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Supporting child–group interactions with hands-off museum exhibit

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ABSTRACT

Technology can be used to augment visitors' experience with a museum exhibit and provide museum visitors with means of interacting with otherwise hands-off exhibits. However, introducing technology to support interactivity has the likelihood of usurping users' attention from the exhibit or diminishing interactions with other visitors. Our approach to this problem involves supporting hands-on interactions for groups visiting a pollinator garden—a science museum exhibit containing fragile species where touching is discouraged. Through interviews with museum experts and docents, we elicited design goals that we then enfolded into an Android application that leverages visual recognition to support interactions with the exhibit. We tested our application in-situ with 65 children in three groups and subsequently propose and describe design approaches that uses the ethos of *scaling* to support different number of users and *leveling* to varied cognitive levels. We conclude by recommending reusable designs guidelines to support interactions within other evolving and hands-off contexts.

1. Introduction

Museum exhibits are typically only accessible by sight to visitors, with all other means of interactions unavailable. These restrictions are necessary in order preserve the exhibits on account of their value or for safety. Depending on the type of museum, visitors expect this interaction restriction and adjust accordingly. Science museums (Diamond, 1986) are notable exceptions: they follow the ethos of encouraging visitors to indulge their curiosity by directly interacting and manipulating exhibits (Feher, 1990). Visitor expectations match this ethos and therefore, hands-off exhibits in these types of museums are an anomaly. When hands-on manipulations are not safe or possible, interaction measures that fill the interactivity gap have included: providing an embodied sensory exhibit to augment an inaccessible original exhibit (Chu, Harley, Kwan, McBride, & Mazalek, 2016), the use of digital labels to provide contextual information to static exhibits (Roberts, Banerjee, Hong, McGee, Horn, & Matcuk, 2018), and re-casting the exhibits to provide accessibility to people with visual impairments (Anagnostakis et al., 2016). Understudied in these efforts are the types of interpersonal interactions that occur, specifically towards finding ways to use technology to connect individuals within, and across groups.

Our research considers a hands-off pollinator garden exhibit (Fig. 1) that is housed within a regional science museum. The museum, a popular stop for school groups on field trips, allows and encourages hands-on interactions with all other exhibits, except the garden exhibit. The combination of a living, evolving, fragile, and hands-off exhibit renders previous approaches providing interaction measures inapplicable. Yet it provides an interesting context by which to consider the problem of providing interactivity to a hands-off exhibit, and how proposed approaches and strategies can scale to other non-garden installations. We use mobile phones in our approach to provide interactivity with the garden due to their portability and the exhibit size.

We ran a four-phase study over an 8-month period involving a total 108 users. First, we conducted semi-structured interviews with two science museum subject-matter experts to understand exhibit themes and museum goals. Second, we elicited design

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Fig. 1. Panorama of a section of the indoor pollinator garden exhibit which emphasizes local plants and insect pollinators. The stone-path guides visitors around the exhibit, with the retaining wall acting both as a barrier and soil holder. Visitors are discouraged from touching the fragile species.

goals from the interviews and developed the *GardenHunt*–an Android application that we pilot tested with 8 university students. Third, we deployed the application in-situ with three school groups (65 children in total). Fourth, we evaluated the design efficacy through a focus group interview with the museum volunteer docents, and also with 28 other users.

Beyond designing for an untouchable exhibit where touch is expected and encouraged, we also make the following contributions: (1) We provide design recommendations that leverage *playful interactions* while also addressing problems that arise when considering the intersection of group interaction, group size variations, time constraints and hands-off exhibits. (2) We contribute to the discourse on designing for scale, by describing our design framework that leverages *scaling* and *leveling*–providing a means for our smartphone application to be extended and reused in other contexts outside the museum. (3) We add to the discourse on informal learning and self-exploration by designing an Android application that leverages our proposed design framework, providing opportunities to examine the framework's efficacy.

Our work builds upon previous research that recommend approaches to support interactivity in public spaces (Wood et al., 2014), and those that consider the problem of balancing interaction with mobile technology without taking the attention away from the exhibit (Mikalef, Giannakos, Chorianopoulos, & Jaccheri, 2012), together with the additional challenge of scaling across group sizes and age groups, and considering non-traditional museum goals.

2. Related work

Our work is at the intersection of smart phones, supportive technology and group interactions. Similar to other work that consider how best to foster engagement in public spaces (Wood et al., 2014) including fostering shared interactions (Franz, Alnusayri, Malloch, & Reilly, 2019), we focus our work in the museum context. We further describe these intersections below.

2.1. Mobile technology use in museums

Many areas of research have taken advantage of the museum rich environment from which to study how people make decisions about their visit: the planning for the visit, the character of those visits—whether undertaken individually, as a family (Diamond, 1986) or as a (small) group. The nature of their interactions (visitor–visitor, visitor–exhibit) have also been of interest (Kuflik et al., 2005), including how the presence of technology impacts these interactions (Rennick-egglestone et al., 2016). The affordability and widespread use of smartphones have made it easier for museums to leverage them in providing services such as logistical information (operating hours, current exhibits etc.), affording self-guided tours, or in the use of mobile games to augment the visitor's interaction with exhibits (Economou & Meintani, 2011; Kotut, Hoang, Shenk, Panda, & Scott McCrickard, 2018). These mobile devices provide avenues to deliver on-demand, personalized, supplementary information, that can then be used to provide nuance (Rennick-egglestone et al., 2016), and/or context (Long, Kooper, Abowd, & Atkeson, 1996) regarding both individual and inter-connected installations/exhibits (Cheverst, Davies, Mitchell, Friday, & Efstratiou, 2000; Hakvoort, 2013), and to cater for unique visitor's need by providing means for visit customization (Bohnert, Zukerman, & Laures, 2012; Lepouras et al., 2015).

While we ascribe mobile technology to smart phones in this work, it can also be used to describe other hand-held devices that support interactions between the user and the exhibit, such as personal digital assistants (PDAs) and other artifacts (Muratsu, Ishiyama, Kusunoki, Inagaki, & Terano, 2014; Shibasaki et al., 2017; Wakkary et al., 2009). The on-demand, contextual information is triggered differently depending on the user's need, the technology used, and the type of exhibit such as: NFC-triggers (Rudametkin, Gama, Touseau, & Donsez, 2010), QR codes (Ceipidor, Medaglia, Perrone, De Marsico, & Romano, 2009), visual recognition (Föckler, Zeidler, Brombach, Bruns, & Bimber, 2005) and visual markers (Ali, Koleva, Bedwell, & Benford, 2018). In addition to these considerations, we also intend our application design to be flexible to allow (re)use outside of the museum context.

2.2. Technology for supporting manipulability

Different interpretations on the nature of augmentative experience range from *assistive* technologies that provide accessibility to physically unreachable *in-situ* (Chu et al., 2016) or off-site (Seo, Sungkajun, & Suh, 2015) exhibits, to depicting the provision of user-adaptive technologies such as self-guided tours (Stock et al., 2007). Augmentative technology geared towards children visiting museums chiefly involve games designed to engender a sense of fun. Task-based games have been found to be useful and are known to provide an enjoyable experience to the children who played it (Cesário, Radeta, Matos, & Nisi, 2017) compared to a control group which undertook a typical guided tour. Manipulability extends augmentation by providing an interactive element to an otherwise unreachable or hands-off exhibit. This has ranged from the use of the sense of smell in an embodied exhibit (Chu et al., 2016), the use of smart replica as an exhibit guide (Petrelli & O'Brien, 2018), and the use of digital labels to accompany fragile authentic artifacts (Roberts et al., 2018). Mobile device portability, integrated sensors, and the capability to connect to the internet have made them useful in affording the museum with a way to support augmentative interactions. These interactions engender a sense of ownership to the visitors and the community, by providing a means to capture and incorporate user-generated content (Simon, 2017) into exhibits. Beyond our decision to use smartphones based on the advantages and advances outlined by previous work, we add to the literature by intentionally designing for attention-manipulability balance and add to the literature in our discussion in Section 7.

