Exploring Relationships between Museum Artefacts through Spatial Interaction

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ABSTRACT
We propose a novel approach, which involves visitors physically manipulating visual representations of artefacts and scanning with their mobile phone different groups or sequences of items in order to reveal digital information about their relationships. To explore this interaction mechanism we collaborated with a museum to develop an interactive paper map, on which visitors can place tangible representations of artefacts and scan the resulting arrangements. Based on an in-situ study of its use, we reveal that museum visitors engaged in different strategies for *exploration of relationships* between artefacts in the museum collection (inspection, strategic and experimental configuration), and for *social collaboration* (sharing the interaction space, adopting interaction roles and sharing a reaction to the "reveal"). We discuss how future interactive installations can accommodate these behaviours.

Author Keywords
Museum installation; interactive map; visual markers; physical configuration; artefact relationships

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous;

INTRODUCTION
Information about museum exhibits has traditionally been presented to the visitor through interpretive labels. However, previous studies show that visitors often do not engage with text labels located on walls, or with printed materials [8, 10]. Templeton [22] suggests this might be because printed materials provide limited information, and in particular do not typically identify an artefact's relevance within a collection or its relationships to other exhibits.

There are some traditional mechanisms by which museums reveal exhibit relationships. Museums commonly utilize stands and display cabinets to show items from their collections; by grouping artefacts in separate displays, taxonomies can be made visible or comparisons enabled with respect to particular highlighted features [10]. However, physical arrangements are fixed, and thus typically present only the canonical order. Making exhibits interactive through the use of technology has the potential to enable more flexible, dynamic and richer presentations, e.g. revealing relationships according to different authoritative perspectives, or allowing visitors to curate their own taxonomies without disrupting the experiences of others.

We suggest that there are two broad technological approaches to enabling the exploration of links between different artefacts. *Trajectory*: where visitors walk from item to item and their experience is tailored based on what they have seen so far and/or suggestions are made about related objects to visit. *Overview*: where visitors can see an overview of (part of) the collection and manipulate items to discover relationships between them. Examples of the former include the use of mobile devices to realize applications, such as recommender systems, and tagged portable artefacts, enabling visitors to accumulate a record of their visit and support their identification as they move around the site. To realize the latter, technologies such as interactive tabletop surfaces and AR installations could be used. While this approach has many benefits in allowing direct comparison between objects and supporting collaboration, it has been underexplored in the museum domain, possibly because of the space and cost requirements of typical AR and tabletop installations.

We propose a novel inexpensive approach, which involves visitors physically manipulating visual representations of artefacts and scanning with their mobile phone different groups or sequences of items in order to reveal digital information about their relationships. To explore this interaction mechanism we collaborated with a museum to develop an interactive paper map, on which visitors can place tangible representations of artefacts and scan the resulting arrangements. Based on an in-situ study of its use by museum visitors and staff, we suggest that this approach affords intuitive exploration through spatial interactions, supports group activity and requires minimal investment from museums. We conclude by discussing the importance of supporting individual differences in interaction, overcoming barriers to engagement and collaboration.

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RELATED WORK

There is a lot of previous work on the use of digital technology to allow museum visitors to access digital content about physical artefacts, including the use of mobile devices with visual markers [e.g., 3], RFID [e.g., 21], GPS [e.g., 18] and AR [e.g., 19]. However, there are less systems that explicitly focus on revealing relationships between artefacts. We categorize related work into two high level categories as outlined below.

Trajectory

This approach usually involves exposing semantic relationships between artefacts as the visitor navigates the venue while adapting the experience based on context. An early representative example is ILEX [15], which generates labels for objects dynamically based on the expertise level of the user and what objects have already been seen. The aim was to deliver a more coherent and educational visit, that treats the exhibition experience as a conversation where links between exhibits are discussed. HIPS [16], a later version of the system, also uses individual visitor's history to adapt the media, but additionally draws on a model of preferences and interests to present appropriate media and interesting relationships between exhibits. More recently, Gicquel et al. tested a system that allows users to explore semantic links between artworks, while also engaging in pedagogical tasks set by teachers (or curators) [7]. They suggest that the constrained tasks help learning, while the freedom to explore beyond the tasks is pleasing. An alternative is the use of a portable object to enable visitor identification and to accumulate a record of the visit. This is exemplified in Assembling History project [6] where RFID tagged paper clues were used to provide more information about objects and to enable visitors in making connection between their activities, the displays and the history of the museum. Overall, this class of systems provide visitors with support in large, complex museums where the information can be overwhelming by helping visitors gradually build up an understanding over the course of a visit.

