Exploring Whole-body Interaction and Design for Museums

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Abstract

Museums increasingly use digital technology to enhance exhibition experiences for families, notably in relation to physically mediated installations for young children through Natural User Interfaces. Yet little is known about how families and children engage with such installations and the kinds of interactive experiences they engender in museum spaces. This paper addresses a pressing need for research to adopt an analytical focus on the body during such digitally mediated interactions in order to understand how bodily interaction contributes to meaning making in the museum context. It reports an observation study of families and children interacting with a Whole-body Interface (using Kinect) in the context of an installation in a museum exhibit on rare Chinese paintings. The study shows how the installation design engenders particular forms of bodily interaction, collaboration and meaning making. It also contributes design insights into whole body interaction installations in museums and public spaces.

Author Keywords

Human computer interaction, Natural User Interface, Whole-body Interaction, User studies, Children, Interactive learning environments, Novel interaction devices

Research Highlights

- Examining the design of Whole Body Interaction (WBI) for museum engagement
- Observation study of families and children engaged in WBI in a art based museum installation
- Making meaning through bodily engagement eliciting cause and effect relationships
- Different forms of collaborative interaction through physically mediated communication
- Contributes empirically grounded design insights to inform the use and design of WBI exhibits in museums

Introduction

Museums are continuously seeking to improve their visitor experience by using technology to increase interactivity. The role of curator and museum educator is also changing, acknowledging the need to look for new ways to enable visitors to find, interpret and make connections across collections (Johnson et al., 2012). Technology in the form of Natural User Interfaces (NUI) provides novel ways of fostering active interaction and enhancing creative and playful engagement that capitalizes on everyday experience (Price et al., 2003). NUIs refer to computing interfaces that are in effect invisible to the user, and remain invisible as the user interacts. According to the NMC report (Johnson et al., 2012) NUIs are predicted to become commonplace in museums in the next 3-4 years. They are appealing in the museum context, since they do not demand any specific technical or developmental skills in order to interact, nor the need to wear or use external devices (Antle et al., 2011). This means that the installation can be accessible to any visitor both in terms of age and experience with technology. Kinect can be designed to serve as a NUI to provide discovery-based learning opportunities through whole body interaction (WBI), where bodily movement is tracked and gesture and movement is used to instrument changes in, for example, visual or audio displays.

While NUIs are being introduced in innovative museums around the world, particularly in natural history, science and children's museums (aiming to provide discovery learning opportunities), they have yet to show widespread adoption (Johnson et al., 2012) and their contribution beyond novelty is unclear. With the impending increased prevalence of WBI technologies in museum contexts, there is a growing need to understand the potential of bodily engagement and interaction in the museum visit process, and how WBI exhibits are best designed to foster improved museum experiences for children and families. This paper reports an observation study of a Kinect-based installation, designed to provide more engaging experiences (through WBI) with typically inaccessible exhibits to children, such as the 'Masterpieces of Chinese Painting' exhibition. This installation enables children to interact with Chinese paintings, and offers an opportunity to creatively explore this art tradition through whole-body movement. As Farrow and Iacovides (2013) state, this "move towards 'whole-body' interactive approaches appears to assume that more 'embodied' interactions will lead to more engaging and immersive … experiences" (p.3). There is a pressing need, therefore, for more research to adopt a critical analytical focus on the body itself during the interaction in order to understand how (rather than simply if) physical interaction contributes to meaning making. To

better understand the value of WBI experience in museums this paper focuses on how children use their bodies to make sense of and interact with the exhibit, communicate or collaborate with one another, and the role of the design of the installation in this process.

Background

Whole Body Interaction Systems

WBI research has focused on how these systems impact on experiences of play and learning, including their potential to support or shape social interaction, abstract learning, motor learning, or affect and immersion, but few studies have considered these potentials within museum contexts.

Research shows how bodily based forms of interaction increase engagement and immersion (Adachi et al., 2013; Zuckerman and Gal-Oz, 2013) and support social interactions, which can support learning as it unfolds (Jakobsen and HornbÆk, 2014; Antle et al., 2011). Bianchi-Berthouze et al. (2007) suggest that whole-body interaction 'removes the burden of physical contact with technology' (p. 102) and can therefore make the interaction more pleasurable. Exertion interfaces, that exploit WBI, have been found to positively impact on user affect and engagement (Lyons et al., 2012). While little research has explicitly examined how these ideas feature in museums, Snibbe and Raffle (2009) and Fatah gen Schiek and Moutinho (2012) argue that as WBI involves highly visceral, social and immersive experiences, they have a clear role to play in enhancing the experience of museum visitors.

A body of research outside museum education considers the potential of WBI to support children's motor learning and development, some work focusing on specific user groups, such as children with motor disabilities or Autistic Spectrum Disorder (ASD) (e.g. Bartoli et al., 2013). One tranche of work showed, for example, that touchless (or whole body) interaction can support focused and sustained attention in autistic children (Antle et al., 2011). Other research has explored the role of WBI in balance training (Vernadakis et al., 2012), its role in supporting an increase and diversity in children's movement repertoires (Landry et al., 2013), and supporting the development of body schemas through body posture, communication and imitation (Casas et al., 2012).

Research has also explored the potential of WBI to support the understanding of abstract concepts. For example, Holland et al. (2011) harnessed the concept of embodied metaphors (Antle, 2007) to facilitate

learning about abstract concepts of musical harmony in a WBI system. Some research suggests a close link between physical experience and conceptual development (e.g. Manches et al., 2010), while others suggest that bodily action used to control digital effects may reduce cognitive load so that users have more attention to invest in the activity (e.g. Antle et al., 2011) or consolidate mental representations through multi-sensory encoding (Chao et al., 2013).

