Comparing a Single-Touch Whiteboard and a Multi-Touch Tabletop for Collaboration in School Museum Visits

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This paper explores two important classes of large screen displays, *single-touch whiteboards* and *multi-touch tabletops*, for the context of collaborative learning by school groups at a museum. To do this, we designed MuseWork, as a worksheet activity, with two phases: first, students explore the museum, individually or in pairs, guided by our tablet worksheet app; then, in groups, they collaborate to create a poster at a large-screen display, using our device-customised MuseWork interfaces. Our goal was to gain insights about the implications for engagement and collaboration when groups use these devices; single-touch whiteboards are important as they are widely available in classrooms and multi-touch tabletops are an emerging technology. Our research questions asked: 1) whether MuseWork enabled groups to complete the collaborative task at both devices and 2) how the whiteboard and tabletop each affect key aspects of collaboration. We report a between-subjects study of 67 students, aged 10–14 years, from 2 schools, in 12 groups. Our results, based on qualitative and quantitative data, indicate the MuseWork interface for each device proved effective, with groups completing the activity and satisfied with the result and the experience (RQ1). Comparisons of groups using each device (RQ2) give new insights in terms of the products of the collaborative activity, and the strategies groups spontaneously developed for group co-ordination and device use. Our contributions are insights from the first in-the-field study of children collaborating at single-touch interactive whiteboards and multi-touch tabletops.

CCS Concepts: • **Human-centered computing → User studies**; **Ubiquitous and mobile devices**;

Additional Key Words and Phrases: Interactive Tabletops and Whiteboards, Tablets, Small Group Collaboration, Museums

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1 INTRODUCTION

One important role of museums is to provide engaging learning experiences for the general public [20–22, 25, 33] and for school groups in *inquiry learning* [5, 7, 13, 14, 36, 40]. One widely used and valuable approach to structuring school group visits is based on a *worksheet* [15, 33, 51]. This may be designed to link with the classroom and the formal syllabus so that the teacher can harness the experience flexibly for their teaching [34].

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This paper describes our system – MuseWork (*short for Museum Worksheet*), which provides a worksheet-guided learning activity in two phases. In the first phase students use a tablet for inquiry learning [6] that *guides* their exploration of the museum galleries. The tablet enables learners, working alone or in pairs, to capture images and text responses to a worksheet. In the second phase, students form small groups to share their work from the first phase, to collaboratively create a poster that addresses the worksheet questions. This phase was motivated by the substantial body of work demonstrating the advantages of collaborative learning [16, 18, 60, 62], and highlighting the importance of *consolidating* individual inquiry learning [1, 37, 61].

Our work aims to support collaborative learning at a large screen display under the particular constraints of class groups at a museum. These are: desirable and pragmatically determined group sizes, strict time limits, ensuring the class teacher can maintain an active role; and that the work is linked to the curriculum and class learning. Shared-displays appear to offer valuable support for the small group collaboration in this setting [17, 47, 57]. But there are important gaps in our understanding of how to support such collaboration. There has been considerable use of interactive surfaces in museum exhibits, such as in Geller [24] and Michael et al. [49], but not for class groups in a combination of inquiry learning and collaborative consolidation. Work has also explored how to support inquiry learning with mobile devices [35, 50, 63, 67, 68], but none followed this with the collaborative phase as part of the museum experience.

Our focus is on how to support the collaborative learning phase with either a *single touch interactive whiteboard* or a *multi-touch tabletop*. Interactive whiteboards are widely available in classrooms and it would be valuable to gain understanding of how they can support small group collaborative learning. Far newer are interactive tabletops. These have been used in just a few classroom studies, such as [10, 30, 41, 44, 45, 55] and those reviewed in Kharrufa et al. [31]. There is a growing body of work comparing collaboration at these two classes of surface, vertical and horizontal [8, 10, 28, 52–54, 58], but the picture is very incomplete. Notably, none of it has involved children or the group sizes that our context demands. There has been work comparing single and multi-touch interaction for small groups. For example, Rick et al. [56] studied groups of 3 children, aged 7-9, at a small (65x49cm) DiamondTouch tabletop, reporting that the children touched much of the table but mostly the area nearest themself, and there were challenges in turn-taking for the single-touch condition; and a lab study, reported by Harris et al. [26] with groups of 3 children, aged 7-10, found interaction equity in both conditions, with much discussion of turn-taking for the single-touch condition, seemingly replacing some task-focused discussion.

Our work explores two research questions:

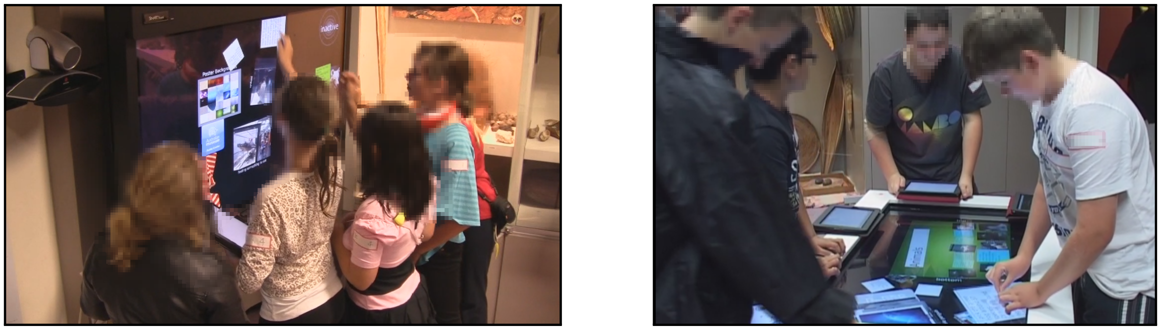
- **RQ1**: How effectively do device-customised designs of MuseWork enable children to complete their collaborative activity at the *whiteboard and tabletop*?
- **RQ2**: How do the whiteboard and tabletop each affect students' participation, collaboration strategies and engagement?

Our key contribution is towards filling the gap in understanding collaboration at large horizontal and vertical interactive displays. To do this, we designed MuseWork, a system that supports rich museum learning – both inquiry and collaboration – then studied children's collaboration at both vertical and horizontal interactive devices (as shown in Figure 1). We provide insights into ways that widely available single-touch vertical displays and far-newer multi-touch horizontal devices can support children's small group collaborative learning activities.

The next section overviews related work. This is followed by our design drivers, and the user view of MuseWork. We then describe our between-subjects study and its results. We conclude with reflections on the system to make both classes of device more effective for small group collaboration.

2 RELATED WORK

We review two areas of related research: collaborative learning systems in museum settings; and work that has compared vertical and horizontal displays. The first characterises systems with similar goals to our own, with



(a) MuseWork at an interactive whiteboard. (b) MuseWork at a multi-touch tabletop.

Fig. 1. Groups of students using MuseWork to assemble a poster of their museum exhibit on a shared interactive display (a–Whiteboard, b–Tabletop) with information collected on their private tablet devices.

children exploring a museum, with mobile devices to capture materials for later consolidation activities. Secondly, we review studies comparing collaboration at vertical and horizontal surfaces.

2.1 Collaborative Learning Systems in Museum Settings

Museums have been early adopters of new technology to enrich the experiences of their visitors. They have also made extensive use of tabletops for exhibits and there have been studies of how groups engage around them, as in [4, 27, 69]. This section focuses on studies of students that are similar to our goals in that they start with a museum exploration activity, using a small portable device – with varying levels of guidance. Table 1 summarises a representative sample of such systems. The first column lists the system name and reference. The next column is information about the students (number and their age). The last column summarises the technology used. All but the first involved children of similar ages to our work. Notably, all the systems had collaborative activities *after* the museum visit, whereas we aimed to consolidate the learning in a collaborative activity at the museum.