Overview

This approach involves providing a central point where visitors can organize their visit to the museum, reflect on objects, or cooperate with other visitors to understand their experience of the museum collection. For example, Ryall et al. [17] developed an interactive tabletop, on which a large number of words were displayed to allow a group of visitors to collaborately assemble words to create poems. On the other hand, the Combination Machine, part of the Retracing the Past exhibition [5], enabled visitors to place objects, represented through RFID tagged keycards (with name and image of object shown on the card), together into a trunk, to reveal some fictional and some possible connections between them, thus priming visitors' imagination about objects. Another example was developed by museum staff using the ARTECT system, which allows visitors to move physical markers (QR codes) representing objects on a table, with sounds played whenever two objects were placed close together [11]. Such systems tend to more explicitly focus on highlighting relationships between artefacts, and they seem to inherently encourage social interaction.

MUSEUM SETTING

We worked with a local archaeology museum to develop the interactive installation. The museum is compact, consisting of one gallery of approximately 100m^2. The majority of the museum objects are pottery and metalwork items that were used by local people. The collection ranges from the Palaeolithic to the post-medieval period, including some Bronze Age artefacts [14].

The museum has 13 cabinets, each containing multiple artefacts that either share a common purpose (e.g. in Figure 1 the artefacts are culinary), or a common era (e.g. Figure 2). The museum employs printed descriptions and labels within display cabinets (see Figure 1) to help explain the relationships, and has not previously used technology to enhance the presentation of artefacts. Visitors are encouraged to discuss the exhibits with volunteers or curators who are often stationed in the gallery.

Figure 1 Cabinet showing individual artefact labels and a description their common purpose

During interviews, the museum curators expressed a desire to be more flexible in highlighting common purposes and time periods, and to reveal additional types of relationships, such as common geographical origins. The museum provides a printed map of the local area (figure 3) mounted on a wall. It is possible for visitors to refer to this map to contextualize the place names mentioned on labels, and to compare the places associated with artefacts, but anecdotal evidence provided by the curators suggests that most visitors find this task complex or laborious.

Figure 2 Cabinet with different artefacts from the Bronze Age

Figure 3 The regional map provided by the museum, showing place names, borders and rivers

Our collaboration with the museum aimed to retain the physical organization of the artefacts (and thus the canonical order presented by the curators), while introducing technology that allows visitors to explore alternative relationships between artefacts, including common purpose, time period and location of discovery/use.

DESIGN OF THE INTERACTIVE MAP

Our review of previous work highlighted advantages of both trajectory and overview technologies, however the benefits provided by an overview approach aligned best with the setting of the museum. The compact nature of the museum means that visitor trajectories are short, and that a central installation is easy and quick to access. In addition, discussion between visitors and staff is encouraged within the gallery, and previous overview technologies have enabled and enhanced social interaction.

Responding to the museum's wish to allow visitors to explore multiple types of relationship between artefacts, including geographical context, we decided to use the existing regional map (Figrue 3) as the basis for a prototype installation, and to extend it with interactive visual markers as a way of adding hidden layers of dynamic digital information that can be revealed by visitors who experiment by physically reconfiguring the map and markers.

Visual marker technologies allow museum visitors to "scan" their surroundings using the camera in their mobile device to reveal digital content. Quick Response (QR) codes have previously been used in museums [20, 25], allowing text, including URLs, to be encoded in characteristic black and white matrices placed in addition to traditional interpretation labels.

However, researchers have shown that museum visitors rarely engage with QR codes [20], possibly because they are neither aesthetically appealing, nor visually meaningful to humans: a QR code gives no visual clue as to its purpose, nor to its relationship to other QR codes. Instead, we chose to adopt Artcodes (previously known as Aesthticodes) [13] as the technology to represent artefacts on the map. Users of the publically available Artcodes app [2] can scan stylized visual markers ("artcodes") to reveal digital content, as demonstrated in a museum setting by Ali et al [1]. Unlike QR codes, there is much more aesthetic freedom in artcode visual representations, to the extent that stylized representations of the original artefacts can themselves serve as the code (e.g. Figure 4 shows a visual artcode that might be linked to digital content about a sword).