While research has begun to explore the potential of WBI to support play and learning, there is a need to examine bodily interaction itself rather than measuring interaction through user reports or post-activity measures. As Malinverni and Pares (2014) suggest, the majority of studies looking at interactions with WBI systems have used retrospective measures to explore user engagement, rather than observing individuals while they interact. A small group of studies have used patterns of gaze as indicators of engagement (D'Mello et al., 2012), or hand movements as indicators of learning strategies (Antle et al., 2009). This study contributes to this area by looking at unfolding bodily behaviours in WBI, analyzing gaze, gesture, movement and other bodily modes of communication and interaction to understand how experience is shaped.

Issues in WBI Design

Research in the context of tangible systems and WBI design has highlighted the large degree of flexibility these systems offer in terms of design, requiring a detailed understanding of the impact of different designs on interaction (Price et al., 2010). Several studies offer insight on specific design parameters and their impact on interaction and cognition, in terms of mapping between action and effect (e.g. Antle, 2007; Hornecker and Buur, 2006; Price et al., 2010), in developing frameworks of understanding interaction (Hornecker and Buur, 2006), or for structuring research (Price et al., 2008). Hornecker and Buur (2006) discussed the importance of 'perceived coupling' in determining actions and interactions, that is, interaction is dependent on the user's understanding of the physical-digital relationship. Indeed observations of users engaging through bodily modes (gaze, gesture, touch, movement) suggest that prior understanding of physical action does not always correspond with the design rules governing digital environments (Tscholl et al., 2013), resulting in increased cognitive load (working out how to interact) rather than an intuitive method of interacting.

Various design frameworks have been proposed to help designers decide which physical-digital relationships are most appropriate. Antle (2007) suggests the need to take into account three kinds of

mappings between physical and digital space: perceptual (how things appear versus how they respond); behavioral (input behaviors versus output effect); and semantic (information embedded in the physical and digital aspects of the system). Other work has looked at interaction from a representation design perspective (Price et al., 2008), and shows how the location of representations relative to one another has a direct impact on focus of attention and awareness of others' actions (Price et al., 2010). With discrete locations, input and output are separate (i.e. an action triggers a distinct digital representation); while in co-located systems the digital representation is adjacent to the action. These parameters of design are important to consider in relation to how action unfolds in the context of WBI. By examining how interactions occur in co-located or discrete designs, designers will have a better grasp of the interactive potentials of the systems. This paper builds on this work to extend our understanding of design for WBI, specifically in museums, with their increased interest in fostering hands-on and experiential interaction.

Frameworks for Examining and Designing Museum Installations using WBI

In examining and designing visitors' interactions with WBI exhibits, some initial frameworks have been developed. Snibbe and Raffle (2009) put forward seven design principles for WBI in museum contexts, which includes, for example, ensuring that systems are responsive in immediate, clear and predictable ways to users' interactions. They also developed a taxonomy of narratives to characterize the different ways that WBI exhibits could be designed for engagement (e.g. game-like, experiential or episodic). Alternatively, Horn et al. (2012) borrowed the notion of Active Prolonged Engagement (APE) from Science Museum literature to analyse video observations of museum visitors engaging with a tangible tabletop. APE is a measure of engagement based on various factors including the length of time spent engaging with the exhibit and the extent and nature of collaboration that occurs between users as they engage. Although APE was not developed with digital systems in mind, Horn et al. use the measure to show that immersive digital experiences, that have a highly physical component, can lead to increased engagement in a museum context. While Snibbe and Raffle (2009) and Horn et al. (2012) both consider how exhibits can be designed to engage users in different ways, the symbolic interactionist approach of von Lehm et al. (2001) stresses the distinct nature of each interaction with an exhibit and the powerful influence of others' affect and engagement on an individual's interaction with an exhibit. Therefore, how a WBI exhibit scaffolds multimodal communication between users is vital in shaping the interactions that unfold around it.

Digital Dragons Installation

The 'Digital Dragons' installation was based in the Victoria and Albert Museum, London, in the Sackler Education Centre for a 6 month period. It was designed to increase visitors' awareness of Chinese Art. The museum installation brief identified the audience as being primarily children and families, with the intention to: encourage interaction between people within the space; engage visitors in the content and context of classical Chinese painting; be playful, contemporary and exciting, providing routes into learning other than through absorption of knowledge in labels; provide a memorable, immersive experience; challenge preconceived ideas of how people interact with collections in museums, discouraging passiveness and encouraging activity and interaction with artworks and with other people (V&A design brief).

The installation, created by Bright Ideas Design in collaboration with the museum, aimed to link with the 'Masterpieces of Chinese Painting' exhibition. 'Digital Dragons' is based on projections of two Chinese paintings: 'Nine Dragons' by Chen Rong and 'Farewell to Xunyang' by Qiu Ying (Figure 1). The installation used four projectors, Xbox Kinect and custom code to create an interactive projection of each painting, placed in an empty room with a wide entrance space along one wall. The wall projection was distributed around the other three walls, the floor projection taking up the space that sat within the wall-projected area (Figure 2).

