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Treasure codes: Augmenting learning from physical museum exhibits through treasure hunting

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Treasure codes: Augmenting learning from physical museum exhibits through treasure hunting

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ABSTRACT

Previous studies have highlighted the difficulty that designers face in creating mobile museum guides to enhance small group experiences. In this paper we report a study exploring the potential of mobile visual recognition technology (Artcodes) to improve users' experiences in a visitor centre. A prototype mobile guide in the form of a treasure hunt was developed and evaluated by means of a field study comparing this technology with the existing personal guided tour. The results reveal a preference for the mobile guide amongst participants and show significant learning gains from pre-test to post-test compared with the pre-existing personal tour. Our observational analyses indicate how the mobile guide can be used to improve visitors' learning experiences by supporting active discovery and by balancing physical and digital interactions. We further expand the concept of design trajectories to consider micro-scaffolding as a way of understanding and designing future public technologies.

Author Keywords

Visual recognition; museum guides; informal learning; trajectories

1 Introduction

In an era of sophisticated interactive personal technologies, designers of museum and exhibition centres are increasingly being challenged to create engaging personal experiences that keep pace with visitors' expectations about interactivity, but that do not detract from the physical nature of the artefacts that they display [16]. Many studies have highlighted the difficulty that designers face in creating mobile museum guides that enhance small group experiences, with many mobile guides designed to support a single visitor experience or treating visitors as a unitary group [21]. A few projects have aimed to address this problem by adding various social aspects into a mobile museum guide [14, 25, 34] and applying design frameworks to design the global experience [19]. In spite of an extensive body of work, the fundamental challenge remains – it is difficult to support collaboration that leads to a deep learning engagement between visitors and exhibits. It is not always clear to designers, particularly in the context of an informal learning space such as a museum or visitor centre, how they can support the role of adults or parents who naturally scaffold the learning experiences of their children and allow them to become participants in the children's activity.

In this paper we address the problem of supporting collaborative and inter-generational informal learning during museum visits by means of a mobile treasure hunt by integrating elements of augmented reality (AR) and games into the experience. We report the design and analysis of a field trial using a mobile application that was designed to provide an integrated physical-digital experience in a visitor centre focused on the science, art and design of local cultural artefacts – Malaysia's Royal Selangor Visitor Centre. The aims of this study were to extend previous research on visual recognition of physical artefacts, to design an experience applying the technology to augment and enhance learning in the visitor centre and to support the collaborative experience of visiting. One of the guiding principles for our research included applying the concept of 'trajectories' [4] in the design of the learning experience to maintain the coherence of the visit. We compared this mobile technology approach with the existing personal guided tour by centre staff. The results of our study demonstrate how such technology can be used to yield positive outcomes in terms of collaboration and individual learning gains.

2 Related work

There has been an increasing interest recently in exploring how the use of personal digital technologies such as smartphones can augment the visitor's engagement with physical objects. Approaches to the design of new

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interactive technologies such as mobile guides for galleries and museums have explored the use of electronic tags [11, 17], Near Field Communication (NFC) [6], visual codes [20] and object recognition [1, 31] to bridge the gap between the physical and digital world. Wein [35] compared these interaction techniques with QR codes and number codes to reveal a preference for visual recognition amongst participants. This provides a strong basis to further explore the potential of AR and visual recognition, as a promising, more intuitive and unobtrusive interaction method to improve visitors' museum and visitor centre experience.

Most of the research conducted in applying AR to learning contexts has used the technology to explain a topic and augment physically presented information [8]. Recent examples include *Save the Wild*, by which children can interact with fiducial markers to access virtual characters that are attached to stories related to sustainability [7] and *Augmented Studio*, which uses body tracking to project anatomical structures over moving bodies for physiotherapy education [23]. Most studies of AR in learning have been applied in the classroom, with very few examples of exploration and discovery of the wider physical environment through AR [9]. There is also the potential problem of students' attention being inappropriately focused on the AR devices and tools, instead of making the most of being in a particular location [18].

In recent years, there has been a trend towards the development of serious games – games designed for a purpose more than pure entertainment to enhance the learning experiences and interactions of users. Previous studies have shown that games can promote learning [32]. Potential benefits of games include improved self-monitoring, problem recognition and problem-solving, decision making, better short-term and long-term memory, and increased social skills such as collaboration, negotiation, and shared decision-making [24].

AR serious games have emerged as an area of particular interest in museums and other informal learning settings. Related work includes the "Table Mystery" game, developed for a science centre in Norway, which encourages players to scan the chemical elements of a periodic table to discover 3D clues, report back and obtain further instructions for the next clue until the whole story is revealed [8]. In another example, visitors respond to image markers that launch AR and gaming experiences in an exhibition to learn the story of the Terracotta Warriors [30], with results showing visitors' preferences for activities with a gaming aspect. Another serious game, MuseUs allows players to match statements to artworks in a museum. However, findings from user studies showed a lack of support for social learning – the kind of learning that is known to take place in social contexts and is co-constructed with parents [10]. At present, little of this research has focused on how these social interactions affected learning achievement or motivation. So far, greater social interaction effects have been found when AR serious games are played between students themselves, compared with those played between students and teachers, or students and parents [23]. The current study fills a gap in the current literature on supporting interactions between students and teachers, and children and parents, and attempts to provide empirical evidence of learning gains, instead of simple anecdotal reports.

One of the issues arising from the relatively new technologies emerging recently is the need to develop consistent guidelines and frameworks to support more effective design of games. Although a general framework to evaluate serious games has been proposed by the Serious Games Institute [13], specific guidelines for developing AR serious games (e.g., in extended learning experiences) are still lacking. This study attempts to contribute towards this need, whilst addressing a major challenge in designing digitally augmented game experiences that do not detract or distract from the benefits of the physical visiting experience.

3 Context and design of the mobile learning experience

The setting for the mobile learning experience was the Royal Selangor Visitor Centre in Kuala Lumpur, Malaysia – a place where visitors learn not only about the company's origins, but also the important history and science of pewter and the story of tin mining in Malaysia through personal guided tours. Our early explorations over a period of a few months involved conducting 1) an ethnographic study, interviews and discussions with centre staff to identify requirements for the mobile experience and 2) a pilot user study demonstrating the visual recognition technology in a mobile tour where museum staff scanned markers to trigger informative videos linked to selected artefacts.

Results of our interviews and discussions with the centre's staff showed that relatively little use was currently being made of the science of pewter exhibits in terms of interactivity. Also, the staff admitted that their guides had relatively little scientific knowledge, and were more confident about the cultural and historical exhibits in the centre compared with the science-related exhibits. Thus, our pilot study was intended to demonstrate the feasibility of using mobile devices to augment the visitor experience by providing more science-related information about the exhibits. However, this pilot study highlighted a lack of interactivity in the initial experience, prompting us to focus on supporting visitors to collaborate in constructing knowledge and learn through a process of active discovery as described below. Since a large number of visitors to the centre are children, our design targeted families with young children and school groups. We chose to focus on science-related exhibits within the centre, since they were less well covered in the guided tours, which tended to focus more on historical and artistic aspects.

We adopted the theme of the "Science of Pewter" to explore ways in which the visual recognition technology and design of the mobile experience might enhance visitors' knowledge and experience. More specifically, our research questions were: 1) How do we design the experience to foster greater social interaction and collaboration between visiting groups? 2) Is the scanning technology usable in a real world setting? and 3) Can it contribute to learning about the exhibits?

Our aim was to design a learning experience that supported or encouraged social interaction and collaboration but that did not enforce it [3]. In other words, we wanted to design an experience that was shareable for small groups, that could be engaged with alone, but that was more enjoyable if shared. This was achieved by having the system pose questions to the user that could only be answered by engaging with the physical exhibits. This also ensured another important learning aim – that the mobile experience would not simply be a substitute for engaging with the physical exhibit, but would encourage greater engagement with the exhibit. This was because our discussions with the centre's staff and our observations of visitors to the existing exhibits was that (a) they were less visited compared to the more cultural/artistic and historical exhibits and (b) although tour guides (museum staff) were available to help explain the science, they lacked some of the scientific background needed for this.