Figure 4 An artcode sketched on a shape and colour-coded piece of card, representing a particular artefact

Furthermore, the technology also supports more complex spatial interactions where users can scan sequences or groups of related visual markers in order to reveal a digital narrative (as demonstrated in [23]).

We selected 11 artefacts from the collection and created cards with Artcode visual representations (e.g. Figures 4 and 5). These artefacts were chosen to encompass a range of geographical origins, purposes, and eras, with some artefacts related in each case. For instance, we chose two coins, which are similar in purpose and geographical origin, but from a different time period (Figure 5); we also chose three potteries which belong to the same time period but were manufactured in different ways using different materials (such as iron and clay) (Figure 6).

Figure 5 Visually similar artcodes that represent 2 coins (note the slight visual variation)

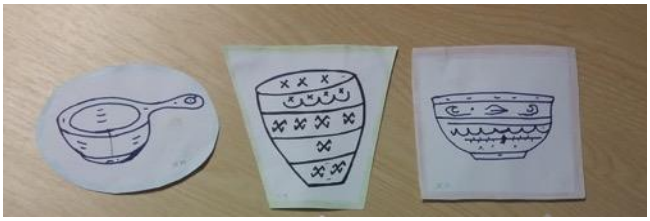

Figure 6 Artcodes representing 3 potteries from the same time period but manufactured in different ways

In [23], a large wall mural had artcodes permanently embedded within it, which could be scanned individually, in sequence or in groups. To meet our aim of allowing visitors to reconfigure and experiment with the map, the markers in our prototype were separate pieces of card that could be attached and detached from different positions on the map using Velcro. To encourage experimentation, we mimicked a puzzle format [12]: the artcode cards were cut into different shapes and these shapes were outlined on the map, hinting at the correct geographical locations for the artefacts. The borders of the cards and outlines of the shapes on the map were also colour-coded to further emphasise the suitable locations (Figure 7).

The installation was set up with all cards detached from the map and laid out on a nearby table (see Figures 8 and 9) providing a visitor with several options for accessing digital content. Visitors might consider the shapes of the cards and artefacts represented on them, and think about their possible locations on the map before attaching one and then scanning it "on location". Alternatively, a visitor might ignore the map and scan a card as it sits on the table. In either case, scanning an individual card revealed background information about the artefact.

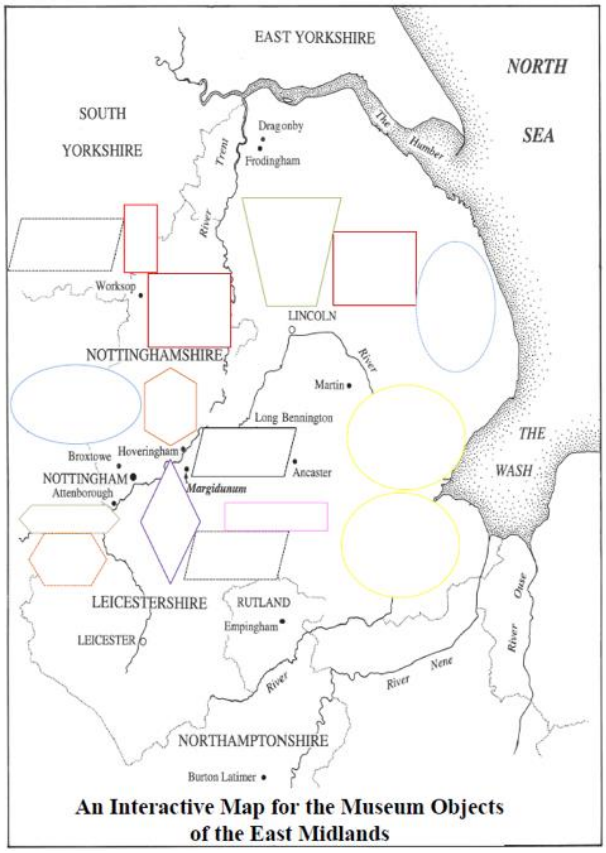

Figure 7 The prototype map with the colour coding and different shapes

Figure 8 Table arrangement

A visitor might also attempt to scan multiple cards. Scanning a group of cards *simultaneously*, if those artefacts were related by common purpose, would reveal information about that relationship. Thorn et al. refer to a valid group of artcodes that can be scanned simultaneously as a "pattern

group" [23]. Figure 10 shows how the digital content link changes when two related cards are brought into the Artcode app's viewfinder simultaneously, from information about one particular coin (the "Hand of God coin") to information about how ancient coins *in general* were manufactured and used. Note that a visual hint is overlaid on the bottom of viewfinder to indicate that one artcode is suitable for inclusion in a pattern group (Figure 10 left) and to show that a pattern group is complete (Figure 10 right).