Figure 1 & 2

The wall-based display showed a visualization of the paintings, which were animated in different ways according to bodily interaction with a visual display projected onto the floor. The floor projection comprised a number of changing features over time. For the 'Nine Dragons' inspired painting, coloured spots (or pearls, which are present in the painting) appeared in different locations on the floor, then disappeared once a user stood on them, or as new ones were projected. Standing on the 'pearls' elicited a dragon chasing a 'pearl' across the wall display. Animated whirlwind images also changed location on the floor projection, but did not elicit any effect in the wall display (Figure 3). For the 'Farewell to Xunyang' inspired projection, circular icons were projected on the floor, which elicited different effects on the wall display, e.g. standing on an icon of a paintbrush added colour to the landscape scene, standing on a boat caused the boat on the

wall display to move backwards and forwards, the hands icon elicited people in the painting to wave and call 'bye bye' (Figure 3).

Figure 3

Study Design and Methods

An observation study was undertaken to collect naturalistic interactions of different groups of visitors with children: members of the public, primarily family groupings who visited the installation as part of their museum visit; and a class of Year 6 school children, making a school trip to the museum.

Table 1

Participants

Observation was of 11 family group episodes varying in number and age (total participants = 25) and 4 groups of school children interacting in groups of four and five (total participants = 18) (Table 1 specifying participating adults).

Design and Procedure

This study took a qualitative approach, using naturalistic observations of children and families interacting with the exhibit, the groups of school children were also interviewed. Observations sought to identify and explore ways that different users engaged with the installation. All interactions were video recorded, video data was collected from three perspectives: two unobtrusive fixed cameras, one positioned high in the top corner of the display to record participants' interaction on the floor space and one positioned in the scaffold structure of the installation to record participant interaction from behind together with the visual display; and a researcher using a roaming iPad who stood to the side and back of the installation where non-participating visitors congregated, holding the iPad at waist height, and not interacting with participants. A second researcher observed the interaction from the back of the installation and also did not interact with participants. A sign at the entrance to the room where the installation was placed highlighted that video recording was taking place. Consent to store and use the video data was sought from parents as they exited the installation by a third researcher. For school groups, consent was obtained prior to the visit for being observed, video recorded and interviewed. Data from any families or participants who chose not to give consent was removed from the analysis.

Family groups came and went as it suited them, thus the time spent in the installation varied from group to group, with an average time of 14-15 minutes, ranging from 2.3 minutes to 18.5 minutes. Sometimes one family's visit overlapped with others. The school children interacted in groups of 4-5 (groupings selected by the teacher) for approximately 12 minutes for each group. During this time the installation was closed to the general public, to avoid overlapping or mixing of groups.

Semi-structured interviews were undertaken with the four groups of school children after their interaction to gain further insight into their understanding of their interaction with the installation, the paintings, and their views on the experience in general. Interviews were not conducted with the family groups for two reasons, visitors had very restricted time to explore the museum and the children in over half the family groups were five years or under. Interviews were undertaken by a researcher in a room adjacent to the installation, video recorded and took approximately 12-15 minutes. Example questions included: *Can you tell me what you were doing? What happens when you do that? How did you know? Did you learn anything from doing that? What did you feel?* Or more specific questions guided by the interview progress e.g. *Were there any other rules? You said it was like a game… Why did you think it was like a game? Were you looking at the floor or the wall? How did you know to put your hands like that?*

Data Analysis

Episodes of interaction were transcribed using a multimodal analytical approach. This approach is concerned with understanding how people communicate and represent meaning and provides the conceptual tools to analyse situated interaction with a focus on how modal resources are differently taken up and configured through interaction (Jewitt, 2014). A mode is a socially organized set of semiotic resources for making meaning: here bodily movement, posture, gesture, gaze as well as talk (although there was little talk in this particular context) are all examples of modes. The analysis draws attention to how each mode offers different affordances, potentials and constraints for making meaning, differences that affect the kinds of meanings that it can be used to realize, or the different ways meaning can be achieved. From a multimodal perspective we understand each mode as partial and account for all modes in our analysis to gain insight into communication and meaning making. The video recordings taken over three days in the museum produced 15 episodes of interaction (11 family group episodes and 4 school group episodes). A multimodal transcript of each episode of video recorded interaction was created to describe the unfolding interaction using the

dimensions of speech, gesture, bodily movement and action. An iterative process of repeated video viewings (including in slow-motion, fast forward, with and without sound) alongside transcripts was used by three researchers to identify key analytical themes, informed by relevant research literature, and relevance to bodily interaction and communication in the museum context. These were: bodily enactment (type of movement e.g. running, jumping, pointing), focus of attention (e.g. on floor or wall display), physical-digital linking (e.g. linking jump on spot to dragon appearing on wall display), peer collaboration (e.g. verbal co-ordination of action, mimicking actions) and the role of adults (e.g. facilitation, direction). Data from each episode was clustered around each of these themes, to examine patterns of interaction and engagement across groups related to each theme, and how the children and families used and configured the modes available to them differently to realize experiences in the installation, including through expressive bodily enactment. Interviews were transcribed verbatim and relevant verbal reports linked to observational data. Thus, the analysis involved identifying patterns of bodily activity and, based on when and how they unfolded, linking these to features of the exhibit design.

Results and Discussion

The data shows that the exhibit elicited high levels of physical activity and different types of physical engagement. Interaction across visitors was primarily through bodily movement, gesture and gaze and commonly led to joint activity. The data analysis focused on the relationship between physical action and interaction, and the specific design features of the interactive exhibit, to gain insight into how the design of WBI experiences in museums can shape visitor interaction and interpretation. Drawing on the analysis, the results are reported and discussed under the following themes: bodily enactment, making links (understanding the exhibit design), collaboration, and engagement with content.