2.3. Effect of group size and group composition

While mobile devices are presumed to be personal, understanding how users collaborate and learn, transcend the use of the device. It has led to designs that consider different interactions between users and technology (Hornecker, 2008), the choice of visit paths around the museum (Alderman, 2011; Civantos, Brown, Coughlan, Ainsworth, & Lorenz, 2016; Ng, Huang, & O'malley, 2018), and engagement levels (Yiannoutsou, Papadimitriou, Komis, & Avouris, 2009). Visitors to the museum specifically tend to be in groups of varying sizes and ages (Carrozzo et al., 2018; Dohn, 2010) with different learning (Armoni, 2017), participation (Cumbo & Leong, 2015; Lo & Quintana, 2013), and interaction (Callaway et al., 2011; Rennick-egglestone et al., 2016) styles. The inter-group relationships and composition also varies, and can include parent–child dyads (Crowley & Callanan, 1998), family (Diamond, 1986) or large groups (Fosh, Benford, & Koleva, 2016). Whereas addressing each group present unique opportunities, challenges emerge when considering scaling across the different group sizes that should be considered, such as territoriality (Woodward et al., 2018), and the will of the many overwhelming the interest of the individual (Cheverst et al., 2000) when in group tours. Our aim in this work, is to consider these challenges in designing for technology to support within-group interactions, while also supporting self-exploration.

2.4. The impact of technology on focused attention

In considering design to support the visitor experience, length of time that they have set aside for a visit impacts both the choice of using an augmentative technology, and what exhibits to view (Antoniou & Lepouras, 2010). The presence of augmentative technology can impact these plans: technology designed for mobile devices specifically have been found to have a danger of diverting attention from the exhibit to the device (Cabrera et al., 2005; Cesário et al., 2017; Mikalef et al., 2012; Petrelli & O'Brien, 2018), sometimes to the disruption of other visitors' experiences (Reyburn, 2018). Previous approaches have also found that extended use of mobile apps may cause cognitive overload, leading to a negative perception of the overall museum visit (Rubino, Barberis, Xhembulla, & Malnati, 2015). Measures to prevent this downside include the use of a strict upper time-limit to the technology use (Rokne, 2011), and designing non-linear apps (with no set starting or ending times) (Rubino et al., 2015), thereby leaving the choice of how long to play or how many levels to complete up to the user. Recommendations for tempering device distraction also argue for deliberative design that supports the visitor's need for information or interaction without distracting attention from exhibit by Molloy (2016) and Simon (2016). Other research argue for simplified approaches such as "leveling" (Cabrera et al., 2005), limiting extraneous tasks (Cosley et al., 2009), and providing intuitive content (Cheverst et al., 2000; Grinter et al., 2002). These approaches have to be careful not to alienate audiences with overly simplistic or uninteresting context (e.g., tasks considered "too childish" Rubino et al., 2015), or devices leveraging glanceable design such as smartwatches Banerjee, Robert, & Horn, 2018). We enfold these lessons in our design approach by using clues in the game design to trigger game progression and to retain users' interaction with the garden. Our use of visual recognition to provide manipulability to an untouchable exhibit also follow these lessons.

3. Study methodology

Our research approach is at the intersection of *people* (group size and age variability), *spaces* (the atypical exhibit) and *bounds* (time constraints and a hands-off exhibit). The tension between the hands-on interactive nature of a science museum and a hands-off garden exhibit make for an ideal test-case to consider previous approaches on how to best augment a museum visit. We started with broad research objectives to identify the elements of the exhibit that the museum most wanted to display, alongside the garden layout and its changing nature as new plants and pollinator insects are introduced. Because of the fragile nature of the plants and insects in the exhibit, children—by far the most common type of visitor, are not allowed to touch anything: the sole exhibit in the whole museum with this restriction.

3.1. Study site

This research was conducted in the context of a pollinator garden exhibit. Typical pollinator gardens are designed to attract and support pollinator insects such as butterflies (Gardens, 2017). Our study site is housed within the regional science museum building. It was established with two long-term objectives: (1) to educate visitors about the local species of pollinators including the plants that attract and sustain them, and (2) to encourage visitors to grow their own pollinator gardens by taking inspiration from the garden (Science Museum of Western Virginia, 2018). There are signs placed at different strategic points in the garden, each representing a part of the ecology surrounding it. The garden exhibit is frequently visited by school groups of up-to 25 children (accompanied by chaperones), and loosely fit with learning objectives about species life-cycles and food chains. A typical school group is led around the exhibit by a docent and is scheduled for 20 min that includes 5 min for both the entrance (Doering & Pekarik, 1996) narrative (docent-led brief of the garden and species, and an exhortation not to touch the fragile species) and exit narratives (end-of-tour announcements).

3.2. Study participants, and analysis procedure

This study was conducted in four phases and involved 108 participants that we summarize in Table 1. In phase 1, we conducted semi-structured interviews with two science museum experts (E1 and E2) in order to understand the museum goals, the nuances of the garden exhibit, and the needs of typical visitors. The interview with E1 took 50 min in their office, while the interview with E2 was conducted inside the garden exhibit for a period of 75 min. We recorded and transcribed the interviews and using thematic analysis (Braun & Clarke, 2006), identified emerging themes that we enfolded in the application design. We repeated this step iteratively until we reached a saturation point, and expert buy-in on the identified themes.

We designed a mobile app prototype based on themes identified from the expert interviews. We presented it in phase 2, to eight design students (P1–P8) in three groups for usability testing in a think-aloud session that took approximately 15 min for each group. After enfolding design suggestions from this phase into the app, we deployed it in-situ in the garden and observed its use with three different school groups (G1–G3) in phase 3.

In phase 4, we evaluated the app's efficacy in supporting adults. We presented the application off-site for use by older users (S1–S28) and obtained their feedback via surveys. At this time, we also interviewed 5 volunteer docents (V1–V5) as a focus group that lasted 45 min. Interview discussion with the docents ranged in topics from earlier expert interviews, to their perceptions of *GardenHunt*'s efficacy—given their expertise of the garden exhibit and the typical visitors.

4. Museum exhibit goals (phase 1)

We sought to first understand both short and long-term museum goals in order to inform our design process. We did so by first conducting semi-structured interviews with two museum experts (E1 and E2), and then interacting with the museum exhibit and with volunteer docents in their day-to-day activities for one week. We summarize and give detail to the themes resulting from expert interviews in Table 2.

Table 1
Participants: We interviewed the experts in phase 1, conducted a usability study with design students in phase 2 and observed the school groups interacting with the app *in-situ* in phase 3. In phase 4, we interviewed 5 volunteer docents as a focus group and conducted a survey of 28 *GardenHunt* users.

#Users	User type	User ID	Study type	Notes
2	Experts	E1, E2	Semi-structured interviews	Experts employed by the museum
8	Design Students	P1–P8	Usability/pilot testing	1 graduate, 7 undergraduate seniors
65	K – 6th grade	G1, G2, G3	*In-situ* observation and app use	3 groups of 25, 25, and 15 children
28	Varying users	S1–S28	Survey/questionnaires	Collected during a day-long showcase
5	Volunteer docents	V1–V5	Semi-structured interviews	Experienced tour-guides

Table 2
Elicited design goals based on the thematic analysis from interviews with museum experts and volunteer docents.

Theme	Attributes
Re-use	Allowing the app to be (re)used in different contexts
Touching	Making interaction with the garden fun Allowing cooperation with other children & mitigating territoriality
Ownership	Providing a sense of ownership of the garden and the artifacts collected
Outreach	Imparting the ethos of the pollinator garden
Usefulness/ Usability	Intervention to *scale* across ages and group sizes Supporting fun and the simulacrum of touching
Magnifying Glass	Providing a better interaction means than the current metaphor
Inclusivity	All children across ages to have a means to participate in their own way Providing "leveling" up to support use across different cognitive levels
Other Themes	Shareability, species awareness, contribution, rewards for participation

4.1. Conveying museum identity and community outreach

As with most museums, the regional science museum seek to have a positive impact in the community it serves (Simon, 2017). This theme emerged separately from both experts as they noted that their museum carves its identity based on its service to the community. Chiefly, this involves providing learning experiences, and being a knowledge repository in the context of a short term visit, and fostering long-term partnerships by imparting a sense of ownership and responsibility of the exhibit. The attempt to achieve the latter include a seed program that the museum uses to distribute pollinator plant seeds to local visitors interested in starting their own pollinator gardens.

> *"[The plants] are mostly native, and at least local. This allow[s] the [museum] to become an interpreter for the local landscape/biology [...] we want to educate people on what our local pollinators are [and] how to attract them to their gardens at home". (E1)*

However, the seed program is not very visible: the information can only be found in the tucked away exhibit brochure or in an older blog post on the museum website. There is also no means of measuring success of how many gardens have been established from the seeds provided by the museum.

4.2. Inclusivity and relevance in supporting school groups

The bulk of group visitors to the exhibit are school groups. To best serve them, the museum developed content that aligned with their learning goals: to make the garden exhibit both relatable and relevant. There are also broad take-home messages that are age-agnostic and convey the ethos behind the establishment of pollinator gardens—as a way to include older children and chaperons, similar to previous approaches that cautioned against "exclusivity and niche" (Simon, 2016).

