions. A two-way ANOVA indicated that neither interaction method nor dyad relationship had a significant effect on total exhibition viewing time or on the total time spent at the three device-enabled sections ($p > 0.050$). We also found no significant

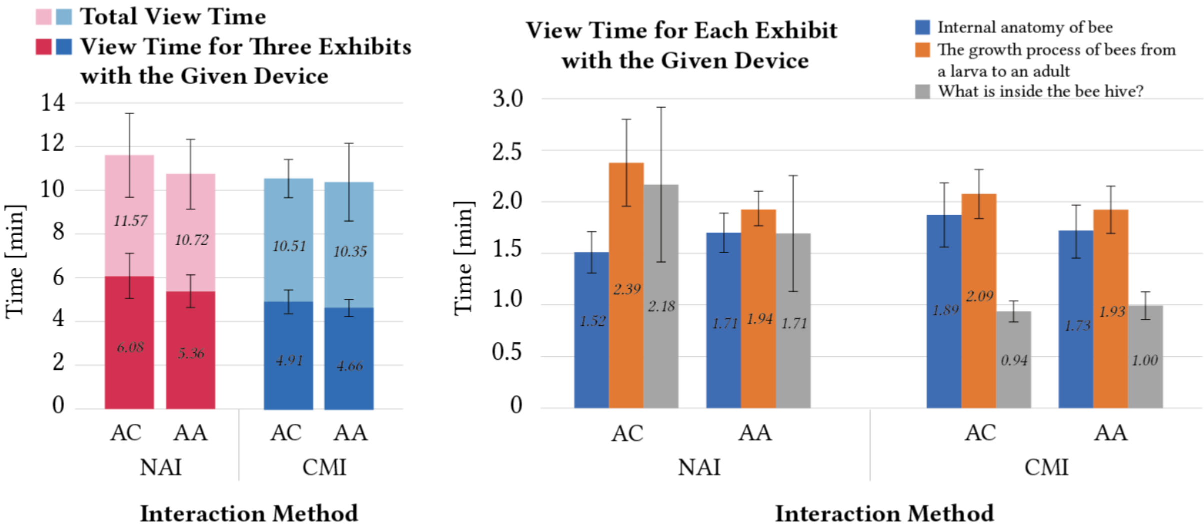


**Figure 7:** Results of the comparison of the total view time and the viewing time for the three device-enabled exhibits. No significant effects of interaction method or dyad relationship were observed.

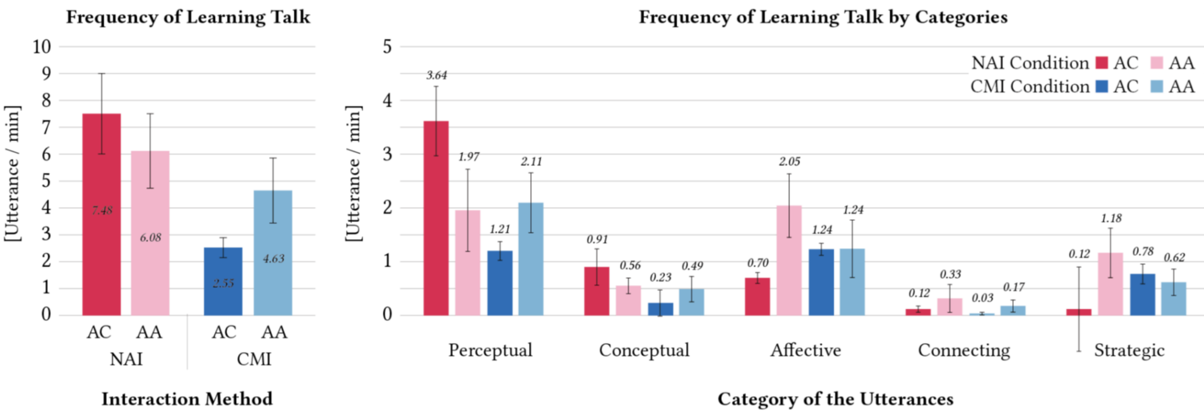


**Figure 8:** Results of the comparison of the frequency of learning talk and its categories across conditions and dyad relationships.

interaction effect. These results suggest that both conditions supported sustained engagement with the exhibition and that the device meaningfully contributed to participants' time on task during the visit.