Bodily Enactment

A high level of physical movement and bodily engagement was observed across all episodes. Bodily movement was initially and primarily evoked by elements on the floor projection, such as coloured pearls, swirling spots, and circular icons. Interaction typically began with children walking or running unsystematically on the floor projection, then specifically interacting with the symbols in various ways: jumping, standing, stamping, twirling, dragging spots with feet, kicking spots along, e.g. whirlwinds towards

pearls (Figure 3). Specific design features of the interactive floor space were observed to shape this interaction in particular ways.

Interactive spots

The appearance and disappearance of interactive spots on the floor projection prompted all children (except E9) to move, often rapidly, from one spot to another before it disappeared, or to be the first in the group to reach the new spot. This type of physical interaction was observed to influence the experience in a number of ways, but also depended on the social make-up and dynamics of the group. In the school groups this form of interaction resulted in rapid and chaotic running, accompanied by shouting and loud nonverbal exclamations. In all family groups with more than one child it also resulted in rapid movements around the floor space, but was less chaotic being accompanied by mimicking and copying between children, e.g. one child following another, copying a 'jump' movement on the spot, or following a developed action repertoire, such as, run-jump-look. In addition, the changing location of spots and presence of multiple spots on the floor fostered other bodily positions and movement. Very young children (aged 16-36 months) were drawn to touch them with their hands, crouching or sitting on the floor to do so. Others tried stepping on two symbols at the same time straddling across the space in between (figure 4).

Figure 4

In both groups (families and school) these patterns of interaction can be linked to game-like activities. One game consisted of watching for and physically standing on all the interactive symbols, as they appeared and disappeared, resulting in rapid running and jumping on the floor projection (E2, E11). In another (E4), one girl created rules where her sibling had to be responsible for certain parts of the floor, jumping on symbols that appeared on 'his' area of the floor. Another group created a game, where they had to step on the spots as if they were stepping stones, with ideas of being able to 'win' or 'lose' (E8, E14). Interview data clarified the school children's interpretation of the interactive spots and the subsequent rule-based games they developed.

"And at the end, there were hands. And you had to cross your hands. And I was the last one to tap it (laughs). We won that game"

In the Nine Dragons painting all school groups reported having to stand or jump on the pearls (or coloured spots) on the floor before the animated dragons reached the pearls they were chasing across the wall or to stop the dragons from capturing the pearls. The landscape painting was thought to be a game with 'levels', as is common with other interactive computer games. Reaching the next level was achieved when they elicited changes that occurred across the sequence of the animation e.g. newly coloured areas, characters appearing and/or interacting.

"When it changed, we went to the next level"

This interpretation while based on the children's game playing experience outside of the installation, may have been amplified by the in built sequential stages of this exhibit that were time related rather than interaction related (colouring the image could only be elicited in the first part of the interaction; people in the animation waving could only be elicited towards the end of the interaction).

Symbol design

A relationship was observed between the specific symbols on the floor and the kinds of bodily enactment engendered. Stepping or jumping on symbols was a common action:

"When you see that paintbrush you have to step on it so that it can colour. We could jump and stamp on it then it would colour in part of the garden. Where the paint brush is on the floor links to the part on the wall that is painted in"

Other actions were based on interpretation of the symbols, e.g. the symbol showing two crossed hands (figure 3) led to various hand actions in all groups, including waving their hands above the symbol without touching, crossing their hands over the symbol or clapping in response (figure 5).

Figure 5

The visual design of other symbols encouraged other specific types of movement, highlighting how design shapes interaction. Twirling on the swirling floor spots suggests ways in which children sought to map their body movement directly to the visual display; or dragging a coloured spot on the floor with their foot to try to move it as one would with finger touch-based interaction (E4, E12), suggests how interactive repertoires are re-used across different spaces. Other symbols encouraged children to experiment with different types of interaction, for example, kicking rather than stepping or stamping on the flowers or whirlwinds (E4, E10).

From a design perspective, the symbols of the 'flowers' and 'whirlwinds' had limited interactivity, whereby they moved slightly away from the individual on the floor, but did not disappear or prompt any changes in the visual display on the walls. Initially, their presence drew attention and physical movement from some children, but introduced confusion for others in terms of their interactive potential, e.g. one school group believed the swirls were like quicksand and, as part of the game, should be avoided (E14).

These findings extend previous work around design mappings in tangible interfaces (e.g. Antle, 2007; Price et al., 2010) that highlight differential benefits of literal and metaphorical mappings, and illustrate the complexity of seemingly direct mappings. The visual symbol with the hands that prompted a number of different responses from the children suggests that this design symbol has a number of meanings, which range from metaphorical to literal. From a design perspective, the hands were there to indicate that it was time to say 'bye bye', as the visual display on the wall did, but in half of the episodes, the symbol was an invitation for children to literally engage with the hands e.g. through touching, patting or crossing hands on the floor (figure 5).

The range of mappings used in symbols in this exhibit, potentially impact on the ease with which they can be interpreted. For example, some icons linked to objects on the wall projection (e.g. the boat), while others linked to nature's processes (e.g. tree elicits the wind to blow), still others related to social gestures (e.g. hands elicits waving goodbye). This means that the mappings had to be translated differently, increasing the effort required for interpreting meaning in relation to action. Expectations of linked changes also affected their interaction and experience. For example, one child reported that "every time we tried to jump on the picture [of the boat] it went forwards and then backwards. I expected it to keep going forwards" (E15, aged 7yrs). This made him feel that he had failed and 'wasn't doing it right' and if he had been doing it properly the boat would have continued to move forwards. The expectation here was the more you jumped the further the boat would move forward.