Broadly, Museum Detective [63] demonstrated the effectiveness of a worksheet-like activity based on a mobile device, compared with pen-and-paper. Myartspace [67] was characterised by its support for collecting rich

Table 1. Summary of collaborative learning systems in museum settings.

Study	Students	Brief Description
Museum Detective [63]	80 students (Grade 3)	Used a hand-held Dell PDA device in pairs to self-explore exhibits. Findings reported high levels of on-task behaviour.
Myartspace [67]	23 students (Ages 13-14)	Used mobile phones to capture information about exhibits, with items automatically uploaded to the web, for later use in the classroom.
MuseumScouts [68]	225 students (Ages 10-19)	Learners collected information at the Museum based on a worksheet, later creating presentations (back in the classroom) to teach findings to peers.
Zydeco [35]	54 students (Ages 11-13)	A science inquiry system, with data collection on smartphones, followed by a collaborative phase (with tablets), spread over multiple sessions after the visit.
Our work	67 students (Ages 10-14)	Data collected on tablets based on a worksheet, followed by a collaborative phase with an interactive display (tabletop/whiteboard). Both in the museum.

materials, gathering information from tagged objects, taking pictures, recording sounds and typing comments, based on questions from a paper worksheet, where students used these in later class activities. For MuseumScouts [68], material collected at the museum was used to create multimedia presentations to share in class. The evaluation highlighted different outcomes across the 25 schools involved, heavily affected by the level of curriculum alignment. For our work, this indicates the importance of linking the museum activity to the curriculum and consolidating the artefact collection with a group activity in the museum. The final system, Zydeco [35], took place in a local history museum, with students using a website to set up questions to investigate, then collecting data for an hour at the museum for subsequent classroom activities over several days (this work was later extended into the EvoRoom project [38], with reactive visualisations on large interactive whiteboards using content drawn from each learner).

Overall, these works point to the potential of a digital worksheet to explore a museum, the importance of linking the activity to the school curriculum, and the need to ensure materials are available for later use.

2.2 Comparison of Vertical and Horizontal Displays

This section positions our work in relation to research that has compared vertical and horizontal displays for collaboration. Table 2 gives an overview, described by items similar to Potvin et al. [54]. Column 1 lists the citation. Column 2 shows if the comparison conditions were non-digital (ND) or digital (D). *The table is ordered on this column.* First are the non-digital studies. Mixed digital and non-digital is next. Then come the three studies most like our work, with digital interfaces for both conditions. These three are diverse in terms of the form of interaction (Column 3), with two being multi-touch; one in a brainstorming activity that also used keyboards for text entry (Clayphan et al. [10]) and Mi et al. [48]; and one, Rogers and Lindley [58] which used a shared pen.

The *task* column shows the tasks are diverse. Column 5 shows if the tabletop interface design accounted for different orientations. This is important as people need to be *around* the tabletop for face-to-face interaction. Conventional desktop layouts may work well for vertical displays since all users view them from the same

Table 2. Summary of horizontal and vertical display orientation studies. Adapted from meta-review in Potvin et al. [54].

Study	Digital / Non-digital	Input	Task	Multiple orientation support?	Sit or Stand	Team Size & Age	Num. Groups, Exp. Design
Inkpen et al. [28]	ND	Pens	Route planning	No	H–sit V–stand	2 (Adults)	6 (within subs) In-the-lab
Potvin et al. [54]	ND	Pens	Software design	No	Stand	2 (22–51)	10 (within subs) In-the-lab
Clayphan et al. [8]	ND (V), D (H)	ND–pens D–multi-touch	Marketing Brainstorm	Yes	Stand	4 (20–54)	6 (within subs) In-the-lab
Pantidi et al. [52]	ND (V), D (H)	ND–pens D–multi-touch	Concept Mapping	Yes	Either	9-10 (Adults)	4 (between subs) In-the-wild
Rogers and Lindley [58]	D	Single pen	Travel planning	No	H–sit V–either	3 (21–40)	8 (within subs) In-the-lab
Mi et al. [48]	D	Multi-touch	Classification task	Yes	Stand	2–6 (Adults)	5 (between subs) In-the-lab
Clayphan et al. [10]	D	Multi-touch & keyboards	Design Brainstorm	Yes	H–Sit V–both	3-4 (Adults)	14 (within subs) In-the-wild
Our work	D	H–multi-touch V–single-touch	Poster Creation	Yes	Stand	3–7 (10–14)	12 (between subs) In-the-wild

orientation. The same interface at a tabletop may force some people to view and interact with orientation-sensitive materials at unfavourable angles, even upside-down. Just 4 studies accounted for this and only 2 had digital interaction in both conditions [10, 48]. The next column indicates whether people were standing as this makes it more natural to move, especially if that helped them deal with orientation problems at the tabletop.

The column for team size and age is important. Groups of 2-3 can easily sit side-by-side at a tabletop. Our work is distinctive in needing to deal with groups up to 7 *children*; all the others involved only *adults*. The final column shows that most of the studies were in-the-lab, with only Pantidi et al. [52] and Clayphan et al. [10] in-the-wild. This column also shows that the numbers of groups studied was similar to, or smaller than our study. Overall, the key picture that emerges is that this work is quite diverse in terms of all the aspects shown in the table with none directly comparable to our own. Particularly notable is that our work involved children in a learning activity.

We first consider the two studies involving non-digital interaction, both involving pairs. Inkpen et al. [28] involved collaboration on vinyl covered maps for route planning. They compared horizontal, vertical and tilted surfaces. They reported more pointing at the horizontal surface but more preparatory communication in the vertical condition. When asked about preferences, *participants were split evenly across all three conditions*. Potvin et al. [54] studied face-to-face contact, verbal utterances, and equality of physical and verbal participation. The vertical condition gave better face-to-face contact, orientation had little impact on equality of verbal and physical participation, and *user preference was equal in both orientations*.

The next pair of studies had digital interaction only at the multi-touch tabletop. Clayphan et al. [8] reported a positive finding for the tabletop as it had *more egalitarian use*. By contrast, the whiteboard had one or two people as scribes – despite ample room for all to write simultaneously. The tabletop also had *a higher rate of idea creation*. Pantidi et al. [52] compared a vertical condition based on various low-tech materials (post-it notes, pens, and a projection display on a static whiteboard) with a multi-touch tabletop. A key conclusion was large groups (9-10) found it hard to keep engaged as a single group, a potentially relevant concern for our groups of up to 7 children.

We now consider the three studies with digital interaction for both conditions. In Rogers and Lindley [58], groups of three shared an electronic pen to navigate websites to fill in an itinerary on a paper worksheet. The horizontal display enabled users to be *more aware* of each other's actions. The vertical display had problems for pen changeover and with room layout. Key conclusions for our work are that *collaboration improved for the tabletop* as it enabled people to be physically near each other. Mi et al. [48] had a focus on understanding the of impact of orientation of information at the tabletop. The horizontal displays had designs with and without orientation support. They reported more *eye contact around the horizontal display*, but *the vertical display had better legibility*. They described differences in user arrangement based on group size, for example, larger groups at the vertical display standing in layers (some interacting, some standing back). Last, is an in-the-wild study by Clayphan et al. [10], comparing how to learn to brainstorm, across three conditions: tabletops, interactive whiteboards, and pen and paper. Both horizontal and vertical displays had similar outcomes on various measures but *participants preferred the tabletop*.

Of these seven studies, four [8, 10, 28, 58] reported *benefits of the tabletop over the wall*, especially for affective measures, as participants liked its face-to-face collaboration. One study indicated the wall may be better, though it was for non-digital software design with pairs [54]. The picture that emerges is still incomplete, with more research needed to compare interactive vertical and horizontal displays, particularly with: groups of 4 or more; with children; and with interfaces customised for the orientation challenges of the tabletop. We aim to tackle these gaps, studying groups of 3–7 children, working at either a tabletop or whiteboard, in an in-the-wild setting.