When examining viewing time across the three device-enabled exhibits, we again observed no significant main or interaction effects of interaction method or dyad relationship ($p > 0.050$). Descriptively, participants in both conditions spent the longest time on *"The growth process of bees from a larva to an adult."* Additionally, participants in the NAI condition tended to spend more time on *"What is inside the bee hive?"* than those in the CMI condition, suggesting that NAI may have encouraged longer exploration when content was distributed over a larger physical surface. However, this trend did not reach statistical significance.

### b) Learning Talk

To assess conversational engagement related to social learning, we computed each dyad's learning talk frequency by dividing the number of coded utterances observed at the three device-enabled exhibits by the corresponding viewing time. A two-way ANOVA (Figure 8, left) revealed a significant main effect of interaction method on learning talk frequency ($F(1, 20) = 7.095$, $p = 0.015$, $\eta^2 = 0.262$), whereas dyad relationship did not have a significant effect ($p > 0.050$). Thus, dyads in the NAI condition produced learning-related utterances at a higher rate than those in the CMI condition. Descriptively, this difference appeared more pronounced among AC dyads, although the interaction between interaction method

**Figure 9:** Behavioral differences in AC dyads by interaction method. The CMI condition (right) yielded more dyad splits than the NAI condition (left).

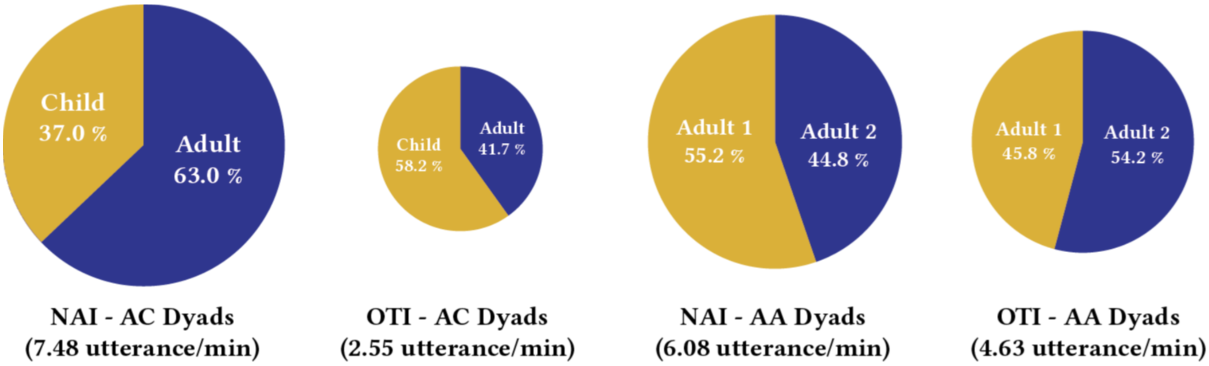


**Figure 10:** Proportion of utterances produced by each dyad member. AC dyads exhibited more asymmetric participation than AA dyads.

and dyad relationship was not significant ($p > 0.050$).

We further compared the frequencies of learning talk categories (Figure 8, right). The dyad relationship had a significant main effect on affective talk ($F(1, 20) = 8.371$, $p = 0.009$, $\eta^2 = 0.295$). Inspection of the coded utterances suggests that AA dyads produced a broader range of affective subcategories and more frequent affective expressions (e.g., disgust or cuteness) than AC dyads, consistent with adults' greater tendency to verbalize evaluative and emotional reactions during museum viewing.

In addition, we observed a significant interaction between interaction method and dyad relationship for perceptual talk ($F(1, 20) = 4.890$, $p = 0.039$, $\eta^2 = 0.196$). Specifically, AC dyads exhibited higher perceptual talk rates in the NAI condition than in the CMI condition, whereas AA dyads showed the opposite trend. For AC dyads, perceptual utterances primarily reflected identification and feature-focused remarks, typically initiated by parents attempting to locate and interpret displayed information, followed by children's responses. This pattern suggests that NAI may have supported more sustained joint attention and perceptual grounding for parent–child pairs.