Figure 9 All the cards on the table

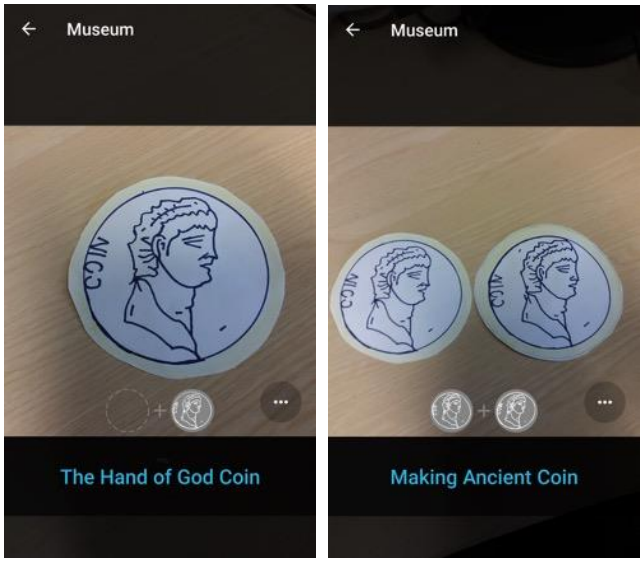

Figure 101 One artcode forming the start of a pattern group (left), and scanning a second simultaneously to complete the pattern group (right)

Scanning multiple cards *sequentially*, if those artefacts had a temporal relationship, would reveal information about that relationship. We use Thorn et al.'s term "pattern path" for a valid sequence of related artcodes. Figure 11 shows how the digital content link changes from information about one coin (the "earliest coin in Britain") when one card is in the viewfinder, to information about how coins changed *from one era to the next*. Note that visual hints are also provided in this case, indicating when an artcode has been scanned that could be part of a pattern path (Figure 11 left), and when a pattern path has been completed (Figure 11 right).

Figure 11 One artcode forming the start of a pattern path (left), and moving to scan a second to complete the pattern path (right)

Using the 11 cards in our prototype, a user could create 8 valid pattern groups and 7 valid pattern paths (in addition to scanning all 11 individually). Therefore, there were 26 unique pieces of digital content that could be revealed. These took the form of text and images, audio or video.

This final design of the map, artcodes and digital content was reached after iteration in response to 2 two-hour pilot studies: one with 7 PhD students (4 male, 3 female, recruited from the authors' University) and another with 5 members of museum staff (1 male, 4 female). In both cases the participants were given a demo of how to interact with the installation using the Artcodes app, then observed for 30 minutes while they freely interacted with the installation, then were brought together for a 30-minute focus group.

These pilot studies revealed that the participants understood how to scan individual cards, as well as pattern groups and pattern paths. The results suggested that the iterative design process had improved the fundamental usability of the map, making it suitable for use in a research study.

USER STUDY

We went on to deploy the improved interactive map prototype in the museum. We were keen to evaluate the technology in an authentic rather than a laboratory context, to increase the chance that the responses might resemble those by visitors in a real museum visit.

Participants

With the prototype installation situated in the museum, four studies were carried out with 16 participants (5 male, 11

female). The participants were recruited through adverts in the museum, the university email network, advertising through the university note boards, and using snowball sampling via the reseacher's social media network. 6 of the recruited participants were individuals without social connections to other participants; the remaining 10 consisted of two separate groups of friends. 7 participants were between 20-29 years old, 6 were aged 30-39, 2 were aged 40-49 and 1 was over 60 years old.

To provide a variety of social configurations for study, the participants were divided into four study sessions. In the first session, one participant was allowed to interact with the installation privately. The second session consisted of two pairs of friends (4 participants in total). The third session consisted of two pairs of friends and two unconnected individuals (6 participants in total). The fourth session consisted of two pairs of friends and one remaining unconnected individual (5 participants in total).

Method

At the start of a study session, participants were introduced to the research context and a short demo was provided by the researcher to explain how to interact with the map, artcodes and the mobile app. This demo highlighted the interactional possibilities, but no specific tasks were given to the participants. They were allowed 1 hour to freely interact with the installation and with each other; participants were also encouraged to walk away from the installation into other parts of the museum if appropriate.