In designing the overall mobile experience, we adopted the framework of design trajectories [4, 19], which encourages the designers of visiting experiences to consider the following key phases: approach, engage, experience, reflect and disengage [4]. We first set about establishing a global trajectory for the visit [4, 19] based on a treasure hunt game, requiring visiting groups to find treasure tokens/codes and complete tasks to collect them in a sequence. We combined physical site exploration with mobile gaming to encourage lateral thinking and teamwork [37]. Each hunt location would only be revealed upon the completion of a previous task, based on a prescribed learning journey, building on visitors' knowledge and starting from the basics of pewter materials to pewter making processes. Then we designed local trajectories that would enhance engagement with each individual exhibit in five stages (see Fig. 1):

1) *Approach*: Using a mobile treasure hunt app, participants used a digital map to find the location of a hidden treasure code and solved a riddle to identify it.
2) *Engage:* Each treasure code had a unique object symbol (designed using Artcodes) that participants had to scan to unlock the task and receive task instructions.
3) *Experience*: We designed a range of tasks that were meaningful in the context of the exhibit to support active learning.
4) *Reflect*: Informative learning content (e.g., videos, animations) were presented to help participants reflect upon the learning experience. They could also go to the 'treasure collection' section of the app to replay previous tasks and review content by clicking on the collected treasure codes.
5) *Disengage*: Having unlocked the previous task, participants would proceed to the next clue on the e-map.

4 Technological approach

Recent research has focused on tangible computing using surface decorations as one possible method for augmenting artefacts created from a range of materials with interactive features (e.g., leather [31], clay [27], wood [5] and glass [28]). For example, the Carolan guitar is a prototype musical instrument whose digital augmentations enable it to tell its own life stories [5]. In this paper, the design focus revolved around the possibilities and challenges of applying these patterns to a new material – pewter – as it is a malleable alloy which can easily be engraved to produce decorative specialty items, and to identify the kind of interactions that this might support in a museum context.

In designing the platform for the experience, our approach has been to work with Artcodes, a visual recognition technology first reported in [26]. Artcodes was built on the D-touch approach proposed by Costanza et al. [12] that recognizes topological structures in images. We chose this particular approach because it enables pewter designers and craftsmen to use existing craft skills to emboss and engrave visual codes within aesthetic patterns onto pewter items. This opens up an opportunity for interaction design to take advantage of visitors' physical experience with pewter in the centre's public space and to embed digital media into it instead of creating a parallel and detached digital experience, overcoming a common issue with marker-based AR as raised by Bannon [2].

The team engaged with pewter designers and craftsmen at the Royal Selangor Visitor Centre, which is also a working factory, to design and manufacture scannable pewter patterns for AR, encompassing both relatively simple iconography and also visually complex scenes. The designers with whom we worked explored a variety of pewter surfaces and crafting techniques. Early testing revealed challenges which included the effects of variable environmental lighting, and specular reflections from the shiny material. Technical feasibility testing provided us with further understanding of usability constraints yielded by different crafting techniques. We eventually designed each 'treasure code' in the visitor experience to suit the context of the physical exhibits, adopting existing pewter products and designs as inspiration. Table 1 illustrates the final treasure code designs and tasks chosen for each exhibit, followed by anticipated learning outcomes. Figure 1 shows a more detailed example of the trajectory for one of the exhibits.

Table 1 The global trajectory experience design with treasure codes, tasks, and learning objectives for each exhibit.

Exhibit		Treasure codes	Physical task	Digital task	Learning objective
1 Weights exhibit			Notice three balanced weighing scales with different volume weights but equal mass.	Drag and drop same volume metal weights on to virtual balance scale. Select heaviest.	Density equals mass per unit volume.
2 Periodic table			Use periodic table to find pewter elements with atomic numbers 50, 51 and 29.	Make pewter before time runs out by clicking on 3 elements.	Learn metals that make up pewter and why it is an alloy.
3 Planet exhibit			Step on the giant scale to find out how heavy is the giant pewter weight.	Enter and slide weight to see how it changes across planets and where it is heaviest.	Learn difference between mass and weight.
4 Chamber of music			Ring the chimes to compare their pitches.	Select the chimes that have a higher or lower pitch.	Learn how different properties of materials affect pitch.
5 Hall of frame			Find pictures on the wall based on descriptions.	Scan treasure code nearest to picture and read learning content to find next picture clue.	Learn unique properties of pewter material.
6 Hand print			Find handprints and names on the wall based on picture clue.	Enter names of craftsmen to watch videos of their crasftsman skills.	Learn different processes of pewter making.

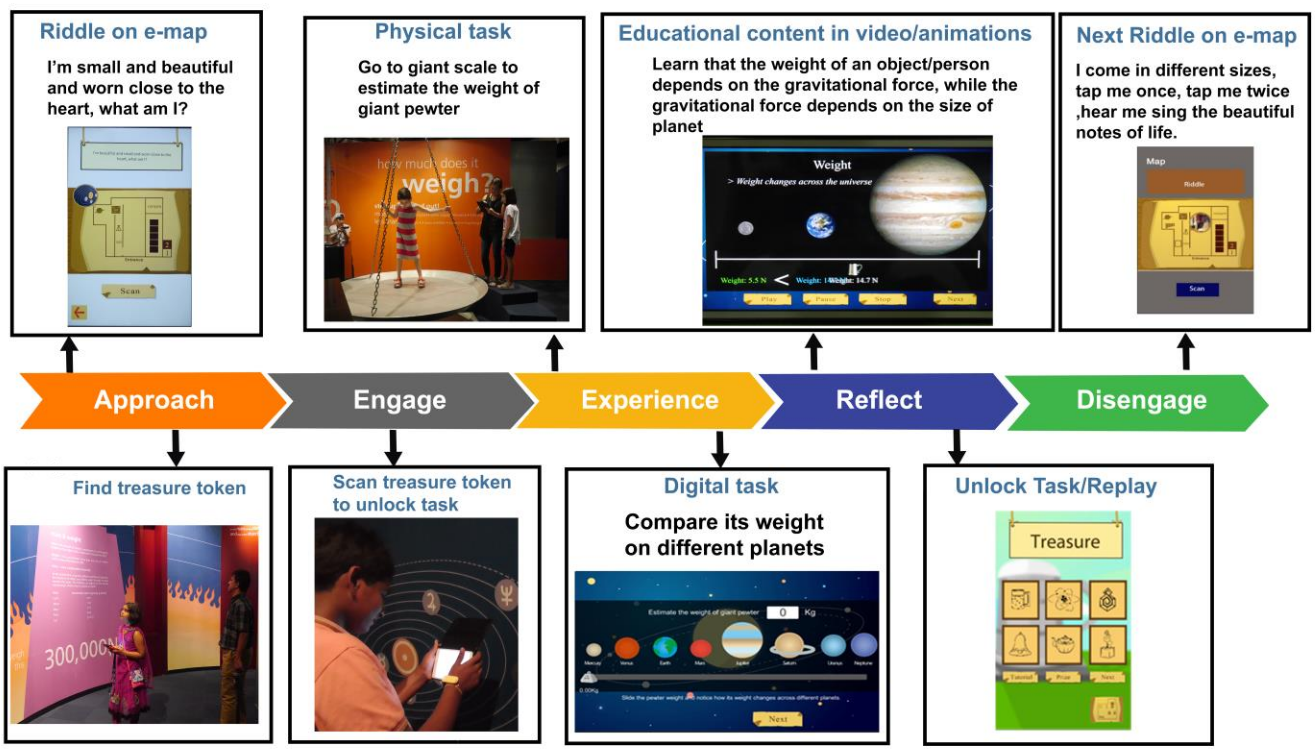

Fig. 1 An example of a local trajectory for an exhibit.