These findings highlight the need for designers to consider the expectations (and experiences) that users bring to WBI interfaces, how to convey what is interactive, and in what way and how or whether to mix design mappings. On the one hand the analysis highlighted how mixed mappings have the potential to introduce complexity into interaction and sometimes led to confusion or despondency (as in the example above). On the other hand the observations also exposed the extent to which the diversity of symbols and

mappings created an environment for a range of movements and physical interaction. This both supports the desire of museum educators to foster interaction that is physically pleasurable and stimulating, and encourages diverse creative forms of interaction.

Making Links

As well as making mappings between symbol and action, a WBI installation inherently requires the need for users to make links between their actions and any elicited digital effect (visual or audio). A design with an interactive floor projection dynamically linked to a wall display creates two separate spaces in the interaction space resulting in a 'discrete' design (Price et al., 2008), which demands attention to two separate spaces simultaneously. Analysis showed that all children paid attention differently to the floor and the wall, and this influenced the degree to which they made links between their action and the wall projection.

The wall projection drew less focused attention in general. A couple of exceptions were toddlers (aged 26 months, family friends) who were initially drawn to the wall display, walking away from the floor projection to spend time touching images on the wall, perhaps seeking to interact with it (figure 6). One toddler (16 months) even used the wall projection as an entertainment screen, assuming a sitting position and watching the projection, while others present from another family group interacted with the floor space (E9). Certain aspects of the installation, like audio, had the potential to draw attention to the wall projection, as well as prompts from carers or parents: yet observation suggests that children did not always respond to these prompts, as they were immersed in their own self-directed experience (see collaboration).

While in this discrete design the floor projection attracted the attention of most children in the first instance, links between the floor and the wall did develop over the course of the interaction in some groups. Children in four of the naturalistic episodes focused primarily on the floor (E2, E4, E8, E9), while six began by attending to the floor, but as their interaction progressed their gaze shifted from the floor to the wall and back, indicating that links were being sought and/or made (E1, E3, E5, E10, E11). In the other two groups attention was on moving elements of the floor and the wall, but analysis of their gaze and body movement suggest these were noticed separately and did not seem to be linked (E6, E7). Children in the school groups formed links via gaze and gesture, between the floor and the wall projections, and verbal interaction: one group explicitly debated the links between their interaction on the floor and the visual activity on the projection whilst in the installation. In the interviews these observations were clarified, with all school

groups reporting ways in which they helped one another make links between their actions and observed effects. However, their interpretation of linking switched around the causality of the designed links, where the wall projection was perceived as a set of clues for how to interact with the floor. In the Nine Dragons interaction, rather than seeing standing on pearls as eliciting dragons to appear on the wall display, one group linked this action to preventing the dragon from catching the pearls by seeing the colours (pearls) that appeared on the wall projection as the ones that they needed to look for on the floor. Thus making their role as protectors in a game more significant than the design intended. In the animated display the dragons chase the pearls, but never capture them. With the landscape interaction, another school group reported being less able to make clear links between action and effect: and again positioned themselves as agentive in this lack. In this design the effects in general involved smaller movements on the wall display e.g. the boat moving backwards and forwards slightly or the trees swaying. Where larger changes were evident e.g. colour being painted across the wall, or where audio was involved, then links were made more easily.

Figure 6

Previous tangible interaction research highlights the effects of attentional split that results from discrete representations (Price et al., 2010). This design, that required standing on specific visually projected symbols on floor to trigger effects on a wall display, demands that children simultaneously maintain two different foci of attention, making linking more challenging. Analysis here suggests that only some children developed an awareness of the potential links and explored these through physical activity. In all groups children's attention was initially on parts of the floor, both interactive and not. The interactive spots that appeared and disappeared fostered continued engagement, but while looking for and racing towards these spots suggests that they understood them to be important in some way, this in itself did not draw their attention to the wall. Thus they often missed related effects on the wall e.g. dragons flying across. Attention often remained on the floor since dynamic changes continued to take place here without the need to look at the wall display.

The installation included audio in different forms in the two painting installations. In the Nine Dragons painting audio comprised of a swooshing sound as the dragons flew across the display chasing coloured pearls; in the landscape painting audio was in the form of music (a traditional Chinese instrumental) throughout the interaction period, with other sounds directly related to interaction with the floor and to

objects and animals in the wall projection, e.g. a horse neighing, the wind blowing, people saying 'bye bye'. This audio provided triggers for drawing children's attention to the wall display, some being stronger than others. People in the landscape calling 'bye, bye' more commonly drew children's attention to the wall projection than the wind blowing or the 'swooshing' of the dragon. The 'bye bye' was distinct, rather than a sustained background sound of the wind and dragons, and potentially easier to identify the related animation, posing no ambiguity. Furthermore, being language it was also easily understood as communication, whereas the swooshing and blowing sounds are atmospheric. However, typically this did not lead the children to attend or to focus on working out what actions had elicited the audio effects. This may have been a function of timing, since the animated image e.g. dragon flying across the screen, had often gone by the time the child looked up from the floor. This suggests that the length and strength of mapping of the audio effect is instrumental in enabling mappings to be made between action and effect in this context and with the discrete representation design. However, it may also indicate a predominant tendency for children to focus on the visual, since adults involved were observed to notice and understand the sounds as signaling something relevant. This suggests the need for audio to be strongly salient or to occur when visual elements on the alternative display (in this case, the floor) are static.