The interactions with the installation were continuously video recorded, using a fixed video camera placed a short distance away. In addition, photos were taken by the researcher whenever participants walked away from the installation, e.g. to look for artefacts elsewhere in the museum. After the session, there was a 1-hour focus group discussion, led by the researcher and starting with a round-table recap of what each participant did during their experience, that was recorded using a single fixed audio recorder.

Analysis

The video recordings of interactions with the installation and audio recordings of the focus group discussion were coded by the lead researcher to generate an understanding of what was seen to happen, combined with what participants thought and said about their experience. The researcher began by coding audio and video with participant identifiers, which then made it possible to consider the sequence of interactions of each participant separately. The timelines were then segmented and coded first by what component of the installation (or wider museum) the participant interacted with (incl. the construction of pattern groups and paths), then by any social interactions the participant was involved in. Finally, these codes were revisited and additional codes were added where the purpose of those interactions was apparent.

FINDINGS

Our analysis of the focus group audio recordings affirmed that the interactional possibilities of the installation were understood by the participants, despite the brief introduction provided to the participants and the novelty of the technology. Some participants related this to the meaningful aesthetic of the cards, e.g. P9 (female,25) reported: "*an artcode actually is a picture; you relate that [picture] to the objects, so if you find a picture [you think,] 'ok definitely I am going to find information I want'.*". Some explained that the common visual signifiers of the map and cards encouraged them to affix cards to the map, e.g. P9 stated: "*I think the shapes work well because it's more visual, especially for children. I think shapes and colour are probably the best option*".

Others stated that the physical process of arranging cards and/or the aesthetic of the cards give hints about how the artefacts might be related, before even using the Artcodes app. For instance, P10 reported: *"The map does for both: you get information about the [individual] object, and then the relationship in terms of [other] objects."*

Although all participants appeared to understand the interactional concepts, they explored those possibilities in different ways. At a high level, our analysis focused on two categories of behaviour: *exploration of relationships* between artefacts in the museum collection, and *social collaboration* between visitors to the museum. Within these categories, participants expressed a range of distinct interaction strategies. These strategies highlight opportunities for improving and extending the design of museum installations, and for further research.

Strategies for exploring artefact relationships

Participants could reveal relationships between artefacts by simply placing cards on the map (revealing geographical relationships), or by physically configuring cards into appropriate groups or sequences and scanning them using the Artcodes app (revealing digital content about relationships in purpose and era). All participants created at least 5 pattern groups and/or pattern paths. The majority of participants (12 of 16) created more pattern groups than pattern paths, while one participant scanned an equal number of pattern groups and pattern paths (4 of each). In total, the participants scanned pattern groups 75 times and pattern paths 56 times.

Looking beyond these headline results, our analysis revealed that the participants differed in terms of whether they explored the cards before affixing them to the map, and in the extent to which they planned the physical configuration of cards and map in advance of using the Artcodes app. Three main strategies were identified:

1. Inspection
2. Strategic configuration
3. Experimental configuration

Each of these three strategies are explained in more detail with examples below.

Inspection

All participants began their experience by scanning an individual card to reveal background information about the individual artefact represented by the card. From our analysis, we developed an understanding of a particular strategy of "inspection" that participants engaged in to familiarize themselves with the artefacts represented by the cards, before attempting more complex interactions later in their experiences.

7 participants' inspections began at the table where the cards were originally laid out. Of these, most went on to inspect further cards on the table, with one participant (P3) spending 5 minutes scanning *all* cards one-by-one on the table, systematically accessing the associated digital content (additional background information about each of the associated artefacts). Once P3 scanned all cards individually, he spent 3 minutes fixing all the cards to appropriate locations on the map (using the coloured shapes on the map as a guide) aiming to understand how all the artefacts were related geographically. Only then did P3 attempt scanning pattern groups and pattern paths.

Figure 12 P3 placing all cards on their corresponding shapes on the map, before forming pattern groups and paths

Most participants undertook less exhaustive inspections of the cards, typically scanning 6-10 individual cards before attempting to form pattern groups or paths. P3's particularly exhaustive inspection behaviour might be expected: he was the lone participant in the first study session and so could interact at a pace that was comfortable to him. In the other sessions, participants had the pressure of sharing the space and cards with each other. In these sessions we regularly observed individuals moving away from the map or table and resorting to inspection of individual cards in order to "give up their space" to other participants. For example, P11 (female, 62 years old) moved back from the map to scan cards that had been left on the table because the space near the map had become too crowded for her to comfortably interact with the artcodes on the map (Figure 13). She continued to inspect individual cards at the table until the map became accessible. In the focus group P12 (female, 22) stated: "*there were more people on the map already so it is easier and quicker to [interact] on table. Otherwise I will use the map"*.