> *"[We want to impart] ... information and lessons that make them more pollinator-friendly so things like: how not to use pesticides [and] how to plant things that are in the host plants for pollinators".(E1)*

The museum success in imparting these ethos is a hit or miss. The younger the children or the larger the school group, the harder it is to determine success of achieving the learning goals and the take-home messages. This is mostly because the only person who is knowledgeable about the garden is the docent. Information and interaction prompts generate from this one source with limited assistance from chaperones.

4.3. The "Don't Touch It" dilemma

The museum is designed to provide a hands-on interactive experience. All other exhibits within the museum achieve this interactivity, except for the garden exhibit—where visitors are requested not to touch any of the plant and insect species that inhabit the garden, given their fragility and to avoid contamination. The challenge in navigating this tension is acknowledged:

> *"Well it's hard to be interactive in an exhibit where you can't touch anything ... or that you're not supposed to touch anything". (E2)*

As an interim measure, we found out that the museum provided plastic hand-held magnifying glasses to provide a sense of interaction. These magnifying glasses were hard-wearing and could support the rough handling by younger children and engender a sense of fun and adventure in discovery. It did not work with older children however, who preferred using the zoom functions in cameras. The challenge was finding an ideal substitute that meet the learning objectives within the time available for the garden tour.

4.4. Maintaining relevance while scaling across groups

Beyond interactivity, the issue of scaling across different audiences (i.e. "leveling") also emerged, especially when the primary audience's needs are divergent from the secondary audience given age differences. The need for providing relevance arises:

> *"The exhibit starts to have a scaling problem once you hit about 5th grade. This is when you start to get a little bit higher frequency of what we sort-of informally refer to as 'too cool for school".(E2)*

Experts noted the lack of self-direction by the older children (unless explicitly directed by the docent). It is a less straightforward concern when considering chaperones—the adults accompanying school groups, who sometimes act as guides in the absence of the docent. The experts noted the chaperones tendency not to interact with the garden but could not determine the reason why this was so:

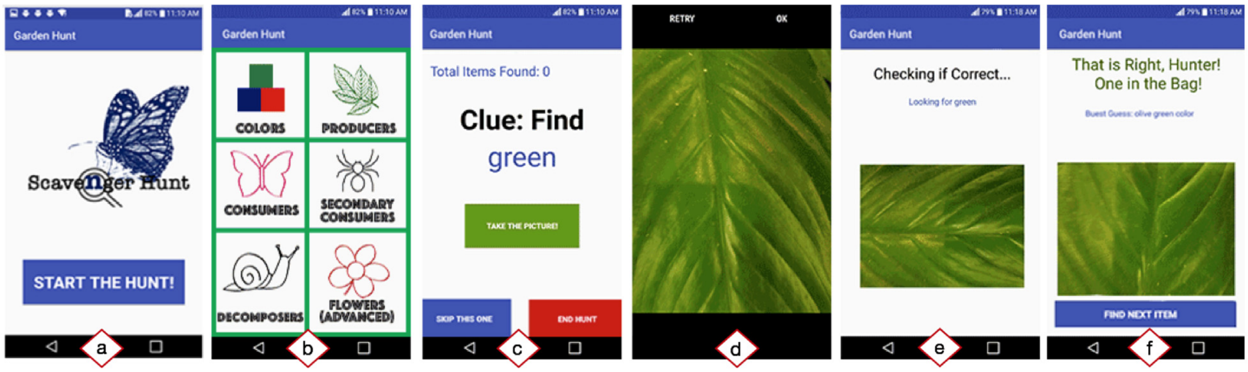

Fig. 2. The GardenHunt application is modeled after typical scavenger hunt game. User selects a category (b), is provided a clue (c) and then takes a picture of the answer to the clue (d). A visual recognition engine checks if the submitted image matches the right answer to the clue (e). It then displays to the user correct/incorrect screen accordingly, including what it "guessed" the image to be (f). Correct answers are added to the user's final tally.

"...often adults tend to find each other and stand to the side. I think because the children are engaged at a different level than the adults are engaged". (E2)

The expert recommendation was non-trivial:

"Our goal is to have a levelled interaction: [...]. So that if you're just a senior who's here because you just like butterflies, then you don't feel talked down to". (E2)

The prescribed approach should ideally allow the parents and chaperones to have a means of engaging with the exhibit in tandem with the younger audience—but at a level that is relevant (and interesting) to them.

4.5. Bring-your-own-device considerations

The cost of device maintenance, device availability, and visitors willingness to download an app were also discussed. Given that the majority of the visitors would be mostly school groups between kindergarten (K) and 6th grade, there is a known restriction in that they are not allowed to bring their phones with them to the museum during their field trip.

Therefore, it was known from the outset that the museum would need to provide the devices to be shared by the children in the school groups. The design for any application for these devices had to take into account the likelihood of the device being used by multiple children at once. Older self-guided visitors with their own personal devices, can also be offered a choice of getting the application from the app store:

"While [school groups] won't have their own devices, [we] can create a space where parents and kids can collaborate together to do a thing". (E1)

While providing pre-loaded application on museum-provided phones equalizes accessibility across children in school groups, we needed to provide a way for the children to have a sense of achievement in finding garden species, and to engender a sense of ownership. The experts suggested a way for the application users to submit their favorite photo(s) of the garden exhibit to be showcased as a slide show at the entrance of the exhibit.

The themes from the expert interview led us to articulate the following research questions:

- **RQ1:** What impact does the presence of technology/device have on self-exploration and roles (e.g. chaperones for six-year-olds or the efficacy of the docent in imparting knowledge)?
- **RQ2:** How do we leverage design that works for both individuals and groups, as well as spanning age groups?
- **RQ3:** How can we define a design approach that can be simplified for re-use outside the garden exhibit/museum context?

5. The GardenHunt application

We designed the *GardenHunt* iteratively through collaboration with the museum experts and volunteer docents. First, we chose the scavenger hunt theme based on the success of previous paper-based activities in the garden exhibit that the museum organized around events (e.g. Halloween and Science Day). As supported by previous work (Cesário et al., 2017; Iga, Wakao, Matsumura, Lopez-Gulliver, & Noma, 2017) even to promote nature-play (Cumbo & Iversen, 2020), the museum through their previous experience, had found the task-based game to be versatile, and easy to understand by users of different cognitive levels, such that there was no need to spend a lot of time explaining the game mechanics. We also found that we could easily scale the game to work across age-groups by incorporating different existing clues that the museum used and working with the volunteer docents in incorporating the various clues that different age-group preferred (Table 3). Second, we incorporated design metaphors based on our observations of how the children interacted with the exhibit, and how they used plastic magnifying glasses provided by the museum. Finally, we included design considerations we elicited from the interview phase with the design experts (Table 2). We paired the mobile application with a paper version of it (*paper-hunt*)—to engender a sense of inclusion, and discuss our observations regarding their performance, use, and other observations later in the paper.

5.1. Design considerations

The time restriction for school group tours preclude the use of most technologies with steep learning curves. Therefore, as a primary objective, we chose to focus on *fun* as a means of improving attitudes towards science (Hofstein & Rosenfeld, 1996), as it provides a means to design for playful interactions without negatively impacting either the user's focus on the exhibit or future learning goals. We also consider augmentation as an intersection of *interaction* and *attention*; and use *manipulability* interchangeably with hands-on interactions. Our approach also leverages the-horse-before-the-cart metaphor (Feher, 1990), that recommends prioritizing hands-on experiences over explanations.

Designing the *GardenHunt* followed a linearity approach (de Montebello, Lowry, Wood, Walsh, et al., 2004): the categories

Table 3
Characteristics of "leveling": Each problem involves clues of different complexity, thereby providing challenge according to age/cognitive understanding. Clues given to the user can be complex, allowing for easy modification, while the answer submitted to the visual recognition engine for checking is straightforward.

	Level characteristics	Clue output to player	Clue input to machine
Beginner	• Straightforward clue • Broad answer	"Find a Butterfly"	"Butterfly"
Intermediate	• Indirect clue • Broad answer	"I fly, I flit, I flutter from flower to flower... What am I?"	"Butterfly"
Advanced	• Indirect clue • Narrow Answer	"King" of the flitters	"Monarch butterfly"

in the *GardenHunt* app (Fig. 2b) are based on the signs around the garden and are arranged according to the tour paths so it is intuitive to use. Once a clue is solved, it is removed from the clue list and added to the final tally (i.e. "total items"). This linear approach takes advantage of intuitiveness, yet does not prevent the user from moving across categories and *skip* clues as needed, giving the users freedom to choose the path to follow (Alderman, 2011), and engage as they wish (Yiannoutsou et al., 2009). The *paper-hunt* makes no category distinction on species provided. We found the use of sound (Grinter et al., 2002) to be distracting to the player and disruptive to other visitors in the exhibit space, and opted to omit its use. To support *re-use*, we designed the application such that it received clues from an external secure CSV file. This simplified the process of adding and removing clues to keep up with the evolving species, and also support themed events.