5 Design iteration based on initial mobile trial

We conducted an initial mobile treasure hunt trial with 12 Royal Selangor and university staff to study how well participants could use the treasure hunt guide system. The initial usability study revealed issues with identifying one of the treasure codes and a relative imbalance between the focus on physical versus digital aspects in some of the exhibits. We re-designed some of the tasks to incorporate more of the physical affordances provided by the existing exhibits to address this imbalance. For example, a digital memory match game was re-designed as a physical-digital match game involving existing craftsmen's handprints on the wall gallery. In so doing, in order to strike a balance between physical and digital interactions, we carefully considered the design of the physical task to couple with the associated digital task to increase user engagement within the complex ecology of each physical exhibit.

6 Method

The main user trial was carried out in the Royal Selangor Visitor Centre, Kuala Lumpur, to involve mainly families with children and teachers with school children. They were invited to participate through emails sent to friends and staff of the Visitor Centre and the university. We employed surveys, user observations and video analyses in a comparative study between two types of tours: the mobile treasure hunt (experimental condition as shown in Fig. 2) and personal guided tours (control condition). The personal guided tours consisted of exactly the same procedure as is normally used in the centre – e.g., a member of the centre's staff would guide a group of visitors, explaining each exhibit as they went along, without any particular 'script' to guide them. In addition, visitors who participated in the guided tour were given the option of participating in the mobile tour after the control condition was completed. Mobile devices in the form of small tablets installed with the treasure hunt app were provided to each group, shared among 2-3 members.

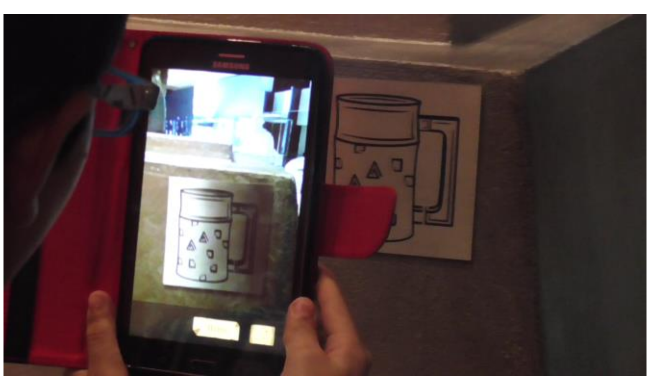

Fig. 2 A user scanning a treasure code.

6.1 Participants

A total of eighty-seven participants took part in the study. Sixteen groups of between 2-5 people participated in the experimental mobile treasure hunt. Seven groups of 2-10 people participated in the control condition (personal guided tour). Most of them went on to do the mobile tour in 12 small groups. All participants were residents in Kuala Lumpur or neighbouring districts. Of the eighty-seven, twenty-seven participants' data were omitted from the quantitative analysis due to incompletion of test surveys. The experimental condition had a total of 28 individual participants with ages ranging from 7 to 48 years (yrs) (mean (m) = 20.89 yrs; standard deviation (sd) = 14.04 yrs). This group consisted of 17 children (m = 10.35 yrs; sd = 2.39 yrs) and 11 adults (m = 37.18 yrs; sd = 6.51 yrs). The control condition had a total of 32 participants with ages ranging from 8 to 45 years (m = 27.63 yrs; sd = 13.06 yrs). There were 8 children under the age of 18 (m = 10.75 yrs; sd = 1.83 yrs) and 24 adults above the age of 18 (m = 32.88 yrs; sd = 10.06 yrs).

6.2 Measures and analysis methods

All participants filled in consent forms agreeing to be a participant and to be video-recorded. They also completed a pre-test survey to provide their demographic details (e.g., age, gender, education level) and a test of prior knowledge of the subject matter of the tour (the science of pewter). After the experience, all participants completed a post-test survey consisting of different items to the pre-test but testing the same knowledge of the subject matter of the tour. In addition, those who took part in the mobile tours (including any participants in the control condition who opted to take part in the second mobile tour) also completed an additional survey providing feedback on the experience and usability of the technology. In addition, any participants who opted to do both the guided tour and the mobile tour were asked about their preferences for either.

The pre- and post-test domain knowledge surveys consisted of 14 items designed to test participants' knowledge of the physical properties of pewter that formed the basis of the science-related exhibits. Learning outcomes were measured using changes in performance from pre- to post-experience.

Video data were collected by filming every tour in both conditions and were supplemented by observational notes taken by researchers. A sample of videos from both the experimental group (mobile tour) and the control group (guided tour) were chosen for analysis of a number of measures of interactivity at the exhibits. The sample consisted of 5 groups of visitors in each condition, out of the possible 15 groups in the mobile tour condition and the possible 7 groups in the guided tour condition. The samples were chosen on the basis of being as closely matched as possible demographically (e.g., small families) and where both pre- and post-test learning measures were available for at least one child in the group. This child became the focus for the video analysis.

We measured the average time taken at each exhibit. The videos were also coded using time-based sampling, with 30-second intervals, focused on the behavior of one child in each group for which we had both pre- and post-test data. At each time point, we coded who was talking (adult visitor, child being studied, other child, guide/researcher, none), where the child was looking (at a relevant part of the exhibit, at the tablet, elsewhere), what the child was touching (tablet, exhibit, nothing/other) and (for the mobile condition only), who was holding the tablet (adult, child being studied, other child, researcher).

Our prediction was that the guided tours would be shorter, the guide would be doing most of the talking, and there would be little hands-on interaction with the exhibit. In contrast, we predicted that in the mobile condition, there would be more talking by the children and more hands-on interaction with the physical exhibits. This is because we intended with the design of the mobile experience to address the potential problem that the device itself might more engaging than the surrounding environment, which would distract the students from the exhibit rather than augmenting the experience of engaging with it. We were also interested in whether the children or the adults had overall control of the tablet in the mobile condition.

7 Results

7.1 Learning outcomes

Figure 3 shows the change in performance on tests of knowledge of the science of pewter, before and after the intervention, by age group.

A three-way analysis of variance (ANOVA) was carried out on learning items, with test as a repeated measure (pre-/post-), condition (exp/control) and age group (child/adult) as between subject factors. There was a significant main effect of test ($F_{[1,56]} = 5.14$, $p < .05$), with post-test scores being significantly higher (m = 60.48; standard error (se) = 3.32) than pre-test scores (m = 54.49; se = 2.32) overall.

There was also a significant main effect of age ($F_{[1,56]} = 20.44$, $p < .01$), with adults scoring higher (m = 66.53; se = 2.59) than children (m = 48.44; se = 3.05). There was no significant main effect of condition, but there was a significant two-way interaction between test and condition ($F_{[2,56]} = 15.21$, $p < .01$). There were no significant interactions with age group.

A simple main effects analysis revealed a significant difference between pre- (m = 43.11; se = 3.49) and post-test (m = 59.69; se = 3.65) for the experimental group ($F_{[1,56]} = 22.44$, $p <. 01$), and a significant difference between the experimental (m = 59.69; se = 3.65) and control groups (mean = 63.17; se = 3.42) at pre-test ($F_{[1,56]} = 23.41$, $p<.01$).

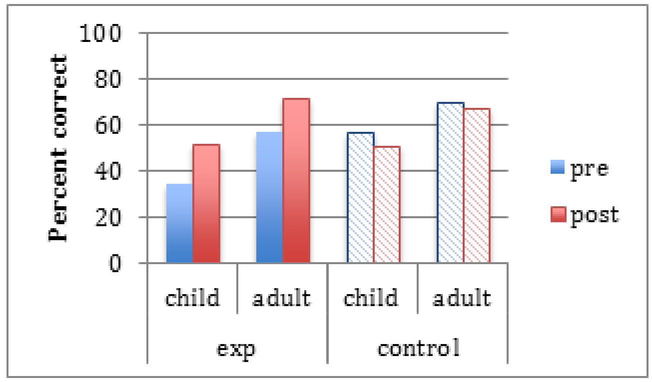

Fig. 3 Learning outcomes from pre- to post-experience.