Figure 13 While other participants crowd around the map, P11 retreats to inspect cards at the table

In these cases inspection was employed as a strategy to cope with the physical and social pressures of sharing the space, rather than to initially familiarize the participant with the digital content attached to the cards.

All participants carried out a form of inspection behaviour then progressed to exploring pattern groups and paths by either *strategic* configuration of the cards and map, or adopting an *experimental* approach to configuring the cards and map.

Strategic configuration

Our analysis suggests that, as a result of inspection, some participants developed a clear model of how cards might be combined to reveal relationships. These participants identified commonalities in the artcodes (e.g. picking out several artcodes that visually represented weapons) or in the shape and border colour of the cards, and deliberately combined these cards on the map with an expectation of the relationship between the artefacts.

Two pairs of friends (P2-P5) exhibited strategic configuration behaviour particularly clearly. For these participants, inspection involved discussing the aesthetics of the cards to reach a consensus on how the cards might be grouped by common features. Once a consensus was reached, they fixed them to the map to form pattern groups and used the app to validate their choice. These two pairs formed pattern groups much more frequently (15 times) than pattern paths (8 times).

For participants who conducted strategic configuration, the in-app hints were used to *confirm expectations*. For example, P5 (female, 29) started her experience by placing a pair of cards on the map that matched shapes and were near to each other on the map; assuming that these were related, she then attempted to scan them as a pattern group and was rewarded

by seeing the "+" hint on the app viewfinder to confirm that this was a valid pattern group, allowing her to open content explaining the relationship. She repeated the same approach for another 3 groups of artcodes, before attempting to form any pattern paths.

A skew towards pattern groups is a characteristic of all participants that we identify as *strategic*: physically collecting cards with common features, then scanning them simultaneously is the quickest and simplest way to use the Artcodes app to check for a relationship. In the focus group, participants in general talked about instinctively thinking of artefacts in terms of groups, whereas valid pattern paths were explained by most participants as being more complicated to form, and the analogy of "sequences" of artefacts as more difficult to understand.

Experimental configuration

Five of the participants started their experiences straightaway by placing cards on the map without identifying cards that could be related to each other, and without physically collecting cards with similar features. Instead their configuration of cards and map appeared arbitrary, and we characterized their interactions as *experimental*. These participants did all reveal relationships between the artefacts, but this appeared to happen as a result of coincidence.

During experimental configuration of the map and cards, participants depended on the in-app hints to guide the process of trial-and-error, trying to form and scan pattern groups and pattern paths at an almost equivalent rate. Of the participants that we identified as experimental, valid pattern groups were formed 54 times, whereas pattern paths were scanned 44 times.

To summarise, we identified three common types of behaviour that helped participants to understand relationships between artefacts. All participants began with a period of inspection, then adopted a strategic or experimental approach to configuration of the map and cards. Some participants took a break, e.g. to avoid a crowd around the map or to walk around the museum to view physical artefacts, but usually returned to continue their adopted approach to configuration at the map.

Strategies for collaboration

Although features of the installation were not designed explicitly to encourage social interaction, our analysis highlighted extensive social interaction between friends and unrelated participants. Behaviours such as cooperating and interrupting tasks, talking, smiling and gesturing to each other were regularly observed in the video, and described in the focus group. A particular category of social interaction – *collaboration* to understand and use the installation – was common, and within this category we identified three distinct strategies:

1. Sharing the interaction space
2. Adopting interaction roles
3. Sharing a reaction to the "reveal"

These strategies are explained in more detail below.

Sharing the interaction space

Three study sessions involved groups of 4, 5 and 6 participants, and in these cases the limited interaction space around the map encouraged the participants to develop a mechanism for sharing the space.

Two pairs of participants adopted a similar approach. They shared the space by dividing the map into halves, allowing a pair to interact with the map simultaneously, with each partner interacting with one half, then alternating to interact with the other. For example, two friends (P4+5) stood at either side of the map, roughly divided the available cards between them, and started fixing their cards on their side of the map. Staying on their sides of the map, each friend then scanned individual artcodes, and tried to form their own pattern groups and pattern paths. Once both were satisfied, they swapped sides. This behaviour happened because each of those participants wanted to have an individual experience to interact with the map in their own way.