5.2. Using visual recognition to provide manipulability

The use of visual recognition was inspired by our observation of the stop-gap measures provided by the museum. The docent dispensed hand-held plastic magnifying glasses to be used by the children in lieu of directly interacting with the garden species. The use of visual recognition has also been studied in the museum context (Föckler et al., 2005), and was found to be superior in comparison to other typical technology at the museum such as QR codes (Wein, 2014). We use commercially available visual recognition in the *GardenHunt* to act as a game-master: checking the correctness of clues found. This use also allows for auto-curation, by preserving only those images that correctly answered a clue.

5.3. Pilot testing (phase 2)

To gauge the *GardenHunt* ease-of-use, we recruited eight design students (P1–P8) in three groups for a usability/pilot testing which we conducted in a lab setting. We only described the purpose of the application in the context of a garden, but did not give a tutorial on how the app features worked. Based on the feedback received, there was a consensus on the ease-of-use of the application, and can be competed without a tutorial. There was also no overt negative impact on the user's attention on an exhibit while using *the GardenHunt*: it was fun, accessible, and managed to meet the goal of avoiding distraction– *"I like how we motivate users to take pictures, people won't get distracted or consumed by the app". (P5)* The design strategy surprisingly sparked continuity: *"it's really fun like Pokemon Go–you [can] take your phone and [just] go out". (P2)*

We initially used in-game timers. This was negatively perceived, as it was found to engendered a race against the clock in completing the tasks. This is in line with findings from previous work (Rokne, 2011). Too, the time taken in explaining the timer's purpose also eroded the main objective in limiting the attention on the app as much as possible.

5.4. In-situ deployment and group characteristics

Three different school groups participated in our field study at the pollinator garden exhibit. Except for the entrance narrative, we did not change the factors of the school visit such as the visit time. The time constraints precluded exit interviews however, so we sought to observe and interact with those students during the visit. We discuss each group below, and make note of different interactions: *child–exhibit, child–child, child–docent* and *child–chaperone*, in the presence or absence of the game as an intermediary. We do this in order to provide extended context, contrast, and to observe gaps in the application performance.

The first group of 25 children served as the observation-only group. We noted the tour details and group interactions starting from the entrance narrative, the main tour, and up to the exit instructions (to return magnifying glasses and assemble at the exit point). In between, we sought to understand movement patterns across the garden, how the children responded to the docent's instructions, and how they interacted with each other, with the exhibit, and with the adult chaperones that accompanied them.

The second and third groups comprised of 25 and 15 children respectively. The entrance narrative was modified to include instructions about both versions of the scavenger hunt and how to play it. The rest of the entrance narrative was similar to *Group 1*'s. All the children in these groups were given the choice of playing the *paper-hunt*, while the older children were offered the choice of using either that or the *GardenHunt*. Eight children from *Group 2* and three children from *Group 3* chose to use *GardenHunt* while eight children from *Group 2* and 10 from *Group 3* opted for the *paper-hunt*. We allowed the children who opted for the *paper-hunt* to keep their copies if they chose to.

After the in-situ study with the school groups, we also tested the application (with no time constraints) as a day-long showcase at a science festival. We elicited user feedback through surveys, in order to better gauge enjoyment and usefulness across age groups, and to also solicit feedback via open-ended questions on present and possible future app functions. 28 users *(S1–S28)* completed the survey. The showcase users skewed older than the school groups, and provided us the opportunity to evaluate the "*leveling*" approach—whether the different age groups would garner enjoyment from playing the game at different levels and with different goals. We also used this as an opportunity to observe parent–child dyads using the application together, and as an attempt to consider its appeal to non museum-going users. During the showcase, we also interviewed five volunteer docents *(V1–V5)* as a focus group. These docents had intimate knowledge of the garden space, and had experience in leading school groups. They also had the opportunity to use the app during the showcase. We wanted their expert opinions on the efficacy of the designed application in mediating interactions between the visitor and the exhibit, together with their general impressions of the garden, separate from the *GardenHunt* application.

6. In the wild interactions

In this section, we detail our observations with various age groups in phase 3 and phase 4 of our study.

6.1. School groups observations (phase 3)

For the two school groups that had access to the game (G2, G3), we did not find an issue with the children understanding the purpose of the application. The entrance narrative was sufficient to convey the game rules, and the presence of the *paper-hunt* also served as a cue to the purpose of the *GardenHunt*. The categories in both games also corresponded to the species in the garden during that season.

6.1.1. Inclusivity

Other than these provisions, we did not demonstrate the use of the *GardenHunt* to the children who opted for the phone. There was a sense of confidence in how they interacted with the app, by rapidly moving through the categories to get a sense of game contents, even though the oldest users were 5th graders—who we estimated to be 10 years old. We observed that children would typically begin with the first category on the list, and after attempting a clue from this category, they would typically then attempt another category from the ones shown in Fig. 2b. They would usually proceed depending on curiosity and/or the section of garden they are currently in. Similar to what we observed during the usability testing phase, it was an intuitive process for the children to solve the scavenger clue using the *GardenHunt*. There was a case in G2, where a child had an issue with obtaining a clear focus of an ant using the phone camera. In that case, we demonstrated how to slowly zoom and pause, and this resolved the issue. We factored this concern about the impact of zoom concentration on both the app function and on the overall impact on attention and interaction with the exhibit. In the second iteration of *GardenHunt*, we offered suggestion to properly zoom to obtain the best possible picture quality.

6.2. Impact on interaction patterns (RQ1)

Guided by **RQ1** (*What impact does the presence of technology/device have on self-exploration and roles?*), we sought to observe any positive and/or negative changes that are caused by introducing technology to the visitor–garden interaction. We found that typical *child–exhibit interactions* with the garden exhibit depended on species that easily caught attention: so children in G1 tended to notice and gravitate towards butterflies. Given the ubiquity of caterpillars, the use of the magnifying glasses to observe them was also a popular option. Most notable however, was a reliance on the docent to point out the reclusive or easily ignored species such as snails and spiders. While the presence of the game changed the dynamics of this interaction, there was no change in how the children interacted with the noticeable species when considering G2 and G3. However, there was an increased awareness of other species to be found in the garden courtesy of the categories highlighted in both the *GardenHunt* and the *paper-hunt*, and this led to increased and improved interactions with those inconspicuous species.

6.2.1. Self-exploration

Although all the school groups were docent-led, there was no restriction on self-exploration in the garden. When considering the role of the docent in the *child–docent interactions* in G1, the children and the chaperons tended to await instructions or hints from the docent (such as where to locate snails), before they could embark on finding them. While there were signs in the garden, the children unsurprisingly did not seem to read them and would gravitate back to the docent instead, for instructions on where else to look for other species. Groups G2 and G3 had different interaction with the docent: the delegation was decentralized allowing for the children through the game, and by extension the chaperons, to have a direct role in species discovery. Because there was a sense of playfulness and initiative, and given that they had the categories of garden species in hand, the children tended to immediately begin group-exploration, instead of awaiting instructions from the docent. The relationship changed, and the docent was used as a source of answers rather than a source of directions.

We did not observe a marked difference with *child–child interactions* between the *GardenHunt* users and *paper-hunt* users. The children were willing to show others where to find the reclusive species that they had discovered, and there was some collaboration on how to find things together. However, there were some children especially in group G2 that were isolated from the main group, and appeared not to be undertaking self-exploration–which reinforced the previous observation by E1. In comparison to G2 and G3, children in G1 tended to be less involved in the garden because of the centralized role of the docent (this group was also quieter, perhaps to better hear the docent). They also tended to move in larger groups, again due to the role of the docent in orchestrating the exhibit tour.

6.2.2. Chaperone support

When considering *child–chaperone interactions*, we observed that none of the chaperones elected to use the game in either form. None had any question for the docent, regardless of whether they were asking on behalf of the children. We found that this observed inactivity was not due to inattention or disengagement: the children had no hesitations with directly interacting with them. The role of the chaperone we understood, was in *supervision*. By taking care of exhibit unrelated questions and other issues, they allowed the docent the space to seamlessly lead the tour session. We find that this dynamic is important and would not recommend having them as primary users of *GardenHunt*-type applications. For G1, the chaperons were in the background, completely ceding the control to the docent. We observed a difference in interactions between the chaperons in G2 and G3. The children would interact with them either by asking for help in finding species (both paper and app users), or in displaying successful hunts (for paper hunters once they had completed the hunt, for app users, in showing the trophy for each successful clue solved).