3 OVERVIEW OF THE MUSEWORK DESIGN AND USER VIEW

Our work aimed to create a learning experience for children on a school visit to the museum. This section describes the key driving goals for the design of MuseWork and the design processes. Then we present the user view.

3.1 Design Drivers and Process

The work began with discussions between the technical team and the learning services staff of the Australian Museum. They had previously been using paper-based worksheets. Children completed these by exploring exhibits in the museum. They took these back to their school, potentially being used in classroom activities there.

The learning services staff wanted to create a richer form of learning activity, that maintained the benefits of the worksheet. We needed to still match the state syllabus topics that schools consider when booking class visits. The learning activity had to fit the time schedule for class visits. We discussed the links between the classroom and the visit and agreed that the children's teachers should have opportunities to contribute to the museum activities and the children's work should be available for later classroom use.

The learning team wanted to use new technology to support richer learning activities based on constructivist and collaborative learning principles [29]. The team agreed on a design based on two stages, around a form of *worksheet* learning activity [33], being:

- An inquiry learning activity, with students working *individually or in pairs* to explore an exhibit gallery, (such as the one in Figure 2), with an iPad providing a *digital worksheet* to guide the exploration and to enable students to collect responses to worksheet questions (in the form of notes and pictures). This aimed to make the museum environment a *"display of rich and authentic objects, and limited guidance, [which] all support a learning approach of active inquiry and engagement" [67].*
- A learning activity at an interactive whiteboard or tabletop, with groups of 3–7 children collaborating to *create a poster* to answer the questions on the worksheet, drawing on the materials collected. This collaborative phase was motivated by the benefits of collaborative learning [16, 19]. This harnesses the large collaborative display for sharing, collaborating, assimilating, and synthesising information, to construct knowledge as a group. This phase was important for consolidating the learning during the museum visit.

The detailed design of the collaborative poster creation was arrived at after a series of team discussions. The museum education staff, drawing on long experience in working with school groups, ensured the design matched the level of the children and the learning goals. They designed the core worksheet, based on the state curriculum and the materials in the museum. The technical team aimed to then design the collaborative part of MuseWork so that it would work well on either display. Our final design had the following steps. None require parallel work, which would have favoured the multi-touch tabletop. In the first step, each child in the group shared the materials from the inquiry phase, sending them from the tablet to the large display. The second part involved creating the poster: the whole group considered the available backgrounds, discussed them to select one; then

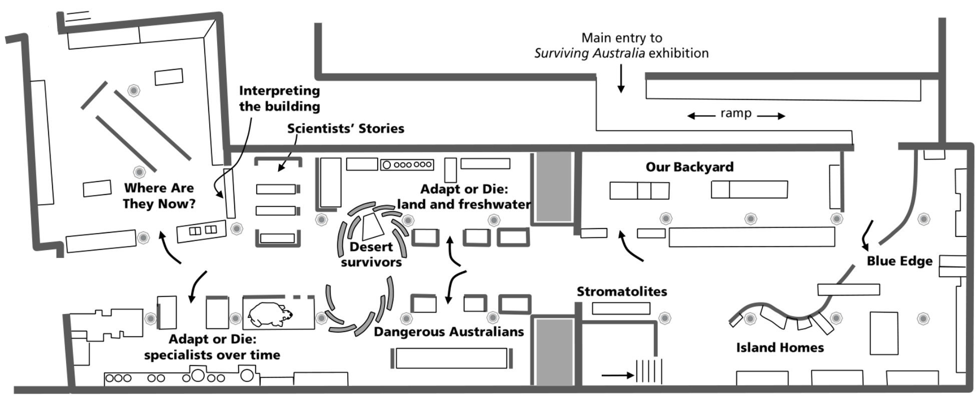


Fig. 2. Floor-plan of the exhibit, which the students explored with their iPads.

they chose and organised the material on the poster. Finally, they discussed what their chosen animals had in common and created a note about this to add to the poster. Together, these involve diverse forms of collaboration.

Another key part of the design was to ensure a link between the museum visit and the normal classroom. We allowed for a classroom teacher to provide materials to prime the collaborative phase. This would enable a teacher to link preparatory class work with the museum activity. In addition, to ensure linkage back to the classroom, the team agreed that the posters should be sent electronically to the schools.

From a technical perspective, we aimed to design MuseWork to support both phases. This made it important to adapt the collaborative phase to either the interactive whiteboard or a multi-touch tabletop. Our design process was iterative, with several versions of the tablet worksheet app and the collaboration interfaces. Some of these were reviewed and tested internally. As MuseWork became more mature, it was made available for class groups that were not part of the study reported below, with the education and technical teams on hand, reviewing each such visit to make refinements to MuseWork and the processes for running the activities.

3.2 User View of MuseWork

Information gathering phase

For this phase, students used a tablet device (an iPad). When there were more students than devices, students worked in pairs. Figure 3 shows the introductory screen of the interface. The tab at the bottom of each screen has buttons for: (a) photo capture, (b) note creation, and (c) the worksheet. Figure 4 shows one of the worksheets designed by the museum staff, to match one set of the state's syllabus learning outcomes.

Clicking on the photo tab presented the photo screen (Figure 5). To activate the camera, the student pressed the '+' button at the top-right of the screen. After taking a picture, students could add a title, by doing a long press. The note tab works in a similar manner to the photo tab, showing snippets of notes already created (Figure 6). To create a new note, the student taps the '+' button (top-right). To edit existing notes, they touched the '>' button.

Fig. 3. Welcome Screen: (a) photos; (b) notes; (c) worksheet.

Fig. 4. The Worksheet tab: providing tasks to students.

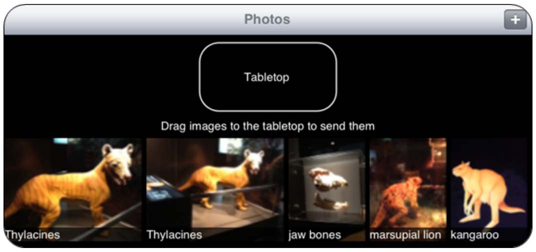


Fig. 5. The Photo tab. Tap a photo to edit the title. Tap the + button (top right) to activate camera.

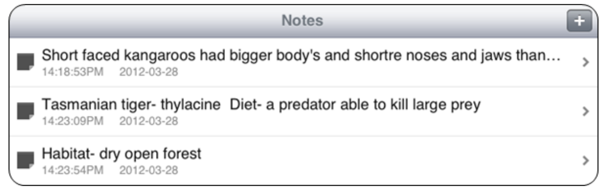


Fig. 6. The Note tab. Shows a preview of created notes, and allows new entries (+ button, top-right).

Collaborative phase

After learners had explored the museum gallery to answer the worksheet, they moved to a space with the interactive whiteboard and tabletop to create their group poster. This had three stages.

(1) Sharing individual materials. Students took turns to send their collected materials to the tabletop or whiteboard, presenting these to their group.
(2) Creating the poster. Students needed to select a poster template, then place materials on it, adding extra elements, such as titles. The students needed to decide which materials to keep, and which to discard.
(3) Reflection. Students were asked to add a note to explain what the chosen animals had in common.

We note that these represent a diverse set of collaboration forms. But importantly, they can all be done effectively at a single-touch device as we explain below.

For each student to share the materials they had collected, they used the photo and note screens on their iPads. For photos, students dragged items they wanted to share at the tabletop/whiteboard to the top labelled part of the screen (Figure 5 – top-middle). For written notes, they pressed the '>' button (Figure 6) to open a sub-menu with a transfer option. Each iPad was pre-configured to send content to either the tabletop or whiteboard – not both. The groupware interface supported touch actions to arrange, rotate, and resize the elements. So, as each student shared and talked about their materials, they could move them, making them larger or smaller. Importantly, this phase can be done well if each child takes control of the display as they share their materials.