Behavioral observations provided converging evidence for this interpretation. We counted instances in which a dyad split (i.e., separated into different sections) and conversational engagement ceased for more than two minutes at least once during the visit; the two-minute threshold corresponded to the average time spent viewing a single exhibit. More dyads in the CMI condition split (5/12) than in the NAI condition (2/12). Notably, all AC dyads in the NAI condition moved together throughout the exhibition while frequently referencing each other's screens and continuing conversation. In contrast, three out of six AC dyads in the CMI condition split when one member finished interacting with a device-enabled exhibit earlier and moved on to another exhibit (Figure 9).

Finally, we compared the proportion of utterances contributed by each dyad member to examine conversational initiative (Figure 10). AA dyads showed relatively balanced participation across both conditions. In AC dyads, however, adults accounted for a larger proportion of utterances in the NAI condition than in the CMI condition. Taken together with the higher overall learning talk rate in NAI, this suggests that NAI may have increased parents' explanatory or guiding talk directed toward children during the shared exploration.

#### c) Preference for Exhibits

After completing the visit, all 24 dyads (48 participants) reported which of the three device-enabled exhibits they found most interesting and explained their reasons. Responses differed markedly between adults and children. Adults most frequently selected *"The growth process of bees from a larva to an adult"* (NAI: 10/18; CMI: 9/18) or *"Internal anatomy of bees"* (NAI: 4/18; CMI: 6/18), whereas children most frequently selected *"What is inside the bee hive?"* (NAI: 5/6; CMI: 3/6) as their top choice. Importantly, this preference pattern was consistent across interaction methods.

Adults often described the sealed-cell metamorphosis exhibit as engaging because it enabled a "see-through" experience of a sequential developmental process that is not directly visible in the physical artifact. For the anatomy exhibit, adults reported enjoyment in locating where familiar bee functions (e.g., honey storage or stinging) corresponded to specific internal organs. Overall, adults appeared to prefer exhibits in which the physical structure and digitally revealed content aligned with their expectations, which is consistent with the longer viewing times observed for the development content (Figure 7, right).

In contrast, children preferred the beehive exhibit, which was comparatively intuitive and offered a large surface that afforded movement around the model. Children in the NAI condition, in particular, frequently mentioned that the hive's size supported walking around while exploring, and that the bee sounds increased the sense of realism. These comments suggest that children valued the embodied exploration afforded by moving the device across a sufficiently broad physical surface. This preference is also consistent with the descriptive trend that NAI participants spent more time at the beehive exhibit (Figure 7, right).

## 6. Discussion

Overall, participants spent a comparable amount of time viewing the exhibition across both conditions. This suggests that the content and task demands were reasonably balanced; otherwise, substantial differences would likely have emerged in total viewing time or in the time allocated to each section. Nevertheless, the conditions differed in the nature of visitors' conversations. More learning-oriented talk occurred under the NAI condition, and AC dyads in particular exhibited more perceptual talk. Visitors' viewing styles also diverged: under the CMI condition, dyads separated more frequently, which may have reduced opportunities for sustained learning talk. In the following, we discuss how these patterns relate to near-surface AR interaction and whether they indicate a positive contribution to social learning in museums.

### 6.1. Difference of Conversation Frequency According to the Dyads' Relationship

Whereas AC dyads showed more cognitive talk with NAI, AA dyads exhibited only a small difference in perceptual talk between conditions. Given that AA dyads' viewing time did not significantly differ, this pattern is unlikely to reflect reduced engagement or interest. Rather, it suggests that increased visibility of each other's screens or closer interpersonal proximity did not, by itself, elicit more conversation among adults. This may be explained by relationship-specific conversational goals. In AC dyads, parents often assumed a guiding role, sustaining goal-directed, pedagogical exchanges (e.g., prompting attention and interpreting exhibits). NAI appeared to support this continuity by enabling shared engagement around the exhibit without requiring the dyad to physically separate. In contrast, adult-to-adult conversations tended to shift topics quickly and to include more affective expressions oriented toward sharing impressions rather than instructing one another. With shorter conversational cycles and potentially stronger preferences for intermittent or solitary viewing, AA dyads may have been less sensitive to interaction proximity. Accordingly, near-surface AR may be particularly beneficial for AC groups by reducing the likelihood that a parent's attention is diverted away from the child due to screen-focused viewing.