6.3. Evaluation: User reception and responses (phase 4)

After the in-situ deployment, we also presented *GardenHunt* to a varied user group during a day-long showcase at a science festival that attracted people interested in the outdoors. 28 people volunteered to complete the survey after having an unrestricted interaction with the *GardenHunt*. Through the survey, we collected demographic information, and measured different functions of the application. We also solicited free responses so as to gain insights on what worked well, and what can be improved. At the time of the showcase, we also held a separate focus group interviews with volunteer docents to further gauge *GardenHunt*'s efficacy in facilitating interaction with the garden exhibit. These docents had been involved with all the phases of the app, including interactions with the in-situ child-groups and adults at the showcase.

6.3.1. Something to do

From the focus group interview, the need for the visitors in a tour to turn from passive recipients to active participants emerged. Unlike the feedback from the usability phase, the docents preferred less information in the application to effect greater participation. This sentiment was echoed by a survey respondent with knowledge of the garden exhibit who as an adult, preferred the ''leveling'' nature of the *GardenHunt* to interact with the garden over the *paper-hunt*, and another who preferred its potential to inspire fun:

> *''I really like how the definition is not included, you figure it out by exploring–it might be nice to have a place to answer''. (V5)*
>
> *''SO much better than just giving them a list of stuff to find'' (emphasis retained) (S5)*
>
> *''I liked it because it gives you something to do'' (S18)*
>
> *''... it's great–my kids would love it''. (S19)*

6.3.2. Increased engagement

From their observation on how the survey respondents interacted with the *GardenHunt*, the volunteer docents noted the increased interactions and extrapolated how that would manifest in the garden context:

> *''When we had first those kids in [the showcase], they were really excited and engaged to see [that] they could name that plant–'cause it's in their garden. Adults could do it too: They were like 'Oh, I love that flower, I've got that at home'. And that sort of localization really, was exciting for a lot of people''. (V2)*

The issue of challenge also emerges from the implementation design that leveraged the ''leveling'' approach in order to engage adult users, or users with more familiarity with the garden species.

6.3.3. (Incidental) learning

How the pollinator garden fits in the larger ecosystem is left to be interpreted either directly by the docent or by the visitor. However, since *the GardenHunt* clues are composed of categories of species to be found at the garden, the docents noted the role it plays in providing the opportunity for the visitor to connect the dots, and on the importance of contextual information towards (incidental) learning:

> *''I think that the life-cycle [of every species in the garden] is really important, 'cause that's a huge thing as well'' (V4) ''... these eat these, and these eat those, and then everything goes around (referring to the life-cycle)''. (V2)*

There were suggestions on making the application more colorful and an additional social media aspect to enable sharing. Most of the suggestions from users at the showcase focused on ''more'': more content, more levels, kids and adult modes to be separate rather than layered, further clarification/cues when working with the camera and the image recognition technology, and better accuracy with the image recognition engine (a trade-off we had considered between app speed vs. accuracy).

6.3.4. Participant–garden interaction

All visitors tended to congregate towards where butterflies were to be found. The participants almost always skipped around categories in *GardenHunt* to find a clue about butterflies in order to use the opportunity to take a butterfly's photo. On asking about the app performance after the conclusion of their visit, we found that there was a sense of discovery, of both the garden species and the technology.

6.3.5. Technical difficulties

There were two users who were not able to successfully use the application during the showcase after having accidentally triggered the airplane mode on their mobile devices. The *GardenHunt* did not provide a warning about the lack of connectivity needed for the validator (visual recognition) to function, and therefore, they were not aware of how to solve the issue. The visual recognition engine was also novel to most of the children. We took time to explain the technology, how it processes images to 'guess' the correct answer, and how the images can then be viewed by the museum outside the *GardenHunt* application context. Once the participants understood its function, the visual recognition became app's most notable and memorable feature.

7. Discussion

7.1. Supporting leveled interactions at scale (RQ2)

In seeking to answer **RQ2** (*How can we leverage design that work for both individuals and groups, as well as spanning age groups?)* and to aid our understanding of how to scale to different number of users, we gave the phones pre-loaded with *GardenHunt* to children who used it in different pairings. The children collaborated in finding reclusive species, and compared their tally of found species with others. There was a sense of accomplishment, community, and ownership over the found species. Therefore, a ''leaderboard'' with pictures taken from the garden would be ideal to be placed close to the garden exhibit. But a ''leaderboard'' ranking players by number of items found would undermine the sense of community we observed from the garden. Also on *scaling*, the presence of the *GardenHunt* allowed the role of the docent to be decentralized allowing for a deeper involvement of the chaperons in helping to provide context to the children.

Using the *leveling* concept (Table 3), we found it straightforward for the app to be customized to different audience while retaining appeal across age-groups. Further, when exploring the avenues of designing for (re)use beyond the garden exhibit, we used a modular approach: categories and clues can easily be modified to fit other objectives. The essence of the application, beyond the potential for different uses, also breaks out of the silo effect inherent in a lot of applications designed for museums, thereby allowing for reuse outside the garden context.

Our use of *layering* in designing for the application was a means of effecting re-use. Each layer is abstracted, and could be customized to fit with a user's requirements (Fig. 3). The top layer (containing game clues) is the easiest to modify without needing to understand the technology underneath, and since it drives the game, the context can be changed according to need. This layer allows the museum to generate clues in keeping with the bloom-and-wither species cycle within the garden, maintaining application relevance. It can also be used outside the garden context as a customized scavenger hunt game. The camera and visual recognition layer allows for the application to be customized to use different cameras and visual recognition algorithms respectively.

7.2. Supporting visitor interactions beyond the museum (RQ3)

In trying to achieve a balance of fun and learning when designing for a limited time for interaction, the choice of fun as a short-term, primary objective worked well. The child-groups were aware of the species to be found in the garden, but the priority was not placed on why these species were chosen for the garden. There is also less pressure for the docent to ensure that all information is imparted to the children, and can instead interact

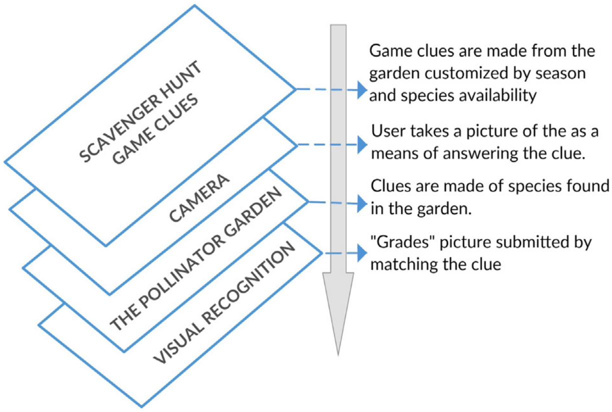

Fig. 3. Layering: We designed the application with distinct layers to allow easy clue customization and use in different contexts, without impacting the application function. The top layer is a simple interface that can be modified by the museum staff in our garden context.

and customize the visit as needed, as guided by **RQ3** (*How can we define a design approach that can be simplified for re-use outside the garden exhibit/museum context?*). Fun as a goal also worked with parent–child dyads, especially considering parents who were not conversant with the garden species. Prior to the scavenger game, without the docent's expertise, limited information about the garden species could be found from the signage placed around the garden. The *GardenHunt* became an activity focus that allowed for interaction.

In considering the tendency of mobile applications to usurp users' attention, our approach followed Molloy's (Molloy, 2016) recommendation, that ''[a] museum app should continuously direct the attention of the user from the phone to the actual objects on display'' (Molloy, 2016). Thus the *GardenHunt* constantly relied upon the user's interaction with the garden for it to work. At the same time, the presence of visual recognition allowed for the garden to be virtually re-represented, providing the user with a means of interaction that also preserves the fragile exhibit.

Our use of visual recognition as a clue validator allows auto-curation of images to be contributed to the museum: only those pictures which were classified to have answered the clue were set aside for sharing. The rest of the pictures were saved locally. As highlighted by the cases of ''selfies'' (self-portraits) submitted (Fig. 4), this curation approach also provided a measure of privacy-preservation in the photos that were shared with the science museum. The answers provided to the validator in order to provide classification is also used to label the submitted image, and together with the metadata, can be used by the museum to chart the bloom-and-wither cycle of species within, and outside the museum.