Despite aiming to allow private interaction, this behaviour often evolved into collaboration. Among both pairs who divided the map, we noticed that partners intervened whenever they noticed each other trying to scan invalid pattern groups or pattern paths. For example, P4 intervened in P5's attempts to form a pattern group containing a "comb" card and "iron bowl". P5 said to P4 that she thought *"... if I put [any cards] together I can scan them"*, prompting P4 to explain how to look for the in-app hints and the shapes and colours of the cards and map to see whether such a configuration was possible.

Figure 14 Experimental participants sharing the space

Most participants were less formal about dividing the space, and tended to cooperate fluidly as a group to interact with the map. Earlier in *Inspection* we described how some participants retreated from the map to the cards at the table to avoid crowds. In the session of 6 participants, the physical movement of participants around the installation to share the interaction space was most obvious. Initially, this group attempted to allow each individual to carry out inspection, by taking turns to fix a card to the map and scan it, afterwards retreating to the table to allow room for others. However, this behaviour became less organized when the group wanted to move on to forming and scanning pattern groups and pattern

paths, where a split between strategic and experimental participants become obvious. These participants interacted with the map at a different pace, and the space around the map was sometimes monopolized by experimental participants (Figure 14), while strategic participants retreated to collectively plan what pattern groups and pattern paths they hoped to scan.

Adopting interaction roles

During the multi-participant study sessions, 10 participants were observed collaborating by assigning each other complementary roles. Most commonly, one participant would adopt the role of fixing cards to appropriate places on the map while others would scan the newly-fixed artcode. For example, two participants (P13+16) collaborated closely throughout their session: P13 almost always chose and placed cards on the map, while P16 waited to scan the cards that she placed (Figure 15).

Figure 15 P13+16 dividing roles of placing and scanning

In some cases such as P13+16, participants adopted specific roles for the whole session. In other cases, the analysis revealed that participants swapped roles, sharing the experience of interacting with the installation from different perspectives. e.g P15 (male, 35) stated: "*I scanned few of the artcodes that she placed on the map and other time she was scanning the ones that I placed. I think it is a natural interaction of using one thing at the same time especially when trying scanning a group together*".

Sharing a reaction to the "reveal"

Members of the multi-participant sessions were regularly observed watching each other. However, particular situations piqued the interest of nearby participants, and encouraged more direct forms of social interaction.

Some of the content revealed by scanning artcodes contained audio (2) or video (6): participants were not asked to bring headphones to the study sessions, so audio was played loudly from participants' mobiles, usually attracting each other's attention. In the focus group discussion, participants highlighted the video content as a reason for their social interaction, and said that anticipation of sharing the "reveal" encouraged them to stay together. For related participants, interactions and digital content that could easily be shared were important. For example, P10 described the difficulty in keeping a large family engaged in a museum: "*if I am coming with my family we would like to share; the best part is the video, because everybody will be there, including the little one*".

The relatively complex process of one participant forming and scanning pattern groups and pattern paths also created anticipation among bystanders, who would often wait to see if the participant was correct, and what content they would be rewarded with. Some bystanders would copy this demonstration to access the same hidden content for themselves. However, some participants were confused about how seemingly similar configurations of cards would reveal different content. For example, P10 and P7 shared the interaction space, forming pattern groups and pattern paths from the same configuration of map and cards. Having apparently scanned the same cards as P7, P10 looked at P7's phone screen and asked "*How did you get the video*?". By retracing their actions, they determined that P7 had formed a slightly different pattern group that, to her delight, P10 then copied.

DISCUSSION

This study aimed to learn about the response of visitors to an installation designed to allow them to experiment with the relationships between exhibits. We consider that the adopted overview approach worked well: participants developed understanding of relationships between artefacts, could go and find the physical artefacts in between using the installation, and socially interacted with each other. Our findings demonstrate that it is a good fit to this particular museum setting. In larger museums, an overview installation such as our prototype might be complemented by a trajectory-based system to help visitors find the physical artefacts, and explore relationships further when they are away from the installation.

Furthermore, our results provide insights into the benefits of combining physically-configurable interactive markers, a mobile scanning app and rich digital content.