### 6.2. Sharing Mobile Screens, More Opportunity to Talk

This study was designed to approximate a natural museum visit by allowing participants to move freely while using the device. Despite the absence of instructions to remain together, most groups traversed the exhibition as a dyad from start to end. Beyond co-located viewing, participants in the NAI condition more frequently oriented toward one another's device screens and engaged in joint talk. We interpret this as an effect of relocating the device from an individual's eye-level "personal" viewing space to a position nearer the exhibit surface. In this configuration, the device can function as a socially accessible entry point for shared attention and conversation [46, 47]. Such entry points may elicit curiosity from a partner who is not currently interacting and can invite participation, thereby increasing opportunities for shared interactions.

At the same time, the physical scale of exhibits and available surrounding space become salient design constraints. During the experiment, even small near-surface exhibits occasionally appeared crowded with only two visitors, which could disrupt comfort and flow. Providing adequate clearance around exhibits and aligning exhibit size with the expected number of co-located visitors may therefore be necessary to realize the social benefits of NAI. Taken together, these observations suggest that NAIs that are physically compatible with exhibit scale and cognitively aligned with the content can better support shared learning experiences in museum settings.

### 6.3. Does More Talks Indicate a Better Learning Experience?

Assessing learning in open-ended environments such as museums remains challenging, motivating the development of multiple observational frameworks. In this study, we adopted Allen's coding scheme [15] and treated the frequency of perceptual and conceptual utterances as indicators of learning-relevant engagement. Visitor talk, particularly utterances with cognitive content, has been widely used as evidence that visitors are attending to and making sense of their surroundings.

Under NAI, parents produced perceptual talk more frequently, and this shift may be associated with improved learning opportunities for children. Importantly, this increase did not appear to come at the expense of children's participation; children's cognitive utterances also increased, mitigating concerns that interaction would merely amplify one-sided adult narration. Moreover, conversations grounded in jointly viewing either the mobile screen or the physical exhibit can be interpreted as signs of shared meaning-making rather than parallel, screen-isolated consumption. Therefore, our findings suggest that interactive exhibit designs that explicitly consider the spatial formation among exhibits, devices, and visitors—such as NAI—can shape social interaction patterns and potentially enhance learning experiences in museums. For future interactive exhibits, curators and designers should account for the physical context of use, including how device placement and interpersonal spacing facilitate (or constrain) joint attention and conversation.

## 7. Conclusion

This study examined how near-surface AR interaction influences social interaction among museum visitors. In a controlled field experiment, we observed visitor groups engaging with an exhibition under different interaction proximities. Although overall viewing time was comparable across conditions, NAI was associated with increased conversation, suggesting a reduction in disconnection that can arise when content is accessed primarily through a personal mobile screen. In particular, parent–child dyads showed higher conversational frequency under NAI, which may support richer learning opportunities. Collectively, these results indicate that near-surface AR interaction can improve museum experiences by mitigating screen-induced separation and fostering more diverse, learning-relevant conversations.

## Declaration on Generative AI

The authors have not used any Generative AI tools.

## References


[1] C. Cahill, A. Kuhn, S. Schmoll, W.-T. Lo, B. McNally, C. Quintana, Mobile learning in museums: How mobile supports for learning influence student behavior, in: Proceedings of the 10th International Conference on Interaction Design and Children, IDC '11, Association for Computing Machinery, 2011, pp. 21–28. doi:10.1145/1999030.1999033.

[2] M. Vazquez, F. Hirata, J. d. D. Sanchez Lopez, E. Jimenez-Garcia, C. Navarro, J. Nieto, Using RFID/NFC and QR-Code in mobile phones to link the physical and the digital world, 2012. doi:10.5772/37447.