To match the previously outlined museum goals, we designed the application to be usable outside the museum. This has the potential of providing the museum with a means of maintaining a connection to the community while providing for a means for the community members of all ages to contribute to the privacy-preserving knowledge database of local species.

7.3. Design recommendations

While we focus our findings on intervention for a specific hands-off science exhibit, our exploration reveal several directions for future research. Our *in-situ* research approach focused on realistic conditions by which to determine the *GardenHunt*'s contextual effectiveness, but the lack of control with regard to group time and interaction style did not allow for an opportunity to probe more deeply about the effectiveness of the application as an interactive supplement. We discuss other themes from our observations that would benefit from further consideration.

Fig. 4. A sample of atypical photos taken during the garden tour. The first two were of lights around the indoor garden, that the teens submitted unprompted as experiments. The third picture is one of a few self-portraits taken within the app and with the phone's camera-highlighting possible privacy concerns.

7.3.1. Group–visitor interactions

For the duration of our research, the only visitors at the garden exhibit during group tours were members of the school groups (adult chaperones included), for which the mobile phones were provided. It is important to consider the interactions among people with and without technology, both in terms of design and evaluation. For example, while some *GardenHunt* design elements–such as omitting the use of sound took into account the possibility of other visitors using the space and sought to minimize distractions, observing and measuring how a group interacts with other visitors in negotiating the shared space would give useful insights about inter-group and intra-group dynamics.

7.3.2. Collecting and sharing information

A significant opportunity for success in supporting interactive exhibits through technology resides in the ability to share information gathered with technology within and across groups. Yet the concerns and safeguards in collecting and sharing information from young people necessarily affects the experience in ways that are not fully understood. Our research focused on children in school groups since they encompass the largest visitor base at the garden exhibit. We also provided phones that allowed and only accounted for *opt-in*, yet some children (and their parents and teachers) chose *not* to participate in either version of the game. Seeking to understand their concerns and make more transparent the ways that intended data use, would provide interesting insights about motivations, expectations, and nuances of participation.

7.3.3. Technology variations, device treatment and sharing

Our research focused on mobile phones as an information delivery medium, due to advantages of familiarity, mobility, and relative cost. However, variations in the manner, type, and style of technology should be explored as well. For example, use of visual recognition is not an exact science, as has been observed with other similar applications such as the Google Arts (Hauser, 2018), and ways to compensate for this limitation would be beneficial. Mobile devices are widespread but not ubiquitous, suggesting a need for comparison with kiosks, physical devices, and even non-technical solutions. We also note that durability of a mobile device borrowed from a parent or museum is an issue, as children in exciting and collaborative learning situations with friends do not always treat devices with care based on reports of how they handled existing physical devices such as magnifying glasses provided at the garden exhibit.

7.3.4. Privacy

There were instances where photos taken were not of elements presented in the game included self-portraits ("selfies") as shown in Fig. 4. We found two-fold reasons why the children took these pictures: (1) to test the validator's bounds in classifying images—as given by the example of the pictures taken of indoor floodlights as clue submissions and (2) for no reason other than to have a self-portrait, and a curiosity in how the image classifier would categorize their likeness. Regardless of the motivation, it brings into question the limitation of visual recognition engines in allowing some pictures to pass through the filter, as long as an element answering a clue can be found in the picture. This leads to an future consideration of how best to include negative keyword bounds to the validator—for instance to reject image containing a person to further provide a means of strengthening user privacy.

8. Conclusion

In this research, we approach the idea of providing museum visitors with an avenue for interacting with a hands-off exhibit aided by *GardenHunt*–a mobile application. In consideration of the known effects that mobile technology has on redirecting attention to the device, we are able to design to mitigate and achieve the attention-manipulability balance by merging tech-centered interaction with active learning. Our rationale follows that, if the groups using the application have fun interacting with the exhibit with focused learning as a secondary goal, the fun approach would improve attitudes towards the exhibit and encourage repeated visits while inspiring self-directed learning outside the museum context.

Using this rationale, we designed an Android application game and tested it with 3 school groups of 65 children, and discuss our observations on how the technology impacted different interactions. Our work in using an atypical museum exhibit in form of a pollinator garden allows the scrutiny of previous designs for augmenting the experience and how they can be scaled/modified to fit other environments, appeal to different audience given their age and museum experience, together with how they can be scaled to larger groups.

This research exemplifies other contexts that may feature: valuable artifacts, live species such as plants and insects, and fragile artifacts especially those that are aged, made of clay or made from glass. Science-centered contexts and especially those that consider exposing children to interact with different types of exhibits and artifacts would greatly benefit from our tech-centered active learning approach to meet those needs as well. Additionally, our work offers a design approach that in addition to inspiring active learning, also constantly redirects attention back to the exhibit instead distracting the user—thus recommending a deliberative design for using smart phone applications and hand-held devices that balance interaction and attention.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Alderman, Christina (2011). I spy: Interpreting artworks through games. In Katy Beale (Ed.), *Museum at play: Games, interaction and learning* (1st ed.). (pp. 576–583). Edinburgh: MuseumsEtc.

Ali, Susan, Koleva, Boriana, Bedwell, Ben, & Benford, Steve (2018). Deepening visitor engagement with museum exhibits through hand-crafted visual markers. In *Proceedings of the 2018 designing interactive systems conference (DIS '18)* (pp. 523–534). New York, NY, USA: ACM, http://dx.doi.org/10.1145/3196709.3196786.

Anagnostakis, Giorgos, Antoniou, Michalis, Kardamitsi, Elena, Sachinidis, Thodoris, Koutsabasis, Panayiotis, Stavrakis, Modestos, et al. (2016). Accessible museum collections for the visually impaired: Combining tactile exploration, audio descriptions and mobile gestures. In *Proceedings of the 18th international conference on human-computer interaction with mobile devices and services adjunct (MobileHCI '16)* (pp. 1021–1025). New York, NY, USA: ACM, http://dx.doi.org/10.1145/2957265.2963118.

Antoniou, Angeliki, & Lepouras, George (2010). Modeling visitors' profiles: A study to investigate adaptation aspects for museum learning technologies. *Journal on Computing and Cultural Heritage*, *3*(2), Article 7. http://dx.doi.org/10.1145/1841317.1841322, (Oct. 2010), 19 pages.

Armoni, Michal (2017). Computing in schools: Non-formal education in K-12 CS –: The case of museums. *ACM Inroads*, *8*(3), 24–26. http://dx.doi.org/10.1145/3123649, (July 2017).

Banerjee, Amartya, Robert, Rovik, & Horn, Michael S. (2018). Fieldguide: Smartwatches in a multi-display museum environment. In *Extended abstracts of the 2018 CHI conference on human factors in computing systems (CHI EA '18)*. New York, NY, USA: ACM, Article LBW061. http://dx.doi.org/10.1145/3170427.3188694, 6 pages.

Bohnert, Fabian, Zukerman, Ingrid, & Laures, Junaidy (2012). GECKOmmender: Personalised theme and tour recommendations for museums. In *Proceedings of the 20th international conference on user modeling, adaptation, and personalization (UMAP'12)* (pp. 26–37). Berlin, Heidelberg: Springer-Verlag, http://dx.doi.org/10.1007/978-3-642-31454-4_3.

Braun, Virginia, & Clarke, Victoria (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77–101. http://dx.doi.org/10.1191/1478088706qp063oa, (2006).

Cabrera, Jorge Simarro, Frutos, Henar Muñoz, Stoica, Adrian G., Avouris, Nikolaos, Dimitriadis, Yannis, Fiotakis, Georgios, et al. (2005). Mystery in the museum: Collaborative learning activities using handheld devices. In *Proceedings of the 7th international conference on human computer interaction with mobile devices & services (MobileHCI '05)* (pp. 315–318). New York, NY, USA: ACM, http://dx.doi.org/10.1145/1085777.1085843.

Callaway, Charles, Stock, Oliviero, Dekoven, Elyon, Noy, Kinneret, Citron, Yael, & Dobrin, Yael (2011). Mobile drama in an instrumented museum: Inducing group conversation via coordinated narratives. In *Proceedings of the 16th international conference on intelligent user interfaces (IUI '11)* (pp. 73–82). New York, NY, USA: ACM, http://dx.doi.org/10.1145/1943403.1943416.

Carrozzo, Federica, Faccini, Ruben, Falci, Angelo, Redaelli, Beatrice, Gelsomini, Mirko, Zannoni, Giacomo, et al. (2018). IDROPO, a hydroponic planting system to teach gardening through play. In *Extended abstracts of the 2018 CHI conference on human factors in computing systems (CHI EA '18)*. New York, NY, USA: ACM, Article D319. http://dx.doi.org/10.1145/3170427.3186489, 4 pages.