The linking actions on the floor to effects on the wall also depended on a range of other factors, including participant age, adult contribution and the duration of their engagement: younger children (under 5 years) in particular did not notice links between the floor and wall. The perception of a relationship between the floor projection and animated aspects of the projections seemed to develop in different ways, for example, standing on a coloured spot followed by serendipitously noticing a dragon chasing a pearl across the wall, developing rhythmic patterns such as run, jump on spot, look at wall, audio linked to action, or direction from an adult. Awareness of others actions while watching the wall display also triggered links to be made, This feature, highlighted in tangible environments to be beneficial for collaborative interaction (e.g. Pontual Falcao & Price, 2011), is shown to also be beneficial in WBI contexts for fostering individual understanding through collective action, as well as collaborative forms of engagement. Since links between the floor and the wall emerged over time, the longer the children interacted with the exhibit, the more likely they were to build links between the floor and the wall, suggesting an unfolding awareness of a relationship between action and effect.

Collaboration

Peer collaboration

Social interaction and collaboration were evident in all visitor groups observed, and was evident within and across family groups, where children from different family groups interacted at the same time. Collaboration took place through action, and formed a core part of the children's interaction, but was realized in various ways across the different groups, differently shaping their experiences. In families with different aged siblings the younger child commonly copied or mimicked the older one(s). For example, they followed the older sibling around, touching the wall, making the same actions on the same spots, imitating new forms of bodily interaction e.g. stepping on two symbols on the floor at the same time, imitating the style and rhythm of interaction, such as, run, jump, wait (E2, E4, E8). In family groups with friends of similar ages the mimicking and copying was accompanied by competitive forms of interaction e.g. racing each other to new pearls/symbols that appeared on the floor (figure 9) (E6, E11); or they engaged in cooperatively noticing interactive elements of the exhibit (E10). Furthermore, there was evidence that children who were strangers to one another interacted, particularly through mimicking actions and following direction of running or walking (E2, E11).

In the school groups, collaboration was manifest in different ways. These groups were of four or five children as opposed to the family groups, which typically involved a pair of children or a single child. Children in the school groups engaged in inquiry-like processes regarding the relationship between their actions and outputs. They also engaged in high levels of competition; this was also seen in observations of family groups when the children in the family were similarly aged to the children in the school groups. In addition, most school groups exhibited some 'division of labour' in terms of their engagement with different elements in the exhibit, with each child assuming or being given responsibility for a particular area of the floor and a particular set of interactive symbols. In interviews children described ways in which they worked together and saw the interaction as a group activity.

"I didn't understand the dragon to begin with, but x pointed out that you had to step on the eggs".

"We were telling each other because we had done it. We had to figure it out. I was telling them which colours to step on"

"With the flowers one, I said you can't step on the flowers"

These particular patterns of interaction may be linked to the motivations and expectations of children on a school trip, e.g. the manner in which they engaged in an inquiry about the relationship between floor and wall had similar qualities to how they might inquire about scientific processes in a classroom. They also provide explanation for differences in group interaction highlighted earlier, that is, that school group interaction was more likely to be rapid and chaotic, accompanied by shouting, versus similar family activity, in which these behaviours were balanced with mimicking and copying between children. The social-contextual mediated motivation differed across these groups.

Role of adults

The floor projection was observed to shape where children and adults stood. The groups confined their interaction to the floor projection area, with the exception of toddler-aged children who were drawn to touch the wall display. Adults tended to stand on the 'edge', in the space outside the floor projection, which engendered interaction from an objective viewpoint rather than being physically immersed in the experience (figure 8). While the extent to which adults engaged in the interaction varied (from non-engagement to full participation), the stance and position – or the bodily position and accompanying verbal interaction that parents and carers adopted illustrates the different ways that parents engage with their children in these exhibits. Four different approaches were observed from their interaction.

Figure 8

One approach we classify as 'instructive'. This involved adults directly drawing children's attention to aspects on the wall, aspects on floor, and the text written about the paintings and following this with explicit directions for action based on the content of the image projection e.g. 'look at the boat'; 'stand on the whirlwind'. Questioning directed the children's attention to the relationship between the floor and screen, and this interaction fostered an understanding of how the interaction worked.

A second approach involved adult interaction through verbal facilitation rather than direction. Here the adult made suggestions and pointed things out on wall and floor and invited the child to explore aspects. In examples of this type of interaction, the adult noticed changes on the wall in relation to the child's movement and described the effects they were noticing on the wall, helping to alert them to various aspects, without giving explicit instructions about how elements of the exhibit were linked. The video data shows

that this approach facilitated engagement and exploration, and maintained open opportunities for the child to independently explore and develop understanding of the interaction at a child-appropriate pace.

The third approach was also facilitative, but through adult bodily interaction supported by verbal solicitation (E1). This group comprise two boys aged 26 months and their mothers. In the earlier part of the interaction the mothers interacted with the floor space while the children watched and touched the wall display. In this way the adults physically scaffolded their children's interaction with the wall display and changes to the 'paintings'.

In the school groups two teaching assistants who chose to sit at the side of the exhibit, took on an active role in order to regulate the behavior of the children. In particular, they told them not to run on or slide across the floor. This directive approach to the children's behavior is interesting in this context, where the intention of the museum exhibit, as articulated in the project brief, was to encourage physically active behaviours and engagement. In the school context, such initiatives may be less successful if relatively strict handling and monitoring of children's physical and verbal behavior is exhibited by school staff. This highlights the need to make the purposes of an exhibit explicit, particularly when it involves provoking high levels of physical activity, in order to avoid confusion and unnecessary containment of bodily engagement with interactive installations.