However, there were no other significant differences. So, even though there appears to be a difference between pre- and post-test for the control groups, this is not statistically significant.

Analysis of the video data show that on average the experimental (mobile tour) groups spent longer overall (m = 20.17 mins; sd = 3.37) than the control (guided tour) groups (m = 7.34 mins; sd = 3.89). Given the size of the difference and the small N for this comparison (N=5 individuals for both conditions), further statistical analysis seems unwarranted. Coding for the behaviours of who was talking, looking and touching the physical exhibits was checked for reliability by having a second researcher code a 20% sample of the data. This yielded Cohen's kappa scores of 0.86 for talking, 0.95 for looking and 0.86 for touching.
For the category *talking*, it is clear that in the guided tour (control) condition, most of the talking was done by the guide, and for the mobile groups, it was fairly evenly distributed between the adult and the child being studied (see Table 2).

For the category *looking*, in the control (guided tour) condition, about 82% of looking by the child being observed was to relevant parts of the physical exhibit (see Table 3). For the mobile tour, about 58% of looking by the child was at the tablet and about 36% at the physical exhibit. For the category *touching*, for the mobile group, about 18% of occasions involved the child either touching the tablet or the physical exhibit, compared with 25% of occasions for the guided tour group.

Table 2 Mean percentage of instances of talking by the child, accompanying adult/parent or guide. (Standard deviations in parentheses.)

	Adult	Guide/ Researcher	Child	Other/ None
Experimental (mobile tour)	23.26 (5.42)	5.59 (4.72)	16.88 (16.36)	54.28 (14.99)
Control (guided tour)	9.15 (10.84)	28.18 (16.90)	4.89 (6.74)	57.79 (15.40)

Table 3 Mean percentage of instances of looking and touching by the child in each group. (Standard deviations in parentheses.)

Looking	**Tablet**	**Exhibit**	**Other**
Experimental (mobile tour)	57.75 (6.28)	36.20 (8.44)	6.05 (4.65)
Control (personal guided tour)	N/A	82.26 (7.27)	17.74 (7.27)
Touching			
Experimental (mobile tour)	11.99 (7.62)	6.45 (3.78)	81.57 (6.45)
Control (personal guided tour)	N/A	25.40 (13.33)	74.60 (13.33)

Observations of the use of the tablet showed that most of the time the adult in the group held the device (m = 51.11; sd = 41.19) as opposed to the child being studied (m = 38.75; sd = 31.51), although the standard deviations show that this pattern was quite variable across the 5 groups.

7.2 User attitudes towards the experience

Based on the results of the post-mobile tour survey, 81% of respondents felt positive about the mobile experience. Their remarks included *"Fun"*, *"Excellent"* and *"Enjoyable"* (see Fig. 4). A high percentage of them felt motivated to complete the treasure hunt, agreed that the use of games facilitated learning and also that the experience promoted collaboration amongst team members. In comparison, 76.5% of survey respondents felt positive about the guided tour experience. In response to the question about what were the greatest challenges they had in the guided tour, the majority of them responded that *"The guide went too fast"* and it was *"hard to understand scientific terms"*. In terms of their tour preference, the majority of respondents (75%) preferred the mobile tour compared to the guided tour. Among the reasons given for this preference were that many felt that the mobile treasure hunt tour was more fun (33%), and provided more opportunities to learn (25%) and discover at their own pace (17%).

7.3 Usability of Artcodes

In the post-mobile tour survey, participants were asked how easily were they able to find and recognise the treasure codes. Responses were measured on a 7-point Likert Scale, 1 being very difficult and 7 being very easy, with results showing that around 70% of them (positively ranked between 5-7), felt it was fairly easy for them to do so (see Fig. 5). Almost 90% of them (positively ranked between 5-7) agreed to the appropriateness of the images used as treasure codes in the hunt and that the task of finding them added to the enjoyment of their experience.

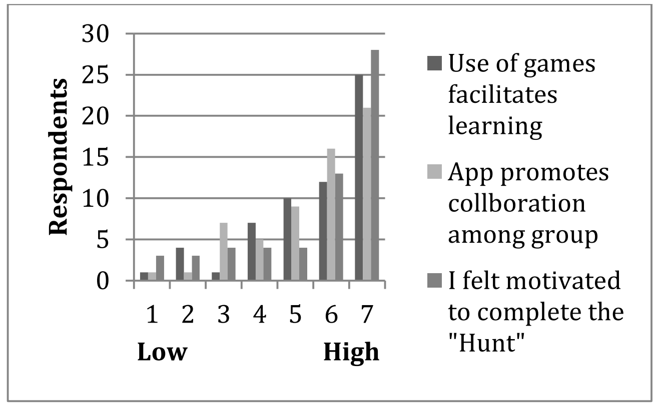

Fig. 4 Mobile treasure hunt experience.

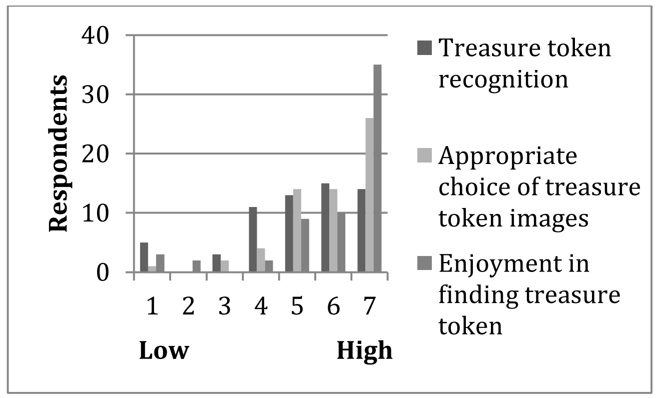

Fig. 5 Treasure code usability.

Collaborative efforts to find the treasure codes often resulted in some discussion. The results of video analysis show the following user interactions with the visual recognition application:

- Some groups ignored the riddles to rely on physical exploration alone.
- The treasure tokens were very often found by the younger children in the group. As the older sibling or parent took charge of the device, the younger child intuitively took to the task or was given the task of finding the tokens. These activities were often scaffolded by parents.

Fig. 6 A mother helps her son with scanning.

- As a result of the treasure codes being placed at different heights, the children had trouble reaching and scanning the higher codes, while the adults had trouble with lower codes, thus affecting the user engagement.
- In most groups, the scanning task was done by the children. Adults often had to help support the children with their scanning when problems arose, for example, by steadying the child's hand or bringing the device nearer or further away from the treasure code (see Fig. 6).
- Some older children were observed to be able to resolve scanning issues themselves by adjusting the physical distance of the scanning device to the code, repositioning their bodies to face the code directly (e.g., when they failed to scan it from an angle due to being blocked) or letting another child help with the scanning. When the latter arose, the '*temporary breakdown*' actually encouraged hand over of the device and collaborative turn taking to take place.