Ceipidor, Ugo B., Medaglia, Carlo M., Perrone, Amedeo, De Marsico, Maria, & Romano, Di Giorgia (2009). A museum mobile game for children using QR-codes. In *Proceedings of the 8th international conference on interaction design and children (IDC '09)* (pp. 282–283). New York, NY, USA: ACM, http://dx.doi.org/10.1145/1551788.1551857.

Cesário, Vanessa, Radeta, Marko, Matos, Sónia, & Nisi, Valentina (2017). The ocean game: Assessing children's engagement and learning in a museum setting using a treasure-hunt game. In *Extended abstracts publication of the annual symposium on computer-human interaction in play (CHI PLAY '17 extended abstracts)* (pp. 99–109). New York, NY, USA: ACM, http://dx.doi.org/10.1145/3130859.3131435.

Cheverst, Keith, Davies, Nigel, Mitchell, Keith, Friday, Adrian, & Efstratiou, Christos (2000). Developing a context-aware electronic tourist guide: Some issues and experiences. In *Proceedings of the SIGCHI conference on human factors in computing systems (CHI '00)* (pp. 17–24). New York, NY, USA: ACM, http://dx.doi.org/10.1145/332040.332047.

Chu, Jean Ho, Harley, Daniel, Kwan, Jamie, McBride, Melanie, & Mazalek, Ali (2016). Sensing history: Contextualizing artifacts with sensory interactions and narrative design. In *Proceedings of the 2016 ACM conference on designing interactive systems (DIS '16)* (pp. 1294–1302). New York, NY, USA: ACM, http://dx.doi.org/10.1145/2901790.2901829.

Civantos, Angeles Muñoz, Brown, Michael, Coughlan, Tim, Ainsworth, Shaaron, & Lorenz, Katharina (2016). Using mobile media creation to structure museum interpretation with professional vision. *Personal and Ubiquitous Computing*, *20*(1), 23–36. http://dx.doi.org/10.1007/s00779-015-0895-3, (Feb. 2016).

Cosley, Dan, Baxter, Jonathan, Lee, Soyoung, Alson, Brian, Nomura, Saeko, Adams, Phil, et al. (2009). A tag in the hand: Supporting semantic, social, and spatial navigation in museums. In *Proceedings of the SIGCHI conference on human factors in computing systems (CHI '09)* (pp. 1953–1962). New York, NY, USA: ACM, http://dx.doi.org/10.1145/1518701.1518999.

Crowley, Kevin, & Callanan, Maureen (1998). Describing and supporting collaborative scientific thinking in parent-child interactions. *Journal of Museum Education*, *23*(1), 12–17, (1998).

Cumbo, Bronwyn J., & Iversen, Ole Sejer (2020). CCI in the wild: Designing for environmental stewardship through children's nature-play. In *Proceedings of the interaction design and children conference (IDC '20)* (pp. 335–348). New

York, NY, USA: Association for Computing Machinery, http://dx.doi.org/10.1145/3392063.3394398.

Cumbo, Bronwyn J., & Leong, Tuck Wah (2015). Wearable audio-video recorders as a tool for investigating child play experiences in nature. In *Proceedings of the annual meeting of the australian special interest group for computer human interaction (OzCHI '15)* (pp. 618–622). New York, NY, USA: ACM, http://dx.doi.org/10.1145/2838739.2838822.

de Montebello, Philippe, Lowry, Glenn D., Wood, James N., Walsh, John, Jr., et al. (2004). *Whose muse?: Art museums and the public trust*. Princeton: Princeton University Press.

Diamond, Judy (1986). The behavior of family groups in science museums. *Curator: The Museum Journal*, *29*(2), 139–154. http://dx.doi.org/10.1111/j.2151-6952.1986.tb01434.x, (1986).

Doering, Zahava D., & Pekarik, Andrew J. (1996). Questioning the entrance narrative. *The Journal of Museum Education*, *21*(3), 20–23, (1996). http://www.jstor.org/stable/40479072.

Dohn, Niels Bonderup (2010). Situational interest of high school students who visit an aquarium. *Science Education*, *95*(2), 337–357. http://dx.doi.org/10.1002/sce.20425, 2010.

Economou, Maria, & Meintani, Elpiniki (2011). Promising beginning? Evaluating museum mobile phone apps. In *Rethinking technology in museums 2011: Emerging experiences* (pp. 1–20). Ireland: University of Limerick, http://eprints.gla.ac.uk/104173/.

Feher, Elsa (1990). Interactive museum exhibits as tools for learning: Explorations with light. *International Journal of Science Education*, *12*(1), 35–49. http://dx.doi.org/10.1080/0950069900120104, (1990).

Föckler, Paul, Zeidler, Thomas, Brombach, Benjamin, Bruns, Erich, & Bimber, Oliver (2005). Phoneguide: Museum guidance supported by on-device object recognition on mobile phones. In *Proceedings of the 4th international conference on mobile and ubiquitous multimedia (MUM '05)* (pp. 3–10). New York, NY, USA: ACM, http://dx.doi.org/10.1145/1149488.1149490.

Fosh, Lesley, Benford, Steve, & Koleva, Boriana (2016). Supporting group coherence in a museum visit. In *Proceedings of the 19th ACM conference on computer-supported cooperative work & social computing (CSCW '16)* (pp. 1–12). New York, NY, USA: ACM, http://dx.doi.org/10.1145/2818048.2819970.

Franz, Juliano, Alnusayri, Mohammed, Malloch, Joseph, & Reilly, Derek (2019). A comparative evaluation of techniques for sharing AR experiences in museums. *Proceedings of the ACM on Human-Computer Interaction*, *3*(CSCW), Article 124. http://dx.doi.org/10.1145/3359226, (Nov. 2019), 20 pages.

Gardens, Smithsonian (2017). Pollinator garden: Emphasizes natural plant partnerships. (Dec. 2017). Retrieved August 16, 2018 from http://www.gardens.si.edu/our-gardens/pollinator-garden.html.

Grinter, Rebecca E., Aoki, Paul M., Szymanski, Margaret H., Thornton, James D., Woodruff, Allison, & Hurst, Amy (2002). Revisiting the visit:: Understanding how technology can shape the museum visit. In *Proceedings of the 2002 ACM conference on computer supported cooperative work (CSCW '02)* (pp. 146–155). New York, NY, USA: ACM, http://dx.doi.org/10.1145/587078.587100.

Hakvoort, Gido (2013). The immersive museum. In *Proceedings of the 2013 ACM international conference on interactive tabletops and surfaces (ITS '13)* (pp. 463–468). New York, NY, USA: ACM, http://dx.doi.org/10.1145/2512349.2514598.

Hauser, Christine (2018). Meet your art twin: A 400-year-old with an oily complexion. (Jan. 2018). Retrieved August 16, 2018 from https://www.nytimes.com/2018/01/17/arts/google-art-selfies-doppelgangers.html.

Hofstein, Avi, & Rosenfeld, Sherman (1996). Bridging the gap between formal and informal science learning. *Studies in Science Education*, *28*(1), 87–112. http://dx.doi.org/10.1080/03057269608560085, (1996).

Hornecker, E. (2008). I don't understand it either, but it is cool – visitor interactions with a multi-touch table in a museum. In *2008 3rd IEEE international workshop on horizontal interactive human computer systems* (pp. 113–120). Piscataway, NJ, USA: IEEE Press, http://dx.doi.org/10.1109/TABLETOP.2008.4660193.

Iga, Naomi, Wakao, Asuka, Matsumura, Kohei, Lopez-Gulliver, Roberto, & Noma, Haruo (2017). Improving relationships between parents and children in shopping malls by using a digital treasure hunting game. In *Extended abstracts publication of the annual symposium on computer-human interaction in play (CHI PLAY '17 extended abstracts)* (pp. 261–267). New York, NY, USA: Association for Computing Machinery, http://dx.doi.org/10.1145/3130859.3131320.

Kotut, Lindah, Hoang, Ann, Shenk, Jennifer, Panda, Havisha, & Scott McCrickard, D. (2018). Technology at the museum: The missing voice. In *Proceedings of the second african conference for human computer interaction: Thriving communities AfriCHI 2018*. New York, NY, USA: ACM, http://dx.doi.org/10.1145/3283458.3283491.

Kuflik, Tsvi, Callaway, Charles, Goren-Bar, Dina, Rocchi, Cesare, Stock, Oliviero, & Zancanaro, Massimo (2005). Non-intrusive user modeling for a multimedia museum visitors guide system. In *Proceedings of the 10th international conference on user modeling (UM'05)* (pp. 236–240). Berlin, Heidelberg: Springer-Verlag, http://dx.doi.org/10.1007/11527886_31.