[3] Y.-P. Huang, S.-S. Wang, F. E. Sandnes, RFID-based guide gives museum visitors more freedom, IT Professional 13 (2011) 25–29. doi:10.1109/MITP.2011.33.

[4] A. Marto, A. Gonçalves, M. Melo, M. Bessa, A survey of multisensory VR and AR applications for cultural heritage, Computers & Graphics 102 (2022) 426–440. doi:10.1016/j.cag.2021.10.001.

[5] K. Charitonos, C. Blake, E. Scanlon, A. Jones, Museum learning via social and mobile technologies: (how) can online interactions enhance the visitor experience?, British Journal of Educational Technology 43 (2012) 802–819.

[6] C. Pollalis, A. Gilvin, L. Westendorf, L. Futami, B. Virgilio, D. Hsiao, O. Shaer, ArtLens: enhancing museum visitors' engagement with African art, in: Proceedings of the 2018 ACM Conference Companion Publication on Designing Interactive Systems, 2018, pp. 195–200.

[7] D. Wessel, E. Mayr, Potentials and challenges of mobile media in museums, International Journal of Interactive Mobile Technologies (iJIM) 1 (2007).

[8] T. Caulton, Hands-on Exhibitions: Managing Interactive Museums and Science Centres, Routledge, 1998.

[9] P. Tolmie, S. Benford, C. Greenhalgh, T. Rodden, S. Reeves, Supporting group interactions in museum visiting, in: Proceedings of the 17th ACM Conference on Computer Supported Cooperative Work & Social Computing, CSCW '14, Association for Computing Machinery, 2014, pp. 1049–1059. doi:10.1145/2531602.2531619.

[10] H. Yi, J. Pyun, C. Lee, W. Lee, Scienscope: Hand-held mediation device for facilitating exploratory behaviors with exhibits in museum visitors, in: Proceedings of the 2020 ACM Designing Interactive Systems Conference, DIS '20, Association for Computing Machinery, 2020, pp. 709–721. doi:10.1145/3357236.3395581.

[11] H. Yi, S. H. Han, M. K. Park, W. Lee, Surfacelens: near-surface spatial interaction with science museum exhibits, Digital Creativity 33 (2022) 18–34. doi:10.1080/14626268.2022.2039208.

[12] A. Morrison, A. Oulasvirta, P. Peltonen, S. Lemmela, G. Jacucci, G. Reitmayr, J. Näsänen, A. Juustila, Like bees around the hive: A comparative study of a mobile augmented reality map, in: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, CHI '09, Association for Computing Machinery, 2009, pp. 1889–1898. doi:10.1145/1518701.1518991.

[13] J. H. Falk, L. D. Dierking, The museum experience revisited, Routledge, 2016.

[14] D. Perry, What Makes Learning Fun?: Principles for the Design of Intrinsically Motivating Museum Exhibits, AltaMira Press, 2012.

[15] S. Allen, Looking for learning in visitor talk: A methodological exploration, in: Learning conversations in museums, Routledge, 2003, pp. 265–309.

[16] H. T. Zimmerman, S. M. Land, M. R. Mohney, G. W. Choi, C. Maggiore, S. H. Kim, Y. J. Jung, J. Dudek, Using augmented reality to support observations about trees during summer camp, in: Proceedings of the 14th International Conference on Interaction Design and Children, IDC '15, Association for Computing Machinery, 2015, pp. 395–398. doi:10.1145/2771839.2771925.

[17] S. Schwan, A. Grajal, D. Lewalter, Understanding and engagement in places of science experience: Science museums, science centers, zoos, and aquariums, Educational Psychologist 49 (2014) 70–85. doi:10.1080/00461520.2014.917588.

[18] L. Solima, F. Izzo, QR codes in cultural heritage tourism: New communications technologies and future prospects in naples and warsaw, Journal of Heritage Tourism 13 (2018) 115–127.

[19] G. Broll, S. Siorpaes, E. Rukzio, M. Paolucci, J. Hamard, M. Wagner, A. Schmidt, Supporting mobile service usage through physical mobile interaction, in: Fifth Annual IEEE International Conference on Pervasive Computing and Communications, 2007, pp. 262–271. doi:10.1109/PERCOM.2007.35.