7.4 Evidence of reflections on learning experience by participants

The design of the mobile experience revealed some success in engaging groups to work collaboratively to solve tasks. This may be attributable to the careful design of the tasks requiring participants to look for answers or clues in the physical exhibit environment in order to complete the digital tasks. For example, in the planet exhibit, groups had to go on the giant scale to estimate the weight of the giant pewter weight. While on the scale, one mother (K2) asked her family members for their weights and added them up: *"180 over kilos"*. Her son (K4) suggested, *"200 kilos"*. In response, K2 looked at the information on the exhibit wall and decided that *"Maybe 180 kilos is not enough, over 180 something should be okay"*. K4 entered the value into the treasure hunt app and said, *"Oh, I get it now! Wait, wait, wait. We weigh 200 kilograms. That's on earth; on Venus it says 180, on Mercury it's 60"*. K2 later tried to get K4 to reason out his observation on how the weight changes across planets by asking, *"Is it the size that matters?"*

We observed many other examples of team members working together, for example, in the chamber of music, normally a parent or child would read the instruction while other group members would ring the chimes to compare their pitches. The task was repeated several times to compare chimes made from different materials. Similarly, in the periodic table exhibit, most of the time group members were observed to work together to complete the physical and digital tasks, sharing the screen and tapping on the elements to make as many pewter objects as they could before time ran out. The design of the experience with its repetitive tasks were well-received by most participants where it provided extended engagement for establishing collaboration, allowing different members to participate while at the same time providing opportunities to reinforce learning.

Based on the results of survey, the craftsmen's handprint (exhibit 6) was the aspect of the experience that participants enjoyed the most. In this task, participants had to find the physical handprint as shown on the screen. In an example, a father (S1) guided his daughter (S5) to "*Find.., see which one matches the one in the (picture)"*. While both held the tablet together, S1 slowly guided S5 to the section of wall where the handprint could be found. S5 pointed and jumped up to show S1 the matching hand print: *"I think it's this one"* (see Fig. 7). Solving this task allowed a video of craftsman to play on the mobile device, prompting S1 to ask questions such as: *"You see, you want to learn how to engrave? Follow the knife."* Such examples illustrate how our intervention gives visitors greater sensory and social experiences.

Adults have an important role in shaping the learning experience of children in family visitor groups. Some learning content involving concepts such as density and weight may be beyond the level of understanding of young children, but we observed examples of where children as young as six years were able to follow adults' explanations when the content was reiterated to them in simpler terms.

For example, having watched a video explaining the concept of density, one father (F1) referred to the physical exhibit and attempted to explain the relationship of various metals and their densities. In another example, a boy (R2) was able to recall the elements that make up pewter, having watched a previous video on the mobile device that explained this. When his teacher (R1) asked *"What makes pewter?"* in a later task, he confidently answered, *"Just now, there are three.. tin, antimony and copper"*.

However, while most participants appreciated the use of video content in the app, one of the problems that most groups faced during the viewing of the videos was the inaudible sound due to the high level of background noise in the presence of large crowds.

Fig. 7 A daughter shows father the matching handprint.

8 Discussion

8.1 Learning gains through the mobile tour

The intervention using the mobile tour resulted in greater learning gains compared to the control condition (the existing personal guided tour), for both adults and children. The analysis revealed significant pre- to post-test gains for the experimental (mobile experience) groups, but no significant differences in pre- to post-test results for the control groups.

From the analysis of the videos, it is clear that part of the explanation for this may lie in the fact that the mobile tour produced longer interaction times at the exhibits compared with the control condition. This is partly to be expected, since the mobile tour required sustained engagement both with the technology and with the physical exhibit. It could be argued that we had simply replaced the usual interaction with the exhibits with interaction with the digital technology. We had deliberately set out to design an experience that encouraged interaction with the physical and not just the digital content. This was intended to avoid the problem of the mobile device being more engaging than the surrounding environment which would distract the visitors from the immediate experience of the location rather than augmenting it. This seems to have worked, given that in the mobile tour condition about 94% of instances involved looking either at the tablet or the physical exhibit, whereas for the guided tour, only 82% of instances involved looking at relevant aspects of the physical exhibit (a difference of 12%). For the category touching, the mobile tour group physically interacted with the exhibits for about 18% of the instances observed, whereas for the guided tour group this was 25% (a difference of only 7%). However, there was a large difference in talking between the mobile and control groups. In the mobile groups about 41% of the talking was done by the visitors (adults and children), compared with only 14% for the control group (a difference of 27%). For the latter, most of the talking was done by the guide. From this we may conclude that the intervention was successful both in creating greater engagement by participants with the physical exhibits (and not just the mobile content), and in creating greater levels of collaboration amongst participants in the groups.

Our findings revealed that the role of the adults was a key factor in the overall learning experience of the children. The scaffolding experiences that adults provided by simplifying ideas or tasks and encouraging the children towards successful experiences seemed to have contributed to the children's overall learning. We observed parents' involvement and interactions with their children in support of learning ranging from simply giving encouragement (e.g., a father giving a pat on daughter's head when she found a treasure code), to giving directions about using the technology (e.g., a father guiding his daughter to scan a code) and to giving explanations that connect the exhibit experience to larger concepts (e.g., a father referencing the physical balance weight to explain the relationship between various metals and their densities). Based on our video analyses, we observed that effective learning experiences seemed to be achieved when adults adopted scaffolding strategies that included a high level of: (1) engagement in undertaking collaborative tasks, (2) verbal interaction such as reading out loud and asking questions, (3) inclusivity to ensure everyone participates in the group or takes turns (4) physical proximity where adults remain close and attentive and (5) focusing on helping children reflect upon their experiences and make connections between the museum experience and wider applications.

8.2 Understanding factors affecting scaffolding

Heath et al. [22] highlighted the difficulty that designers face in creating exhibits that engender collaboration involving more than one or two visitors, with many interactives treating visitors as a group or having them undertake individual actions in parallel with each other. It is not always clear to parents how they can become collaborative participants in their children's activity [33]. Downey et al. [15] highlighted three main barriers to parent involvement: (1) most parents lack a clear understanding of the benefits of play in children's museums (2) parents lack confidence in, and knowledge of, how to play with children in a children's museum, and (3) the nature and design of children's museums may not fully encourage and facilitate parent involvement. In using child-centred approaches museum professionals tend to emphasise the importance of individual discovery and downplay the role of teaching [36]. We suggest that there should be meaningful roles for parents at most exhibits through extending and enriching children's activity through assistance and conversation.

Based on our observations about how parents scaffolded some part of the experience for their child, we propose that exhibition planners and designers should take into consideration the following guidelines that may affect how mobile guides may be used to support parental-child engagement:

Beliefs about learning – Parents' beliefs about learning are often different from each other. We observed some very positive examples of parent-child learning, such as focusing on aspects of exhibits for and with their children, helping them reflect upon their experiences or making connections with the larger world. However, our results also showed that whilst some parents viewed their role as teachers, others do not. The extent to which a parent sees him/herself as a teacher can enhance or inhibit cognitive processes and can therefore impact on their children's learning in museums and visitor centres. Some parents who do not see themselves as teachers [29] focus on (1) fun, allowing their children to play and explore without drawing an explicit connection between their children's play and learning, (2) self-discovery, allowing children to take lead and explore independently, (3) engaging in the experience themselves without involving their children. To support parental engagement, designers need to purposefully integrate a learning strategy of scaffolding into the design of associated exhibits and technology augmentation.

Inclusion – Some parents are better at including all children in the learning experience than others. General observations in this study showed that parents had a tendency to focus on the learning of older children, whilst unintentionally excluding younger children. Possible design ideas can be developed in multiple ways using learning frameworks that provide more age-specific designs, taking into account differences in cognitive abilities, characteristics of age groups and the capacity of children in different content areas by age. This may be done by providing actvities with varying difficulty levels.

Communication – Verbal communication is an important skill that some parents may lack but could be supported by technology. For example, we observed a mother learning to read out loud instructions having observed a volunteer doing so, resulting in her children and herself coming together as a group. Simple strategies that mobile guides could employ include explicitly encouraging parents to read out loud to improve the learning experiences of children.

Engagement – Our findings showed that groups can be encouraged to engage deeply with the exhibits when they perform physical tasks. Collaborative efforts within each group can be encouraged by designing for more balanced physical-digital interactions.

Physical proximity – Close physical proximity between adults and children provides security for children, enhances conversation/discussion and increases interaction time with exhibits. This is often valued by younger children, potentially impacting on their learning experience. This may be encouraged through sharing of devices or implementing multi-player games.