Supporting individual differences in interaction

Previous literature shows that museum visitors have different preferences for exploring collections. Our installation was designed to give freedom in exploring relationships between artefacts. Our findings show that participants pursued 3 distinct strategies. These results demonstrate some ways that future interactive installations can accommodate these differences.

Inspection was an important strategy that formed part of all participants' experiences – helping them understand each artefact in detail. The digital content revealed during inspection gave participants extra hints about what relationships artefact might be a part of. We suggest that it is

important to enable a phase of inspection as it supports the further exploration of artefact relationships.

In comparison to inspection, the installation encouraged a more active approach to understanding the relationships between artefacts. Both strategic and experimentation approaches motivated users to physically configure the cards by placing them on the map to explore the relationship between artefacts. This was appreciated by visitors, as P11 (female,62) summarized: "*Sometimes you can go around in places you know you are passive as a person just walking around whereas this feels much richer experience because you are going to take so much in different ways*".

Overcoming barriers to engagement

However, engagement with physically configurable, interactive installations can also be problematic. In our prototype, revealing a relationship was typically a three-step process, involving scanning an artcode, placing the card on the map, then forming a pattern group/path. Visitors can encounter interaction barriers in each of these steps.

Step 1: interacting with a visual marker (artcode)

Previous studies of the use of QR markers show that people might not scan a QR code in the first place because they are not sure what it will do [20, 24]; if they never scan a code, they can't begin to reveal a relationship. We suggest that the interactive marker needs to reflect its purpose and our use of Artcodes appears to address this issue.

Step 2: configuring the markers and map

Colour and shape coding the borders of the cards and outlines on the map were essential in emphasizing suitable locations and combinations. This feature emerged as a result of the first pilot as without it some participants were afraid to try creating pattern groups/paths. Design needs to constrain the possibilities for configuration, to convey that experimentation isn't endless and strategy is possible.

Step 3: confirming pattern groups/paths

Because people were confident in configuring the map, sometimes they created valid groups/paths, but most participants still relied upon the in-app hints to give them confidence and to understand why they were right or wrong. We successfully designed positive feedback, but overlooked negative feedback. P1 (male, 34) suggests the need for explaining what went wrong or what artefacts are not related: "*There should be information because there is no point to continue scanning if they are not related because I was still holding".*

Regarding scanning in pattern groups and pattern paths, we discovered that participants used the pattern group option the most. This result might be because the design of the interactive map encouraged people to move the artcodes around and group them together to take pictures of them. Thus, we conclude that the pattern groups mechanism is a more natural form of interaction for our design. This finding differs from the study reported in [23] where pattern paths were used more frequently than pattern groups. This result arose, because the designers of the study materials had embedded the artcodes statically in a large illustrative display, so they were not movable, making pattern paths a more natural interaction to explore.

Importance of social Interaction

We observed a lot of social interaction, even though some of our participants didn't know each other. We did not target the design to enable specific types of social interaction. However, as previous studies show, public displays/installations that allow a group of people to gather round, motivate and attract more people to join in and maximise the opportunity for social experiences [4, 9]. Our findings reveal 3 different strategies for collaboration and the associated benefits.

As in [24], visitors observed others to understand how to use the installation. Even with all the hints in the app, described in the previous section, some participants still preferred to/relied upon learning from others. Social interaction also helped people to access more of the content. In our study, participants interacted with one another to understand why they revealed different relationships (see Strategies for Collaboration). Without this sort of interaction, these participants may have missed out on this extra content. This is particularly useful for visitors who are driven to maximise their experiences (to "complete" the installation). Generally speaking, it is useful to encourage social interaction as a means of ensuring that visitors access as much of the hidden digital content as possible.

Future research can explore how further opportunities for social interaction can be designed in to ensure that these benefits are realized. For example, in-app hints could be provided to bring people together who are working towards similar pattern group/paths. However, interactive systems should be designed in a way to enable visitors to have control over their experience to select whether they wish to interact individually or with others and whether they wish to complete all activities or a subset.

CONCLUSIONS

We have presented the design and study of a physically configurable map, which allows museum visitors to explore relationships between artefacts. Our findings showed that participants engaged in different strategies for *exploration of relationships* between artefacts in the museum collection (inspection, strategic and experimental configuration), and for *social collaboration* (sharing the interaction space, adopting interaction roles and sharing a reaction to the "reveal"). Subsequently, we highlighted the benefits of supporting individual differences in interaction, overcoming barriers to engagement and encouraging collaboration.

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