After sharing materials, students began creating the poster. Figure 7 shows an example of the interface toward the end of the collaborative phase. This shows the full set of tools available; in actual use, most of these were not on the screen at once. There was some flexibility in making the poster. We now describe a typical group sequence.

(1) Students chose a poster background (from the container shown in Figure 7–b).
(2) A student dragged an agreed poster-background to the main screen area. They then often moved the backgrounds-widget into the "black hole" (Figure 7–a) as it was not needed any more.
(3) Students collaborated to agree on the pictures and notes they wanted on the poster, "dragging" these items onto it. Students could also use the application menu, shown in Figure 7–d to bring up additional tools, for creating title boxes, text boxes (similar to a note) and containers. Students dragged them out of the menu for use in the poster. Figure 7–c shows a poster with a title "Animals of the sea!".
(4) During the discussion, students often decided to create new notes. They could do this in two ways: (1) using their iPads to create more notes, potentially working in parallel, and then send them to the screen; or (2) they could type a note directly at the groupware device using the virtual keyboard (Figure 7–e).

This part of the collaboration should involve all group members discussing each step and deciding what the group wants to do. Then the actions on the poster could be done by one student. So the design of this stage should

Fig. 7. User view of the interactive whiteboard/tabletop interface late in the creation of a poster, showing all major interface elements: (a) the black hole – which provides a mechanism to hide items; (b) available poster backgrounds to choose from; (c) a poster in construction; (d) the application menu to activate poster elements (containers, title and text boxes, keyboard and export tool); (e) an on-screen keyboard (from the tool menu); and (f) a text box.

work well with the single-touch whiteboard. One exception to this may occur if the group needs to check through materials that have been hidden; then, there may be minor advantages from parallel action, as supported by the multi-touch tabletop. The MuseWork interface at the tabletop, with its support for easy rotation, is important for supporting collaboration.

In the third stage, the students needed to discuss the common aspects of their chosen animals and create a note, using the methods described above. This stage also should involve whole-group discussion, and then one student could create the note. In summary, our design of both MuseWork interfaces and the tasks took care to ensure that both devices supported the required activity.

4 EVALUATION STUDY DESIGN

We now describe the design of the evaluation of MuseWork. Broadly, this had two major goals, in terms of our research questions:

- **RQ1**: How effectively do device-customised designs of MuseWork enable children to complete their collaborative activity at the *whiteboard and tabletop*?
- **RQ2**: How do the whiteboard and tabletop each affect students' participation, collaboration strategies and engagement?

The first is foundational in that it assesses if MuseWork supports the collaborative phase at both groupware devices. In previous work comparing horizontal and vertical large collaborative displays, this aspect had little attention. The second aims to fill the gap in understanding the ways these devices differentially affect key aspects of the collaboration, particularly for children in our museum setting. To inform these questions, we collected quantitative data from the devices, and qualitative data based upon questionnaires, observations and video-recordings of the groups, as well as analyses of the artefacts they collected and created.

4.1 Participants and Setting

Two visiting school groups to the Australian Museum (located in the Sydney CBD) participated[1] for a total of 67 students. For this research, independent and catholic schools were recruited as part of the 'Search and Discover' school visit program the Museum runs each year – and only those schools where parents, teachers and the principal provided consent were observed. No extra compensation was made to schools for taking part, outside of the broad merit of advancing surface computing and educational research. Of the two schools that provided consent, both were of similar socio-economic ranking (according to the national standardised assessment program).

The first school group had 21 students (ages 10–12, 67% female), and the second had 46 students (ages 11–14, 50% female). The teachers allowed the students to form their own groups. This resulted in all groups being single gender, common for students of this age [65]. This is the type of factor that arises in-the-wild, with the teacher in control. It had the merit that students appeared comfortable with their peers. From the background questionnaire, 10% of the students reported having used a tabletop before (unrelated to this experiment), and all students reported previously having used a touch-capable tablet.

4.2 Apparatus and Data Capture

Twelve iPads were provisioned by the Museum for the individual stage of the activity – 6 configured for each condition. When there were more students than iPads, a device was shared between two. This is a constraint in-the-wild, with the need for adaptation, due to limited resources. This happened for one pair of the groups with 7 students in each condition. The whiteboard was a 60-inch LCD-based *SMART Board*, with *DViT* technology for sensing touches. While this hardware accepts up to two concurrent touches, we found the accuracy of two concurrent touches to be unsatisfactory (this anomaly was found during application testing with the museum staff before MuseWork was used by students). Thus the SMART Board operated as a single-touch device (which it could do accurately and predictably). The tabletop had a 46-inch multi-touch screen (capable of sensing up to 32 concurrent touches), with a widescreen resolution of 1080p. The tabletop enclosure had a 10cm rim, where students could place the iPads. The tabletop was at a standing height suitable for the students.

The main task was video-recorded at each display. In addition, MuseWork was configured to log all interface actions. During the tasks, two experimenters took notes using pre-defined criteria: task timing, student positioning (at the table/wall, away but still engaged, away and disengaged), the use of the iPads during the collaborative activity, and interface conflicts.

4.3 Experimental Design and Procedure

A between-subjects design was dictated by time constraints for each school visit. Table 3 summarises the approximate timing of the phases of the MuseWork activity. Upon arrival, students gathered in the main activity room and were welcomed by the Learning Services staff, who explained the activity. The students were given tablets to use for the self-guided activity. The tablets had a flap case, in either red or black (the colour was later used to group students at the tabletop or whiteboard). The activity sheet, preloaded on the tablets (Figure 4), asked students to explore a specific gallery and collect photos and notes to answer a set of questions, with each student selecting an animal, and collecting details of its habitat, prey or predators. The experimenters gave a short tutorial on each part of the iPad application, using sample images and notes from an unrelated gallery. The

[1]Ethics Protocol 12560 – Collaborative tabletop file system access in pervasive computing environments.

Table 3. Timing plan for visiting school groups.

Start	Duration	Activity
00:00	5 mins	General introduction, task overview and tutorial for the iPad interface.
05:00	20 mins	Individual gallery activity.
25:00	5 mins	Interactive display interface tutorial, and reminder overview of this part of the task.
30:00	20 mins	Collaborative practical activity on the interactive display.
50:00	10 mins	Background and post-experiment questionnaires.

students tried each feature, to ensure understanding before starting the activity: viewing the worksheet; taking a new photo; giving a photo a title; deleting a photo; writing a new note; editing a note; and deleting a note.

Next, students spent approximately 20 minutes exploring the gallery capturing information for the worksheet tasks. They then returned to the main activity room, splitting into two groups, whiteboard and tabletop, at opposite ends of the room. The experimenter at each device gave an interface tutorial, with students trying out each introduced feature. The tutorials were similar at each device. But groups at the whiteboard were told to use only one finger at a time and they were taught a combined rotate and resize gesture for enlarging and rotating images. On the tabletop, a 2-finger 'pinch' and 'rotate' gesture was demonstrated instead. At the end of the tutorial, the interface was reset, ready for the main group activity.

The experimenter instructed students when to begin the poster creation activity. While students completed the activity, experimenters stood slightly away, writing observations on an experiment sheet. The class teacher split their time between groups. As described in the learner view of MuseWork, this had three stages: sharing materials; creating the poster; and adding the reflective note about what their animals had in common. The experimenter announced each stage, to ensure students moved on, but allowed them to finish the current one. At the end of the activity, the experimenter saved the poster to send back to the school and for later use.