8.3 Extending the trajectories framework

Design frameworks often focus on designing for the global experience in museums. Previous work on applying the trajectories framework in designing an experience have focused on relatively simple settings involving individuals or pairs of adult visitors [19, 21]. Further issues in adapting the trajectory to crowded settings and larger groups were observed in this study, which increased the challenges of considering how multiple participants' trajectories interweave with one another. Given that adults naturally orchestrate or scaffold the experiences of their children, the question remains concerning how we should approach the task of designing effective interleaving trajectories to support parental mediation at a micro level, within a group. We propose extending the trajectory framework of [4] to consider a pair of trajectories – parent and child – to support collaboration and inter-generational informal learning during museum visits.

The trajectory framework of [4] encouraged us to consider how multiple participants' trajectories might interweave with one another. Our study further suggests the need for future designers to think about supporting parent-child trajectories that deliberately oscillate between moments of scaffolding encounter and personal engagement. Figure 8 summarises some micro-scaffolding strategies with detailed examples to be considered by designers when designing future mobile guides at different phases of the trajectory experience: approach, engage, experience, reflect and disengage. At the heart of this micro-scaffolding design proposal is the aim of identifying and presenting learning objectives with supporting learning resources and activities in ways that can be orchestrated or scaffolded by the adults/parents at each stage of the trajectory. We give examples below:

- Approach – The mobile app allows adults to model problem solving behavior to their children, for example, by being able to get clues and help solve riddles in the treasure hunt game.
- Engage - Upon entering the 'engage' phase, adults will need to focus the children's attention on the exhibits, for example, by being able to point out physical information or artefacts in the environment.

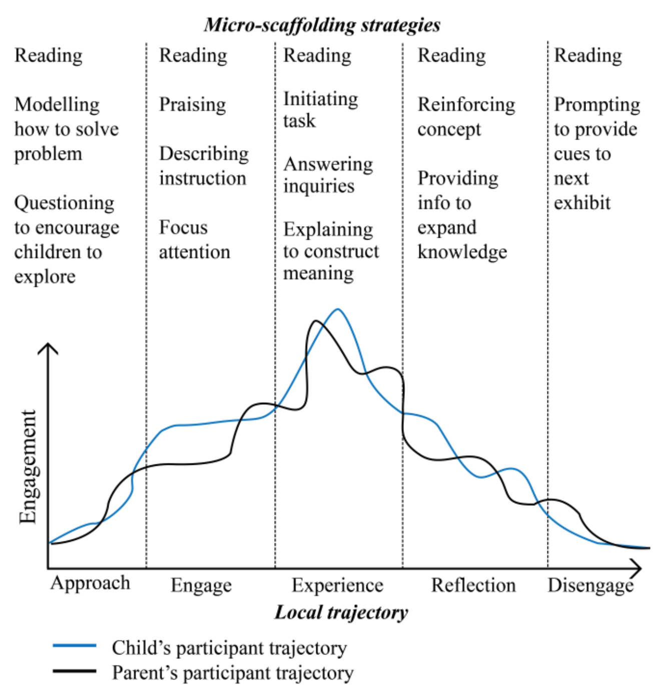

Fig. 8 Micro-scaffolding strategies to be supported by designers at different phases of trajectory experience.

- Experience – Adults will now play the role of orchestrating team actions, for example by initiating and delegating tasks.
- Reflection – This is important for reinforcing learning concepts, for example, by providing information to expand knowledge.
- Disengage – Adults may help navigate the visiting group to the next station by providing clues to the next exhibit.

9 Conclusion

This work has contributed further to our understanding of how to augment visitor experiences and learning in museums, visitor centres and galleries through the use of interactive technologies. The use of the trajectories framework led us to consider how the learning journey might unfold through key phases of approach, engage, experience, reflect and disengage. We can express the nature of collaboration in multi-user experiences by considering how multiple participants' trajectories interweave with one another. The major contribution, we feel, is both technical – how to exploit physical artefacts to embed interactivity into exhibits themselves rather than making it a separate activity that takes attention away from the exhibit, and theoretical – how to extend design trajectories to incorporate micro-level scaffolding by co-visitors and macro-level trajectories that prescribe the global experience through the visit.

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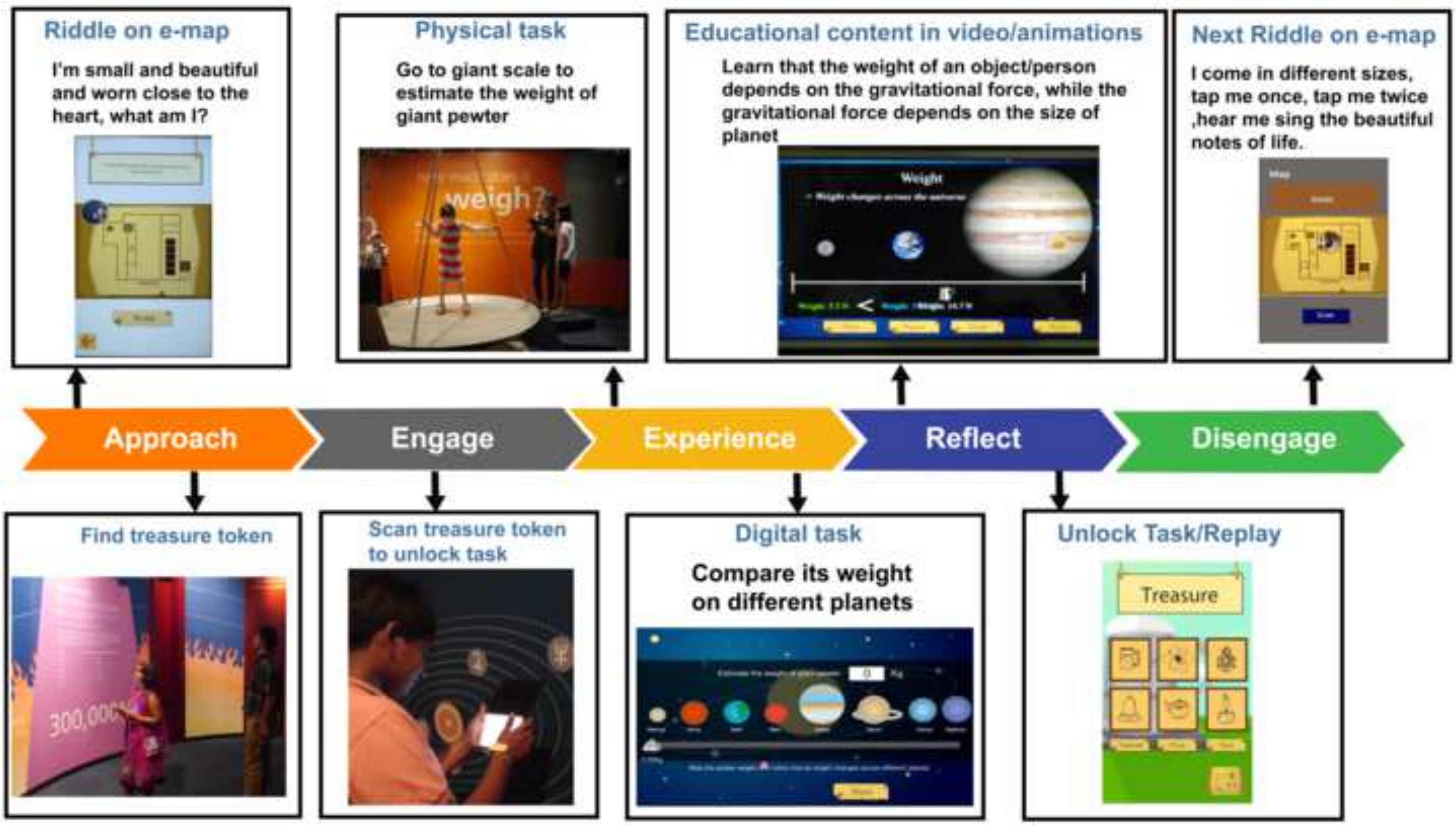