[20] A. M. Rahman, A. E. Saddik, Touch me interaction paradigm for physically browsing personal learning spaces, in: 2010 IEEE International Conference on Multimedia and Expo, 2010, pp. 436–441. doi:10.1109/ICME.2010.5583565.

[21] A. Zafeiropoulos, E. Solidakis, S. Zoi, N. Konstantinou, P. Stathopoulos, N. Mitrou, Location based guidance services in a museum environment: Deployment issues and a proposed architectural approach, 2011, pp. 201–208. doi:10.5220/0002148402010208.

[22] T. Kuflik, J. Lanir, E. Dim, A. Wecker, M. Corrà, M. Zancanaro, O. Stock, Indoor positioning: Challenges and solutions for indoor cultural heritage site, 2011, pp. 375–378. doi:10.1145/1943403.1943469.

[23] B. Al Takrouri, K.-O. Detken, C. Martinez, M. K. Oja, S. Stein, L. Zhu, A. Schrader, Mobile HolstenTour: Contextualized multimedia museum guide, in: Proceedings of the 6th International Conference on Advances in Mobile Computing and Multimedia, MoMM '08, Association for Computing Machinery, 2008, pp. 460–463. doi:10.1145/1497185.1497283.

[24] D. G. Luca, M. Alberto, From proximity to accurate indoor localization for context awareness in mobile museum guides, in: Proceedings of the 18th International Conference on Human-Computer Interaction with Mobile Devices and Services Adjunct, MobileHCI '16, Association for Computing Machinery, 2016, pp. 1002–1009. doi:10.1145/2957265.2962649.

[25] M. K. Bekele, R. Pierdicca, E. Frontoni, E. S. Malinverni, J. Gain, A survey of augmented, virtual, and mixed reality for cultural heritage, Journal on Computing and Cultural Heritage 11 (2018).

[26] H. Salmi, A. Kaasinen, V. Kallunki, Towards an open learning environment via augmented reality (AR): Visualising the invisible in science centres and schools for teacher education, Procedia - Social and Behavioral Sciences 45 (2012) 284–295. doi:10.1016/j.sbspro.2012.06.565.

[27] A. Damala, E. Hornecker, M. van der Vaart, D. van Dijk, I. Ruthven, The loupe: tangible augmented reality for learning to look at ancient Greek art, Mediterranean Archaeology and Archaeometry 16 (2016) 73–85. doi:10.5281/zenodo.204970.

[28] M. Billinghurst, Augmented reality in education, New horizons for learning 12 (2002) 1–5.

[29] J. R. Cooperstock, et al., The classroom of the future: enhancing education through augmented reality, in: Proc. HCI Inter. 2001 Conf. on Human-Computer Interaction, 2001, pp. 688–692.

[30] E. Goff, K. L. Mulvey, M. Irvin, A. Hartstone-Rose, Applications of augmented reality in informal science learning sites: a review, Journal of Science Education and Technology 27 (2018). doi:10.1007/s10956-018-9734-4.

[31] G. W. Fitzmaurice, Situated information spaces and spatially aware palmtop computers, Communications of the ACM 36 (1993) 39–49. doi:10.1145/159544.159566.

[32] L. Coconu, B. Ullmer, P. Paar, J. Lyu, M. Konkel, H.-C. Hege, A smartphone-based tangible interaction approach for landscape visualization, in: Proceedings of the 7th ACM International Symposium on Pervasive Displays, PerDis '18, Association for Computing Machinery, 2018. doi:10.1145/3205873.3210707.