The background questionnaire gathered demographic information (age, gender) and past computer experience, as the mean number of hours per week of computer use, and previous smartphone/tablet experience. The post-experiment questionnaire had 6 closed questions on a 7-point (Likert style) rating scale, each with space below for a comment. These asked about: the group's sharing of the display and ability to work without interrupting each other; awareness of other group members' actions while using the interface condition; enjoyment, general usability, and learnability of the interface; and satisfaction with the outcome (i.e. the created poster). Three additional open questions asked which aspects the student liked, disliked, and any other general comments.

5 RESULTS AND ANALYSIS

For Research Question 1 (RQ1), whether both conditions enabled the children to complete the collaborative task effectively, we looked at three areas: task achievement; interface use, and student feedback. *Task achievement* analysed the *final product*, the posters, to determine whether the children completed the worksheet as instructed, and how well. This was based on the log data and video. *Interface use* utilised observations and video. Finally, RQ1 was informed by *student feedback* collected via pre and post-experiment questionnaires.

For Research Question 2 (RQ2), exploring how the whiteboard and tabletop each affected students' collaboration, one of the important aspects is the degree to which students remained engaged and how this related to the ways they worked at each device. We studied *physical participation*, using logged details of touches at each device as well as analysis of the video to gain a qualitative understanding. To gain insights about the opposite phenomenon, *disengagement from the group activity*, we used a combination of observations and post-hoc analysis of the video. Complementing understanding of participation and disengagement, we analysed *how students arranged themselves* at the devices. Finally, *student feedback* (via questionnaires) informed this research question.

5.1 Task Achievement

Literature on small groups indicates that high levels of collaboration do *not always* correlate with the production of high quality outcomes [11]. Even so, it is important to consider the final product. Table 4 shows whether the final poster met the *worksheet criteria* of at least one key animal, its name and habitat and whether there was another animal (prey or predator) with its name. Three quarters of the groups met the criteria.

Rows in grey mark groups that failed to meet more than one worksheet criterion. All 3 of these, were tabletop groups, with just 2 of the 6 tabletop posters meeting all the criteria. By contrast, 5 out of 6 whiteboard posters met all criteria and the 6th met all but one. Of course, this must be interpreted by taking account of the materials that group members had collected on their iPads. The table shows a superscript annotation where one of the iPads had photos or notes to meet the objectives but the group failed to use these for the poster – the case for 2 groups: S1-G3 (WB) which had a photo of a predator on an iPad; and S1-G4 (TT) which had 2 relevant (detailed) notes on an iPad. The last two columns of the table indicate another aspect of the quality of the posters in terms of the number of relevant images and detailed notes. These columns indicate that groups with no detailed notes also failed to meet 3 of the 5 criteria. No individual school effects were found.

We explored possible gender effects since the work of Harris et al. [26] indicates female groups have more on-task discussion and more equitable participation at a single touch interactive display, and Underwood et al. [64] reports girls tend to be more sociable when working together, regardless of whether they are told to co-operate or not. We do not see any clear effects. For the single-touch whiteboard, our qualitative analysis shows similar outcomes for boys and girls. For the broader collaboration aspects, we see that 2 of the 3 groups (S2-G1, S2-G6) marked in grey were boys. Both these groups failed to collect the materials needed and they also failed to write any detailed notes during the collaboration. There is a different picture for the one weak female tabletop group.

Table 4. Assessment of posters on worksheet criteria. Rows shaded grey indicate > 1 failed criteria.

School/ Group	SDG/ Gender		Group Size	Base Animal			Prey/Predator		Relevant Images	Detailed Notes
				Photo	*Name*	*Habitat*	*Photo*	*Name*		
S1-G1	TT	M	4	✓	✓	✓	✓	✓	6	6
S1-G2	WB	M	3	✓	✓	✓	✓	✓	3	1
S1-G3	WB	F	7	✓	✓	✓	✗[1]	✓	4	4
S1-G4	TT	F	7	✓	✓	✗[1]	✗	✗[1]	3	0
S2-G1	TT	M	6	✓	✓	✗	✗	✗	5	0
S2-G2	WB	F	6	✓	✓	✓	✓	✓	2	3
S2-G3	TT	M	5	✓	✓	✗	✓	✓	5	3
S2-G4	WB	F	6	✓	✓	✓	✓	✓	4	5
S2-G5	WB	M	6	✓	✓	✓	✓	✓	4	3
S2-G6	TT	M	6	✓	✓	✗	✗	✗	4	0
S2-G7	WB	F	5	✓	✓	✓	✓	✓	3	5
S2-G8	TT	F	6	✓	✓	✓	✓	✓	6	5

[1]Elements present on the iPads, but did not make their way to the final poster produced by the group.

It had 7 girls (S1-G4) and there appears to be failure of communication since they had actually collected materials for 2 more of the criteria. This group also failed to produce any detailed notes on their final poster.

Main Finding: *Less task completion was observed at the tabletop, even with evidence that material was collected during the information gathering phase for all groups. No gender effects or individual schools effects were found.*

5.2 Physical Participation, Collaboration Strategies and Engagement

Table 5 summarises key results for this section (tabletop groups shown in blue), with the following areas examined: analysis of number of touches; analysis of overall engagement and play; teacher involvement; management of clutter and text entry; formation around the display and sub-groups; and sitting out.

Analysis of the Number of Touches

We expected the single touch WB to have fewer touches than the multi-touch TT. We hoped that larger groups would average fewer touches per student as the task design did not call for parallel work. The second block in Table 5 (*'Duration, Total Touches, Touches Per Min, Touches Per Min/Per User'*) shows counts of all touches that manipulated an object (e.g. move, rotate, resize). The *touches per min* row indicates rate of activity. This ranged from 74.31–102 touches per minute for the tabletop groups, and the much lower range, 20.31–42.72, for the whiteboard groups. On average, the tabletop groups had 15.2 touches per minute per student (SD 2.74) far more than the whiteboard average of 6.1 (SD 2.86), a statistically significant difference (two-tailed p = 0.0004). As

Table 5. Summary of log and video data (*TT–Tabletop, WB–Whiteboard*). Columns in blue were performed at the Tabletop.

Data / Groups	***S1-G1 (TT)***	***S1-G2 (WB)***	***S1-G3 (WB)***	***S1-G4 (TT)***	***S2-G1 (TT)***	***S2-G2 (WB)***	***S2-G3 (TT)***	***S2-G4 (WB)***	***S2-G5 (WB)***	***S2-G6 (TT)***	***S2-G7 (WB)***	***S2-G8 (TT)***
Size/Gender	4 (M)	3 (M)	7 (F)	7 (F)	6 (M)	6 (F)	5 (M)	6 (F)	6 (M)	6 (M)	5 (F)	6 (F)
Ages	12	11-12	10-12	11-12	13	13	13–14	12–13	12–13	13–14	13–14	12–14
Satisfactory Poster[1]	✓	✓	✓	✗	✗	✓	✓	✓	✓	✗	✓	✓
Duration	14:59	14:18	09:48	12:48	14:02	17:08	13:39	15:24	14:40	13:25	17:31	17:30
Total Touches	1142	508	199	1119	1069	732	1201	445	389	997	475	1778
Touches Per Min	76.22	35.52	20.31	87	76.18	42.72	88	28.9	26.52	74.31	27.12	102
Touches Per Min/Per User	19.05	11.84	2.9	12.49	12.7	7.12	17.6	4.82	4.42	12.39	5.42	16.93
Engaged/Play	E	E	E	P	E	E	E	E	E	E	E	E/P
Teacher Involvement[2]	-	-	-	T	T	-	-	M	C	C	-	C
Strategies for Clutter	-	-	-	-	-	✓	✓	✓	-	-	-	-
iPads for Notes[3]	✓	-	-	-	-	✓	-	✓	✓	-	-	-
Formation[4]	A	AB	BC	A	AB	BC	A	BC	BC	A	BAC	AB
(ATDISP) *% at TT/WB (avg)*	89%	66%	23%	91%	71%	50%	96%	32%	32%	98%	41%	95%
(AWDISP) *% away (avg)*	11%	34%	51%	9%	29%	30%	4%	67%	51%	2%	49%	5%
(SITOUT) *% sitting-out (avg)*	0%	0%	26%	0%	0%	20%	0%	1%	17%	0%	10%	0%

[1]The final poster met all but one of the specified worksheet criteria.
[2]Teacher role: T – encourage the group to get on task, C – observe and check, M – major involvement.
[3]Complementary use of the iPads for text entry in the collaborative phase.
[4]Formations: (A) all students at the display; (B) some away from the screen; (C) some students behind others – an obstructed view.

discussed in the description of MuseWork, the interface and task design could be achieved with single touch. The strikingly larger number of touches at the tabletop is potentially an indicator of off-task activity.