Figure 2

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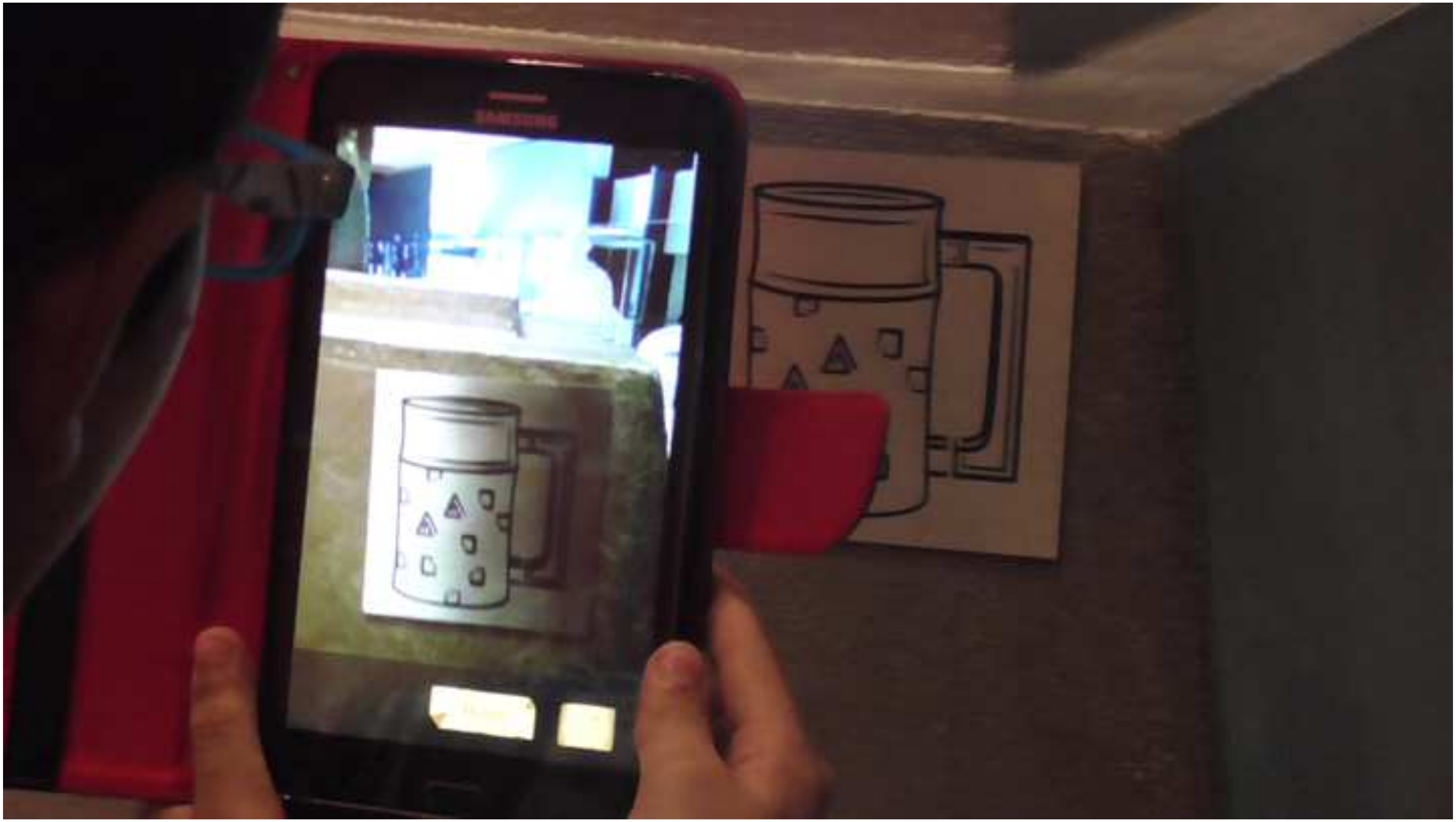

Figure 3

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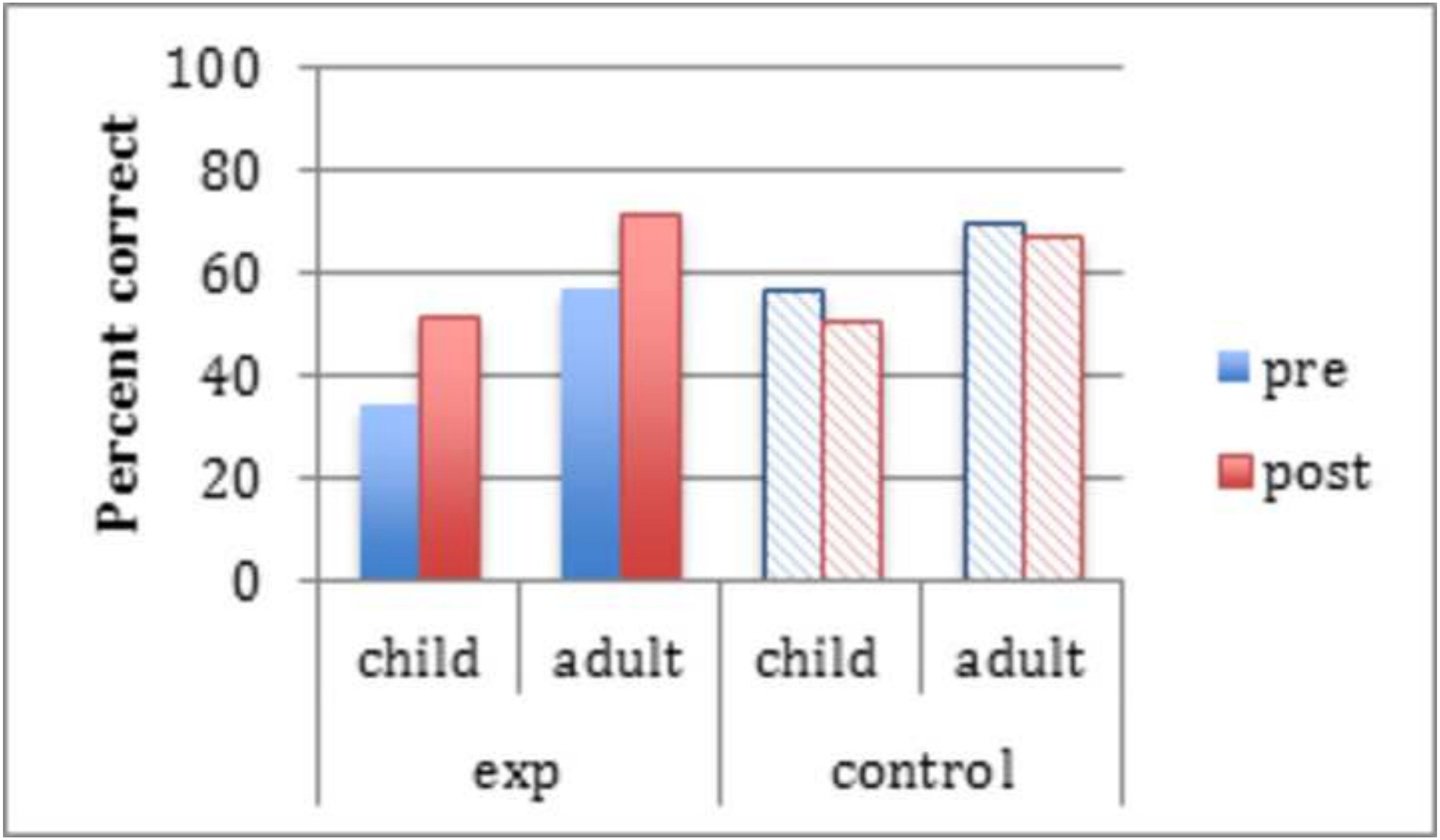