The different ways in which adults interacted with the children is seen from a multimodal perspective as pointing to different relationships to museum learning, and how a child might learn in this kind of environment. The analysis shows that while the adult's exhibited different roles in their child's engagement and/or learning, the Digital Dragons installation enabled, and even supported, these different ways of scaffolding from adults.

Figure 9

Engagement with Cultural References of the Content

The content design can be examined in relation to the surface features (e.g. colour changes, interactive visuals) of the installation – discussed in the previous sections, and the deeper cultural references (e.g. specific characters, people's clothing, the landscape, or music) evoked by the content.

Deeper cultural references were more apparent to some children (particularly two girls aged 5 years, one pair being friends, the other being incidental collaboration E6, E8) and led to some imaginative interactions, including the creation of oral narratives and engagement with culturally-specific forms of dance that related to the exhibit music, or enactment of kung fu poses, that are stereotypically linked to East-Asian culture. Analysis revealed examples of how engagement with cultural perspectives was played out through bodily interaction, in particular with the landscape painting. One pair of girls (both aged five years and friends prior to their visit) invented stories about the projected images, and engaged in socio-dramatic play that 'followed on' from the Chinese cultural references contained in the projection. They elaborated their stories with praying and bowing stances, dancing in culturally related poses, as well as adopting a range of martial arts positions as they moved around the floor, mentioning 'kung fu' to each other (figure 7). This example illustrates the potential of the exhibit to foster wider meaning-making through bodily interaction as a result of the culturally resonant aspects of the paintings featured in the exhibit. Interviews also elicited examples of children reporting that they were 'trying to say some Chinese words' during their interaction.

Figure 7

However, overall the analysis highlights the difficulty of using interaction to prompt discussion and interpretation of the cultural artefacts on display. While confusion around the interactive symbols and the mapping between symbols and their corresponding action on the wall invited some discussion and prompted collaborative forms of engagement, this confusion led to a focus on how to interact and engage, rather than on enabling or fostering rich discussions and engagement about the meaning of the paintings themselves.

Implications for Design in Public Spaces

These findings make a contribution to our understanding of naturally occurring in situ interaction with WBI across a range of children and families, and provide important implications for design in the following ways:

Promoting Physical Engagement

Bodily movement was central to eliciting changes in the paintings, but not necessary for the paintings to appear in the first place. While the potential for just 'looking' existed, and was present at some points in the interaction, all participants were physically active, suggesting that children readily engaged in physical forms of interaction prompted by interactive elements that appeared and disappeared. This is an important

facet of the interactions we observed since previous research has highlighted the positive implications for affect of high levels of bodily engagement (Bianchi-Berthoze et al., 2007; Snibbe & Raffle, 2009). A number of design aspects are instrumental in influencing bodily engagement.

Interactive elements

The diversity in the visual design of the interactive elements prompted different kinds of movements, with specific designs eliciting particular interpretations and subsequent bodily actions or encouraging creative forms of bodily interaction. For example, visual designs that elicit 'simulated' movement (e.g. twirling on a whirlwind) could be used to foster specific actions; and particular symbols – those related to bodily forms (i.e. hands symbol) - can facilitate a varied repertoire of movements through alternative interpretations. The appearing and disappearing of 'spots' on the floor specifically fostered children's construction of competitive and game-like social structures between those interacting with the exhibit. This builds on previous research highlighting the potentials for playful social interactions in WBI spaces (e.g. Shaer, 2009) by suggesting specific features of WBI design that inspire and facilitate children to create their own games.

However, the number of distinct visual elements that appear in the interactive space, and the nature of their interactivity, need to be taken into consideration. Non-interactive moving elements added complexity to interpretation of interaction and potential confusion around the function of interactive spots. Furthermore, the continuous dynamic changes on the floor space maintained attention on the floor, and precluded the need to look at the wall display. This highlights the need for designers to clearly convey what is interactive, and in what way. Introducing periods of time where there is no action-effect based on floor related interaction would also encourage a better balance between attention to floor and attention to wall. Nevertheless the observations here exposed the extent to which the diversity of symbols and mappings created an environment for a range of movements and physical interaction. This not only supports the desire of museum educators to foster interaction that is physically pleasurable and stimulating, but also encourages diverse creative forms of interaction.

Design mappings

The study confirms ways in which discrete representations in WBI contexts as well as 'tangible' can render the linking of action and effect problematic (e.g. Antle, 2007; Price et al., 2010). Yet it also suggests ways of better supporting linking with the use of simultaneous effects through dual modalities, specifically audio. In

these instances the audio needs to be sustained, distinctive and consistent in order to draw attention, and related visual changes to be sufficiently salient to be noticed. This is particularly true when visual elements continue to be in movement, or do not change their dynamic state, since the visual was found to hold attention better than audio. The 'split attention' spatial-temporal contiguity principle (Mayer and Moreno, 2013) proposes that separation between related graphics and text is detrimental to learning, and presentation of simultaneous narration and animation has better supports learning than temporally separate presentation (Moreno & Mayer, 1999). In the context of gaze related to bodily action the use of simultaneous dual modalities could enable better access to understanding action-effect links in discrete designs, rather than demanding a split locus of visual attention. In addition, a system that could detect other bodily actions, such as clapping or waving, would enable users to be visually attending to a wall projection while performing actions that do not involve looking at the floor.