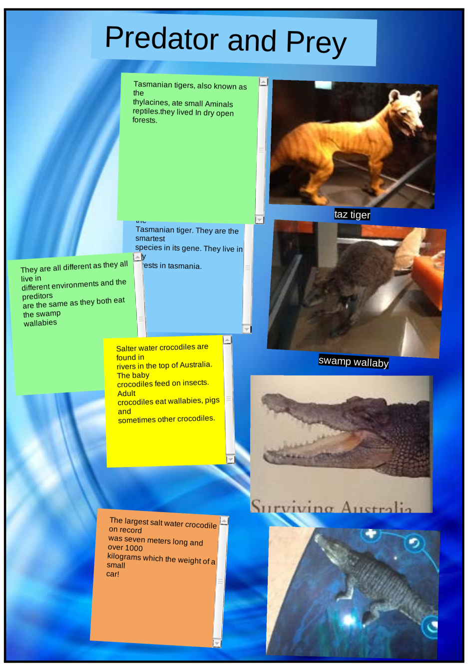
As we had somewhat expected, group size negatively correlated with touches per student. The 3-student groups, S1-G1 (TT) and S1-G2 (WB), had the highest touches per student. The 11.84 average for S1-G2 (WB) is similar to three of the larger tabletop groups: S1-G4, S2-G1, S2-G6. The groups of 7 students: S1-G3 (WB) and S1-G4 (TT), had low touches per student (S1-G3 was the lowest of any trial, while S1-G4 had the second lowest).

Main Finding: *Results show high levels of activity in both conditions and are in line with expectations of lower counts for the single-touch WB and in line with the task design (touches per student dropped as group size increased).*

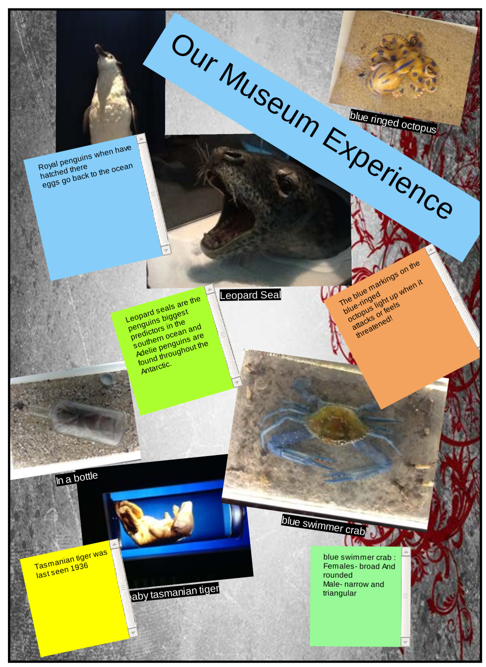
Analysis of Overall Engagement and Play

Our observations recorded that groups invested genuine effort in assembling their posters (for example, those in Figure 8), taking care to select appropriate backgrounds, colours for notes, and arranging collected information to address required tasks. However, we also observed some play (coded in Table 5 as *'Engaged/Play')*, indicating if the group, as a whole, was engaged throughout or if, they instead had significant off-task activity or play. Most groups were engaged. The one exception was S1-G4 (TT), a group of 7 girls at the tabletop with a weak final poster. They had an initial period of team discussion. Then they became distracted, taking photos of themselves. A quite different case held for S2-G8 (TT), a group 6 girls who completed their poster before the time available (meeting all criteria and producing 5 detailed notes) and then they played in the free time.

Main Finding: *All groups, but S1-G4 (TT) were engaged in the task (S1-G4 did not satisfy the worksheet criteria).*



(a) Poster created by S2-G4 (WB)



(b) Poster created by S2-G8 (TT)

Fig. 8. Two representative posters, one at the whiteboard (left), the other at the tabletop (right).

Teacher Involvement

The students were accompanied by one or more class teachers. The observers recorded their interactions with the students. The teachers mainly tracked the children but there were some cases of involvement (Table 5 – *'Teacher Involvement'*). Some actions were to *help students stay on task* – the case for 2 of the 3 tabletop groups (S1-G4 and S2-G1) with weak posters. A teacher also *checked in* on tabletop groups S2-G6 and S2-G8 and whiteboard group S2-G5 (however, these involvements were minor). For one group, S2-G4 (WB), though, a teacher took a *major role*, staying with this group of 6 girls throughout the session. We take this into account in the results below.

Main Finding: *For half of the groups, the teacher intervened in some form, providing aid or further support.*

Management of Clutter and Text Entry

One focus of ours was to assess how students managed clutter, since this is a known problem for large collaborative displays [59]. As summarised in Table 5 (*'Strategies for Clutter'*), three groups, S2-G2 (WB), S2-G3 (TT), and S2-G4 (WB), adopted strategies to carefully arrange materials on the display to support their discussions. For example, S2-G4, a whiteboard group, arranged all their collected material on the left and right sides of the display, with the poster background in the middle to mitigate occlusion issues. In contrast, quite a few groups made the poster very large, filling much of the screen, with some materials obscured until the poster was moved out of the way.

Another known problem for large displays is text entry [2]. Both interfaces could support multiple keyboards but the keyboard needed to be quite large for effective typing, and at the tabletop this often meant protruding into another students' personal work area. The single-touch whiteboard meant text entry stopped other activity, which we observed to help focus the attention of the group on this task. This happened for 5 of the 6 whiteboard groups when choosing their poster title (all but the 7-student group, S1-G3). Further, we noticed 4 groups (one tabletop group – S1-G1, and three whiteboard groups – S2-G2, S2-G4 and S2-G5) tackled the problems of text entry at the display by using iPads to type notes during the collaborative phase (*see: Table 5 – 'iPads for Notes'*).

Main Finding: *A quarter of the groups engaged in clutter minimisation strategies; and a third of the groups used the iPads as a complimentary device to input text during the collaborative stage with the interactive surfaces.*

Formation Around the Display and Sub-Groups

We now move to the analyses of how the students organised themselves during the collaboration. Table 5 – *Formation* summarises the three categories we observed: all students at the display (A); some students away from the screen but still involved (B); and some students behind others, with obstructed access and view (C). For the tabletop, all groups had most of the time at the display (A), with just S2-G1 and S2-G8 having some time away (B), and no cases of view obstructions (C). For the whiteboard, most groups alternated between having some students away from the screen, but with still a clear view (B) and some students behind others, in layers (C). The smallest whiteboard group of 3 had much of their time in arrangement A (all at the display), as did a larger group (S2-G7) with 5 girls spending much of their time standing in a row. This meant that all whiteboard groups adopted collaboration strategies where part of the time students were away from the display.