Lepouras, George, Naudet, Yannick, Antoniou, Angeliki, Lykourentzou, Ioanna, Tobias, Eric, & Rompa, Jenny (2015). Museum personalization based on gaming and cognitive styles: The BLUE experiment. *International Journal of Virtual Communities and Social Networking*, *7*(2), 1–30. http://dx.doi.org/10.4018/IJVCSN.2015040101, (April 2015).

Lo, Wan-Tzu, & Quintana, Chris (2013). Students' use of mobile technology to collect data in guided inquiry on field trips. In *Proceedings of the 12th international conference on interaction design and children (IDC '13)* (pp. 297–300). New York, NY, USA: ACM, http://dx.doi.org/10.1145/2485760.2485837.

Long, Sue, Kooper, Rob, Abowd, Gregory D., & Atkeson, Christopher G. (1996). Rapid prototyping of mobile context-aware applications: The cyberguide case study. In *Proceedings of the 2nd annual international conference on mobile computing and networking (MobiCom '96)* (pp. 97–107). New York, NY, USA: ACM, http://dx.doi.org/10.1145/236387.236412.

Mikalef, Konstantinos, Giannakos, Michail N., Chorianopoulos, Konstantinos, & Jaccheri, Letizia (2012). Do not touch the painting! the benefits of interactivity on learning and future visits in a museum. In *Proceedings of the 11th international conference on entertainment computing (ICEC'12)* (pp. 553–561). Berlin, Heidelberg: Springer-Verlag, http://dx.doi.org/10.1007/978-3-642-33542-6_73.

Molloy, Mark (2016). The real story behind a viral rembrandt 'kids on phones' photo. (Jan. 2016). Retrieved August 10, 2018 from https://www.telegraph.co.uk/news/newstopics/howaboutthat/12103150/Rembrandt-The-Night-Watch-The-real-story-behind-the-kids-on-phones-photo.html.

Muratsu, Keita, Ishiyama, Ayako, Kusunoki, Fusako, Inagaki, Shigenori, & Terano, Takao (2014). Stampon in a museum: Helping children's scientific inquiry. In *Proceedings of the 2014 conference on interaction design and children (IDC '14)* (pp. 233–236). New York, NY, USA: ACM, http://dx.doi.org/10.1145/2593968.2610460.

Ng, Kher Hui, Huang, Hai, & O'malley, Claire (2018). Treasure codes: Augmenting learning from physical museum exhibits through treasure hunting. *Personal and Ubiquitous Computing*, *22*(4), 739–750. http://dx.doi.org/10.1007/s00779-018-1126-5, (Aug. 2018).

Petrelli, Daniela, & O'Brien, Sinead (2018). Phone vs. Tangible in museums: A comparative study. In *Proceedings of the 2018 CHI conference on human factors in computing systems (CHI '18)*. New York, NY, USA: ACM, Article 112. http://dx.doi.org/10.1145/3173574.3173686, 12 pages.

Rennick-egglestone, S., Brundell, P., Koleva, B., Benford, S., Roussou, M., & Chaffardon, C. (2016). Families and mobile devices in museums: Designing for integrated experiences. *Journal on Computing and Cultural Heritage*, *9*(2), Article 11. http://dx.doi.org/10.1145/2891416, (May 2016), 13 pages.

Reyburn, Scott (2018). What the mona lisa tells us about art in the instagram era. (April 2018). Retrieved August 16, 2018 from https://www.nytimes.com/2018/04/27/arts/design/mona-lisa-instagram-art.html.

Roberts, Jessica, Banerjee, Amartya, Hong, Annette, McGee, Steven, Horn, Michael, & Matcuk, Matt (2018). Digital exhibit labels in museums: Promoting visitor engagement with cultural artifacts. In *Proceedings of the 2018 CHI conference on human factors in computing systems (CHI '18)*. New York, NY, USA: ACM, Article 623. http://dx.doi.org/10.1145/3173574.3174197, 12 pages.

Rokne, Arnfinn Sendahl (2011). Smartphone interaction: The museum as a gaming board. In Katy Beale (Ed.), *Museum at play: Games, interaction and learning* (1st ed.). (pp. 274–285). Edinburgh: MuseumsEtc.

Rubino, Irene, Barberis, Claudia, Xhembulla, Jetmir, & Malnati, Giovanni (2015). Integrating a location-based mobile game in the museum visit: Evaluating visitors & rsquo; behaviour and learning. *Journal on Computing and Cultural Heritage*, *8*(3), Article 15. http://dx.doi.org/10.1145/2724723, (May 2015), 18 pages.

Rudametkin, Walter, Gama, Kiev, Touseau, Lionel, & Donsez, Didier (2010). Towards a dynamic and extensible middleware for enhancing exhibits. In *Proceedings of the 7th IEEE conference on consumer communications and networking conference (CCNC'10)* (pp. 774–778). Piscataway, NJ, USA: IEEE Press, http://dl.acm.org/citation.cfm?id=1834217.1834390.

Science Museum of Western Virginia (2018). Hidden garden revealed. (May 2018). Retrieved August 16, 2018 from http://smwv.org/hidden-garden-revealed/.

Seo, Jinsil Hwaryoung, Sungkajun, Annie, & Suh, Jinkyo (2015). Touchology: Towards interactive plant design for children with autism and older adults in senior housing. In *Proceedings of the 33rd annual ACM conference extended abstracts on human factors in computing systems (CHI EA '15)* (pp. 893–898). New York, NY, USA: ACM, http://dx.doi.org/10.1145/2702613.2732883.

Shibasaki, Mina, Iwazaki, Karin, Takeda, Minato, Kamiyama, Youich, Obata, Koichi, Yoshino, Koichi, et al. (2017). Melight: Embodied appreciation of inouzu. In *Proceedings of the virtual reality international conference - Laval virtual 2017 (VRIC '17)*. New York, NY, USA: ACM, Article 16. http://dx.doi.org/10.1145/3110292.3110309, 3 pages.

Simon, Nina (2016). The Art of Relevance. Museum 2.0, Santa Cruz.

Simon, Nina (2017). How do you inspire visitors to take action after they leave? (July 2017). Retrieved August 8, 2018 from http://museumtwo.blogspot.com/2017/07/how-do-you-inspire-visitors-to-take.html.

Stock, Oliviero, Zancanaro, Massimo, Busetta, Paolo, Callaway, Charles, Krüger, Antonio, Kruppa, Michael, et al. (2007). Adaptive, intelligent presentation of information for the museum visitor in PEACH. *User Modeling and User-Adapted Interaction*, *17*(3), 257–304. http://dx.doi.org/10.1007/s11257-007-9029-6, (July 2007).

Wakkary, Ron, Hatala, Marek, Muise, Kevin, Tanenbaum, Karen, Corness, Greg, Mohabbati, Bardia, et al. (2009). Kurio: A museum guide for families. In *Proceedings of the 3rd international conference on tangible and embedded interaction (TEI '09)*. New York, NY, USA: ACM, Article 0. http://dx.doi.org/10.1145/1517664.1517712, 8 pages.

Wein, Leonard (2014). Visual recognition in museum guide apps: Do visitors want it? In *Proceedings of the SIGCHI conference on human factors in computing systems (CHI '14)* (pp. 635–638). New York, NY, USA: ACM, http://dx.doi.org/10.1145/2556288.2557270.

Wood, Gavin, Vines, John, Balaam, Madeline, Taylor, Nick, Smith, Thomas, Crivellaro, Clara, et al. (2014). The department of hidden stories: Playful digital storytelling for children in a public library. In *Proceedings of the SIGCHI conference on human factors in computing systems (CHI '14)* (pp. 1885–1894). New York, NY, USA: Association for Computing Machinery, http://dx.doi.org/10.1145/2556288.2557034.

Woodward, Julia, Esmaeili, Shaghayegh, Jain, Ayushi, Bell, John, Ruiz, Jaime, & Anthony, Lisa (2018). Investigating separation of territories and activity roles in children's collaboration around tabletops. *Proceedings of the ACM on Human-Computer Interaction*, *2*(CSCW), Article 185. http://dx.doi.org/10.1145/3274454, (Nov. 2018), 21 pages.

Yiannoutsou, Nikoleta, Papadimitriou, Ioanna, Komis, Vassilis, & Avouris, Nikolaos (2009). Playing with museum exhibits: Designing educational games mediated by mobile technology. In *Proceedings of the 8th international conference on interaction design and children (IDC '09)*. New York, NY, USA: ACM, Article 38. http://dx.doi.org/10.1145/1551788.1551837, 4 pages.