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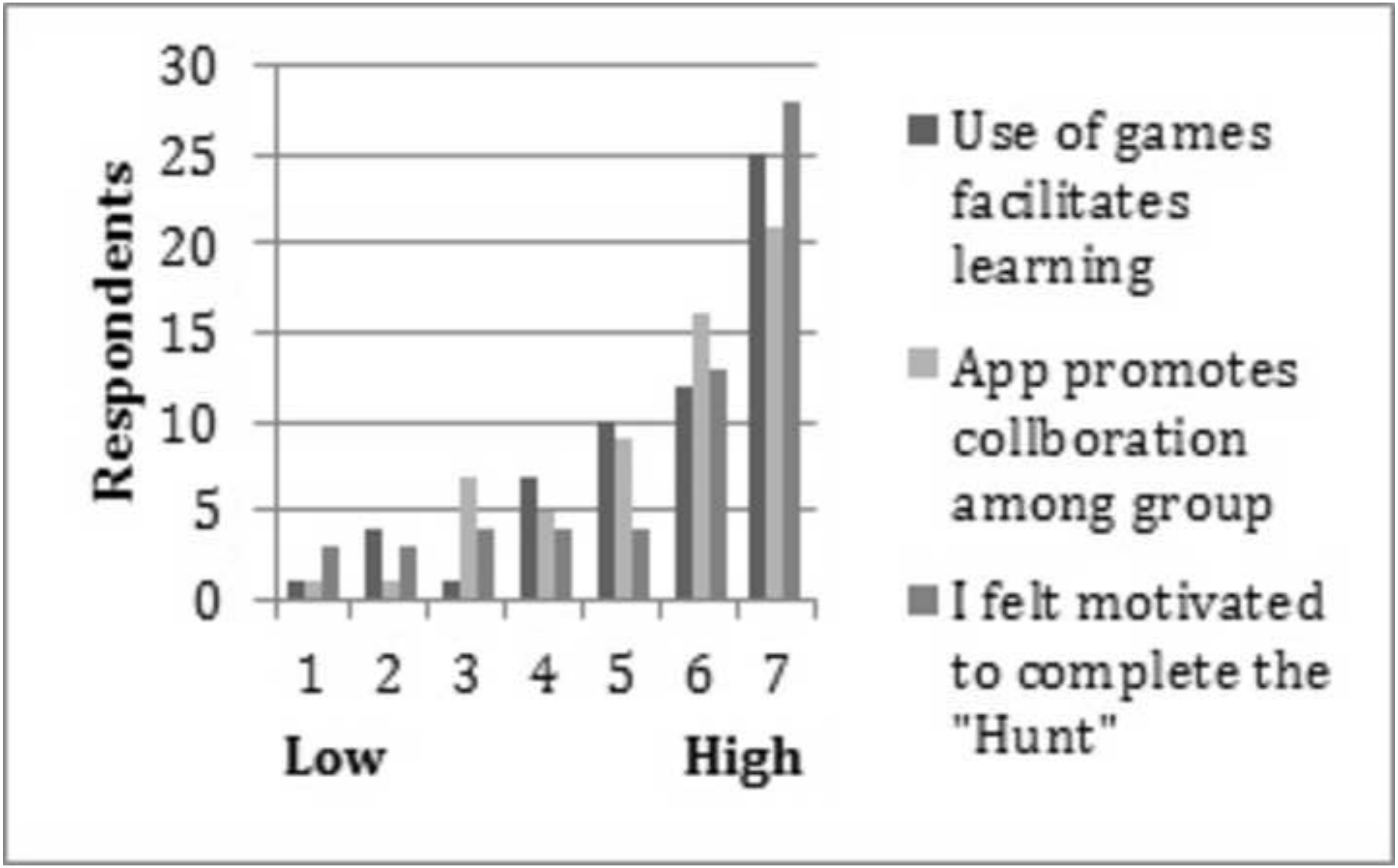

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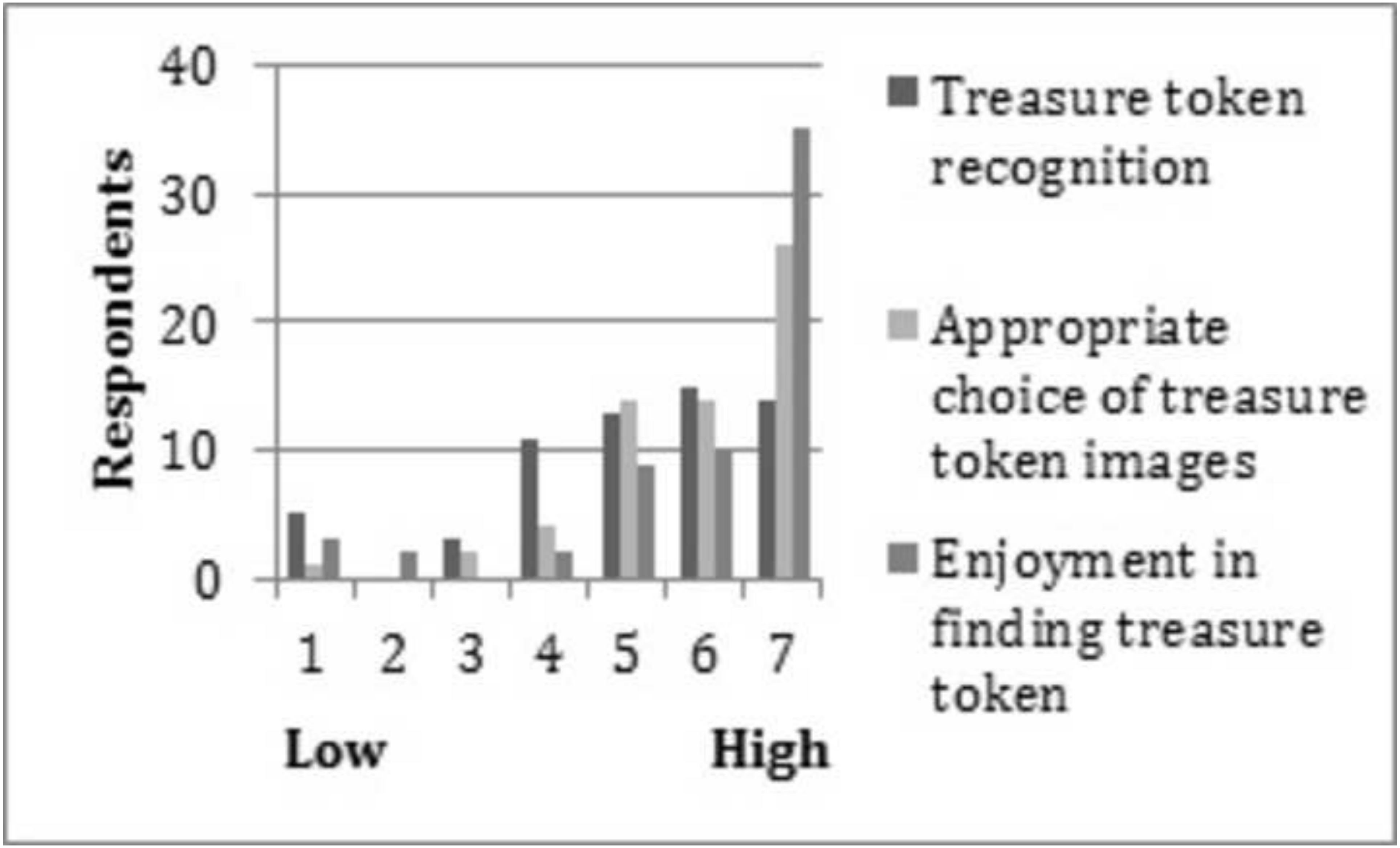

Figure 6

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Figure 7

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