We analysed the ways in which students broke into subgroups. For the whiteboard and tabletop, very different working styles emerged. In WB groups, all but one group (S1-G2, a group of 3 males) split into subgroups of 2-3 students each. For example, in S1-G3 (WB), the team of 7 girls split into 3 subgroups of size 2, 2 and 3. These sub-groups coordinated having direct interaction with the whiteboard, ensuring each person contributed to the poster. This meant they were often in layers near the whiteboard, with the teams not directly in front of the whiteboard, often using an iPad to write detailed notes, or the team discussing what to do next – thus finding ways to work in parallel. Much task focused discussion was observed within the sub-groups.

For tabletop groups, no subgroups were observed. Rather, we saw more parallel and independent activity. Although tabletop groups did not seem to form smaller groups, they faced challenges in co-ordination. For example, S1-G4 (TT), a group of 7 girls at the tabletop, spent time discussing who should do what, with comments such as "let's take turns touching", and even voting on what to do (though they did eventually move onto playful behaviour); and S2-G3, 5 males at the tabletop, worked as a team to keep on topic – when a student suggested off-topic conversation, the rest of the group kept that person on-track.

Main Finding: *Students at the whiteboard broke into subgroups, either due: to space issues (i.e. not all could comfortably fit in-front of the screen); or to work in complimentary ways toward goal achievement. In contrast, the tabletop with its larger direct interaction surface, did not motivate the need for groups to split into smaller sub-groups.*

Sitting Out

All videos were coded by a single experimenter; with half coded by a second experimenter to check coding consistency (*Table 5 – bottom-most block*). The coding included:

- *ATDISP* – number of students at the display and able to reach the screen;
- *AWDISP* – engaged in the task but standing back from the display and letting other users interact;
- *SITOUT* – sitting out of the activity (away from the display) and not participating (disengaged).

These measures aimed to measure — over the whole experiment — how many students were: at the display and engaged; standing back and watching; or having at least one student sitting-out completely. This approach was feasible in our in-the-wild context as it only required the observer to carefully observe those students who were away from the display, so as to determine whether they were disengaged. The *sitting-out* tallies indicate students being disengaged from the activity. There were striking differences for the two conditions. All tabletop groups had 0% *sitting-out* events. By contrast, the whiteboard average at 12.3% (SD 9.5%) sitting-out, was statistically significant ($p = 0.035$). Only the 3-student group S1-G2 had no sitting out. We now discuss the observations around the other 5 (whiteboard) groups, starting with those with the highest levels down to the least.

In S1-G3 — a group of 7 of the youngest girls (26% sitting out) — there were striking coordination problems in the first half of the activity. Students reached over each other, trying to move items, with many touch conflicts. Although no individuals dominated the workspace, we observed frustration. For example, one participant started the activity at the WB, then gradually moved back and lost interest after 3 minutes. She later returned to the WB when it was not crowded, but only used it for 1 minute while the others were talking. Her questionnaire confirmed her frustration: "people hogged it." Similarly, another girl tried to participate initially, but withdrew and sat out once the WB became full. This group of 7 could not find effective collaboration strategies at the single-touch WB.

Similarly, S2-G2 (20% sitting out) had 6 girls who stood very close to each other, frequently reaching over each other early on, then some girls gradually stood back, sat down and did not pay attention to the activity. Here, 4 girls stayed at the screen for much of the time, and in the last 7 minutes were the only ones still participating.

S2-G5 had 6 boys (17% sitting-out), with one student particularly dominant — he stood in the centre and rarely stopped touching throughout the activity. This made it difficult for others to use the display. The dominating student had positive responses in his questionnaire — he thought his group was effective at sharing the display. Notably, this group had the second lowest average number of students at the display (32%) during the activity.

S2-G7 had just 10% sitting out. They were careful in how they shared the display. This was the only WB group where all five students shared the display at a time. Although the total time where the WB was shared between four or more students was just 64 seconds, it happened in key discussion stages, with all group members careful to include everyone to decide on what to do. This group had no teacher intervention but adopted successful strategies, including use of the iPad for creating notes. This group spontaneously found effective ways to collaborate throughout the session, producing a coherent well-formed poster, that met the worksheet criteria.

S2-G4 had the lowest level of students sitting out (at 1%). As we have noted, this was the only group that had a teacher present throughout. They provide a case study of the ways that guidance in collaboration can help. They demonstrated strong teamwork. For example, one student who could not fit around the display stood aside with her iPad and wrote additional notes for the group. Two other students periodically worked with her while others were using the WB. Thus, students who were waiting their turn were still actively contributing. There was also a frequent rotation of students at the display, providing interaction opportunities to those standing back.

Main Finding: *The results highlight the challenges this age has in collaboration, particularly in dealing with dominant students. We saw that the single-touch and limited space at the whiteboard tended to spur students to split into subgroups and make use of the iPads as well as the display. However, the spontaneous and effective management strategies of S2-G7 and the teacher-aided effective work of S2-G4 suggest that the whiteboard can be used effectively with groups of this size (5+ students) doing a series of collaborative subtasks to create an effective poster.*

5.3 Student Feedback

Table 6 reports the post-experiment questionnaire, with responses overall very positive. While this may be partly due to the novelty effect of the interfaces, it also supports RQ1, the perceived effectiveness of MuseWork. Responses were closely matched in both conditions, with no statistically significant difference. Students were particularly positive on Q6 *(enjoyment in the task)*. Although differences in scores across conditions did not reach significance, the tabletop scores are high for all but Q1 (which refers to only loading materials from the iPad).

The response for Q3 *(ability to share the TT/WB without interrupting each other)*, had the lowest mean and highest standard deviation. It was the only question to record *strongly disagree* responses – partly from those who sat out of the experiment or felt excluded. For the whiteboard, all groups with 4 or more students, had 1–4 students who were unhappy with the sharing of the display. Students supported their rating with additional information, e.g. *"everyone wanted to do their own thing and didn't share well, they just wanted to do it themselves"*. Eight of the 33 whiteboard students commented on issues of sharing, ranging from annoyance – *"When two people touch the screen the wrong object would move and others were getting frustrated" (S2-G2)* to inconvenience – *"We sometimes got in each others way and forgot that only one person could go at a time" (S2-G4)*. Although responses were more positive for the tabletop, 4 students made a similar comment – *"many people wanted to be the lead person and take control" (S2-G3)*; and *"it was a bit crowded" (S1-G4)*.

For the final poster, high levels of satisfaction were noted in the comments from the students, such as – *"I was stunned with what we made with our photos," (S2-G3 (TT))* and *"the poster looked really good and we all agreed on its setup" (S2-G3 (TT))*, although some remarked that the posters were a little messy at times (e.g. Figure 8b).

We asked an open response question about the most positive/negative aspects of the experience. Positive responses were balanced across conditions, with comments such as "fun", and "easy to use". Students at the whiteboard made comments like – *"easy to figure out how to use it" (S2-G2)*, and that it was – *"a creative way to get info through. Interaction [was] great!" (S2-G2)*. The negative responses referred to a lack of multi-touch at the

Table 6. Post-Experiment Questionnaire Results – Mean and SD (Rating scale: 1–7, with a 7 being 'strongest agreement').

Question	Tabletop	Whiteboard
Q1: I was able to easily load information from the iPad onto the tabletop/whiteboard.	5.93 (1.00)	6.24 (0.95)
Q2: I was able to easily organise the objects on the tabletop/whiteboard to my liking.	5.39 (1.08)	5.12 (1.61)
Q3: I was able to effectively share the tabletop/whiteboard and not interrupt each other or get in each other's way.	4.68 (1.28)	4.12 (1.65)
Q4: I was aware what my group members were doing through the task.	5.79 (1.15)	5.39 (1.52)
Q5: I was satisfied with the outcome of my group's work at the tabletop/whiteboard.	5.63 (0.87)	5.34 (1.51)
Q6: I enjoyed using the tabletop/whiteboard for the tasks.	6.39 (0.94)	6.06 (1.46)

whiteboard (24% of students made explicit mention of this) with comments like – *"it would have been good to have more people able to use and type information" (S2-G4)*. For the tabletop, students commented – *"it was easy to [physically] move around the tabletop" (S2-G3)* and *"it was very quick, and easy/simple to use. I liked how you could easily make things smaller/bigger, change the colour, and transport things quickly" (S2-G8)*.