[33] S.-w. Leigh, P. Schoessler, F. Heibeck, P. Maes, H. Ishii, THAW: Tangible interaction with see-through augmentation for smartphones on computer screens, in: TEI 2015 - Proceedings of the 9th International Conference on Tangible, Embedded, and Embodied Interaction, 2015, pp. 89–96.

doi:10.1145/2677199.2680584.
[34] T. Menzner, T. Gesslein, A. Otte, J. Grubert, Above surface interaction for multiscale navigation in mobile virtual reality, in: 2020 IEEE Conference on Virtual Reality and 3D User Interfaces, 2020, pp. 372–381. doi:10.1109/VR46266.2020.00057.
[35] D. Xu, A. Momeni, E. Brockmeyer, MagPad: A near surface augmented reading system for physical paper and smartphone coupling, in: Adjunct Proceedings of the 28th Annual ACM Symposium on User Interface Software and Technology, UIST '15 Adjunct, Association for Computing Machinery, 2015, pp. 103–104. doi:10.1145/2815585.2815740.
[36] L. Coconu, H.-C. Hege, DevEyes: Tangible devices on augmented passive surfaces, in: Proceedings of the Eleventh International Conference on Tangible, Embedded, and Embodied Interaction, TEI '17, Association for Computing Machinery, 2017, pp. 409–411. doi:10.1145/3024969.3025065.
[37] A. Olwal, LightSense: Enabling spatially aware handheld interaction devices, in: Fifth IEEE/ACM International Symposium on Mixed and Augmented Reality (ISMAR 2006), 2006, pp. 119–122. doi:10.1109/ISMAR.2006.297802.
[38] A. Olwal, S. Feiner, Spatially aware handhelds for high-precision tangible interaction with large displays, in: Proceedings of the 3rd International Conference on Tangible and Embedded Interaction, TEI '09, Association for Computing Machinery, 2009, pp. 181–188. doi:10.1145/1517664.1517705.
[39] M. Rohs, G. Essl, Which one is better? information navigation techniques for spatially aware handheld displays, in: Proceedings of the 8th International Conference on Multimodal Interfaces, ICMI '06, Association for Computing Machinery, 2006, pp. 100–107. doi:10.1145/1180995.1181016.
[40] M. Spindler, W. Büschel, C. Winkler, R. Dachselt, Tangible displays for the masses: Spatial interaction with handheld displays by using consumer depth cameras, Personal and Ubiquitous Computing (2013). doi:10.1007/s00779-013-0730-7.
[41] K.-P. Yee, Peephole displays: Pen interaction on spatially aware handheld computers, in: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, CHI '03, Association for Computing Machinery, 2003, pp. 1–8. doi:10.1145/642611.642613.
[42] K. Hasan, D. Ahlström, P. P. Irani, Comparing direct off-screen pointing, peephole, and flick & pinch interaction for map navigation, in: Proceedings of the 3rd ACM Symposium on Spatial User Interaction, SUI '15, Association for Computing Machinery, 2015, pp. 99–102. doi:10.1145/2788940.2788957.
[43] A. Roudaki, J. Kong, G. S. Walia, A. Roudaki, PhoneLens: A low-cost, spatially aware, mobile-interaction device, IEEE Transactions on Human-Machine Systems 44 (2014) 301–314. doi:10.1109/THMS.2014.2305436.
[44] D. Reilly, M. Welsman-Dinelle, C. Bate, K. Inkpen, Just point and click? using handhelds to interact with paper maps, in: Proceedings of the 7th International Conference on Human Computer Interaction with Mobile Devices & Services, MobileHCI '05, Association for Computing Machinery, 2005, pp. 239–242. doi:10.1145/1085777.1085820.
[45] H. Yi, Y. Shin, S. Lee, E. Youn, A. Ham, G. Lee, W. Lee, WonderScope: Practical near-surface AR device for museum exhibits, in: ACM SIGGRAPH 2022 Emerging Technologies, SIGGRAPH '22, Association for Computing Machinery, 2022. doi:10.1145/3532721.3535564.
[46] E. Hornecker, J. Buur, Getting a grip on tangible interaction: A framework on physical space and social interaction, in: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, CHI '06, Association for Computing Machinery, 2006, pp. 437–446. doi:10.1145/1124772.1124838.
[47] E. Hornecker, P. Marshall, Y. Rogers, From entry to access: How shareability comes about, in: Proceedings of the 2007 Conference on Designing Pleasurable Products and Interfaces, DPPI '07, Association for Computing Machinery, 2007, pp. 328–342. doi:10.1145/1314161.1314191.