These findings extend our understanding of design mappings by highlighting the complexity of defining a mapping, specifically where seemingly direct mappings take on a number of meanings and subsequent actions, for example the 'hands' symbol led to waving, placing hands over the hand image, tapping the image. The interview data showed how children made different inferences about mappings placing different meanings on their interaction. While mixed mappings have the potential to introduce complexity into interaction, in the context of installations that are primarily playful such as this one, such narrative development shows how this form of interaction can foster creative engagement. This confirms the positive role of ambiguity in design in enhancing creative experiences (Gaver et al., 2003). Even when mappings were not realized, interaction with the floor space in itself provided engaged interaction with the exhibit (albeit not with the paintings directly). However, in contexts where mappings are important in leading to a specific understanding as shown in previous research looking at formal learning contexts, then such creative meaning construction may well be disruptive to the goals of the installation/ exhibit, for example, in understanding scientific ideas (Antle, 2007; Price et al., 2010).

Design space

The observations of interaction show how space is perceived and defined by the visual displays, suggesting ways that designers can think about the interactive space design in museums. Both adults and children of 5 years and older constrained their interaction to within the projection space, while adults facilitating,

directing or just observing child interaction stood at the edges of the floor projection area. This suggests that specific spaces of interaction can be implicitly delineated through the inferred boundaries created by the projection. This offers the potential for creative use of open areas that are common in museum contexts.

Overall the study indicates how design influences bodily engagement. Findings around interactive elements and design mappings suggest that designing for specific forms of action and interpretation require designs that are simple and well defined with clear interactive and non-interactive elements, whereas designing for more creative moments of engagement requires a more open-ended design that offers a diversity of symbols and mappings. Thus, the design of whole body installations is most apt for creative collaborative interaction in museum contexts where follow-up teaching support is not usually available, and that their use in formal learning installations need to be accompanied by detailed attention to clear mappings. A design that enables repeated sets of interaction would also foster link making, given the unfolding awareness of a relationship between action and effect together with a design that fosters joint action, and thus enabling awareness of others actions.

Supporting diverse audiences

The study suggests how diversity in representation design and scope supports a wide range of users e.g. family and school, single children and multiple children, younger children and older children. Toddlers and infants were engaged by changing colours, animated icons or objects, and in jumping and running, enabling the practice of motor skills and development of contingency awareness. Older children (e.g. 5-10 years) were able to make links between their actions on the floor display and changes in the wall display, but minimally. More common was their engagement in creative practices of game-like interaction, or narrative construction, and exploring perceived culturally related aspects. For museums this is important in providing exhibits or installations that are appealing to a broad audience.

This study showed ways in which the exhibit challenged prior experiences of how people interact with collections in museums. Specifically it discouraged passiveness and encouraged interaction with artworks and with other people through bodily activity, increasing the potential for pleasurable social experiences (Bianchi-Berthoze et al., 2007; Shaer, 2009; Snibbe & Raffle, 2009). The installation was ‘open’ enough for people to bring diverse experience, knowledge and culture to the interaction to have a playful and engaging

experience. Yet this openness did not necessarily foster direct engagement with the paintings and their content, for example, a sense that there was a game to be won or a puzzle to be solved focused engagement on those aspects. This highlights a trade off in providing an 'open' experience – enabling creative development of game-like interactions - versus a more channeled form of activity direction that foregrounds and structures cultural, historical or artistic aspects of the installation. The observations presented here suggest that experimentation with how to interact with the exhibit was a valuable part of the visitors' experience. This conflicts with previous work by Snibbe & Raffle (2009), which emphasized the importance of creating systems that respond to WBI in clear and predictable ways. This points to the need to balance between openness and predictability as an important aspect for designers to consider.

Providing routes into learning through engagement

The findings show a range of ways that children engage with the installation features, one another and adults. One challenge however is in enabling an enjoyable, exploratory experience that draws attention to, or engages children in the installation content in more meaningful ways. The study revealed ways in which WBI design primarily fostered creative forms of narrative construction and collaborative communication rather than formal learning concepts, and engagement with classical Chinese painting through cultural references, for example, the presence of culturally resonant music leading to culturally-specific styles of dance the children's interaction, or the cultural specific postures they adopt in the presence of people in the landscape painting. Involving them in the interpretation of art works, and encouraging them to think about symbolism at a generic level is all key for awareness of art and the types of artefacts exhibited at the V&A.

A second challenge is in designing exhibits that scaffold adult interaction to foster facilitation that opens up opportunities for children's explorations, rather than directing their interaction; and to develop ways to foster moves away from traditional assumptions around orderly, quiet and restrained behavior and clear knowledge outcomes that are incongruous with physically mediated exploratory digital installations.

Conclusion

Museums aim to create particular types of experience and in recent years, this has involved significant investment in digitally interactive exhibits as part of this experience creation. By focusing on physical action and engagement of families, children and school groups with a WBI exhibit, this paper shows how design

elements shape interaction and support the development of collective interaction within and between visitor groups in the museum context. Importantly for museums it shows how WBI exhibits can support collective and collaborative interactions between family members as well as between strangers. It shows the potential of WBI installations to enable interactive experiences from an early age, the different ways that the experience is made meaningful (e.g. through expressive ideas, such as culturally related postures and dancing, mimicking and witnessing), as well as the challenges of engaging a diverse audience in the content and learning context. The analysis highlighted a number of important design considerations in relation to promoting physical engagement; design trade offs in terms of fostering linking between action and effect in a discrete representation design, and the role of different modalities of input relative to output; how best to design for diverse audiences that enables individuals to bring their own ideas and assumptions and expectations; and contributions to learning interactions. The paper contributes design insights grounded in empirical work on bodily interaction to inform the use of WBI with NUI museums and public spaces; as well as HCI research on the relationship between action and representation, central in shaping interaction.

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