Main Finding: *Sharing was a problem among students at both devices, with some feelings of exclusion at the whiteboard. It appears some students needed more guidance and orchestration to help spur collaboration in the activity.*

6 DISCUSSION AND KEY INSIGHTS

We set out to design MuseWork to support inquiry learning, based on a museum worksheet, followed by a collaborative learning activity at either a single-touch whiteboard or a multi-touch tabletop. Our first research question was to assess whether school children visiting the museum could use MuseWork effectively to do these activities. Our results, based on observations, analyses of videos, data logs, the children's work and questionnaire responses indicate that it was successful for both conditions. This was a foundation for considering the second research question about the ways that the whiteboard and tabletop each affect students' participation, collaboration strategies and engagement. In the next subsections we summarise our main findings, then the key lessons learned and their implications as well as limitations of our study.

Our results are based on the analysis of task performance and processes, including participation levels, disengagement, and strategies the children adopted. The main findings are:

- On the whole, MuseWork proved effective.
- More whiteboard groups produced strong posters.
- More whiteboard groups made use of the iPads for text entry in the collaborative phase.
- Only whiteboard groups tended to split into highly visible subgroups.
- The single touch of the whiteboard may have reduced off-task activity compared with the tabletop.
- There were higher levels of sitting out in the whiteboard groups (no such cases at the tabletop).
- More parallel and independent (non-group) activity at the tabletop.
- Children had positive feedback about both the whiteboard and tabletop (with a slight preference for the tabletop, with complaints about the whiteboard, primarily due to single touch).

6.1 Lessons Learned

As our review of the related work highlighted, the previous comparisons of groups working at horizontal and vertical interfaces painted a very incomplete picture. This study adds to that, particularly as it is the first to consider how children collaborate at each of the surfaces. Our main insights come from the *qualitative observations*, particularly the strategies the children spontaneously used. We now discuss these, and consider their implications for the design of future systems. We particularly consider the impact of falling prices and the increasing availability of both tablets and large multi-touch displays. These insights reflect what we learnt about how to help children collaborate at each device type. The following are our insights:

- ***Several groups found successful management strategies at the single-touch whiteboard***
  Most of the whiteboard groups avoided standing in front of one another for most, or all of the time. For example, some stood in a slightly curved arc in front of the whiteboard. Several groups formed sub-groups that worked effectively. Most of the time, children co-ordinated well to take turns to control the whiteboard. We did not teach these strategies, yet several groups adopted them for much of the time. In the future, there could be explicit teaching of such skills, and the system design (for both the whiteboard and tabletop) could further encourage students by explicitly directing them to follow a script [9, 23, 42, 66]. For the vertical display, this is easier for a teacher to monitor at a glance.

- ***Students worked out they could use tablets for text entry at the large display – tablets could support personalisation and accountability***
  We had not anticipated this (or encouraged students to do it). Yet four groups did this spontaneously (three at the whiteboard). With the steadily decreasing cost of tablets, we envisage that soon children could bring their personally owned tablet for use at the shared display. This would go beyond the uses we observed for text entry. For example, the large display materials could be tagged to show the author, enabling the children and their teacher to readily see whose work was used in the poster.
- ***The tablets could help children track content they have used***
  Some groups that produced weaker posters failed to use relevant content on the tablets. Future interfaces could help children explicitly consider all such content in the sharing phase. There is also potential for other personalised interventions, targeted to both the group and the individual (such as in [41]).
- ***The multi-touch tabletop resulted in some off-task parallel, independent activity***
  This observation is similar to Birnholtz et al. [3], who found that participants sharing a large display, with multiple inputs, tend to act independently, rather than keeping to the group task and goals. In a tabletop classroom, Kharrufa et al. [31] also reported off-task behaviour. When children found the single-touch vertical display frustrating, some sat out; this is highly visible to a teacher where off-task multi-touch activity is less so. As multi-touch displays become more widely available, we should explore restricting interaction at multi-touch displays, at least in periods when only one student at a time is intended to act on the surface.
- ***Lessons from observing children ... for adults***
  Ours is the first work to study *children* collaborating at the single-touch vertical and multi-touch horizontal displays. We believe that the failures we saw, in collaboration and staying on task, were more pronounced than we would have seen for adults. Collaboration is challenging – even for adults. But children have had less opportunity to build collaboration skills. So the lessons above may well hold for adults who may also benefit from mechanisms for greater accountability and support for structure.
- ***MuseWork as a class-group enquiry and consolidation activity***
  Most of the groups did well on the full set of the MuseWork activities, collecting materials for the worksheet, then collaborating to share them and create their poster, ready to send to the school. While many museums have large interactive displays for use by the public, MuseWork, with pedagogic theory grounding the design of both inquiry and collaborative learning is one model for future class groups in museums.
- ***Teacher involvement should be supported***
  In half of the groups, a teacher intervened, sometimes to keep the group on task, or to observe and encourage children. As described above, making contributions identifiable could make it easier for the teacher to monitor a group. For example, utilising the information at the displays to supply an awareness dashboard on different aspects of the group process (such as in [32, 43, 46]). This can have the advantage of helping a teacher decide how to regulate and adapt activities according to the state of the group; as well as potentially alert the teacher to when a group needs attention. Whilst studying teacher interventions was not the focus of our research, this is a direction for future work.

Broadly, our work indicates that both the single-touch whiteboard and multi-touch tabletop were mainly used effectively in our museum setting. Our lessons indicate that both could be even more effective, especially with richer use of personal tablets, additional guidance and scaffolding for collaboration, and accountability of contributions.

6.2 Limitations and Generalisability

Our study design aimed to enable us to study the children in an actual school museum visit. Our findings contribute to understanding about the ways children can make use of large screen displays as part of a rich collaborative learning activity. This adds to the literature on children collaborating at multi-touch displays [12, 39, 41]. It also contributes to the work comparing horizontal and vertical displays we reviewed.

Our between-groups study design was a forced choice because of the time constraints on school visits. It is unclear that a within-groups study would be stronger because of the deeply complex nature of the full MuseWork activity, particularly the collaborative phase, and particularly for children, who can be expected to have room for growth in collaboration skills. More generally, the in-the-wild study constitutes a trade-off. It gives greater authenticity about this class group museum activity. But this also introduces constraints and confounds, particularly in terms of the timing, the need to link to the state syllabus and the teacher's role and the potential impact of classroom activities before the museum. In addition, there were restrictions that influenced design decisions for MuseWork and the study, where the study had to fit with the goals of the museum, as well as their hardware, with an existing interactive whiteboard for regular group-use, 12 iPads, and a space for our tabletop.

7 CONCLUSION

Our work provides insights about the ways school children in groups of 3–7 collaborated at the different interactive displays. The whiteboards resulted in students forming subgroups, making more use of the iPads and producing consistently higher quality results. These are new results. This is because of the limited work comparing such displays and none about children collaborating at these two important types of large display interfaces. Even for the studies involving adults, using digital whiteboards, only Mi et al. [48] considered large groups (6 people), but in their set of 5 groups, the main observations were about whiteboard groups standing in layers.

Our comparative study of collaboration at the single-touch whiteboard and the multi-touch tabletop, highlights that a system, like MuseWork, that is carefully designed to take account of the affordances and limitations of each, can be effective at either class of display. With large screen displays already widely available, especially in learning settings, our findings can inform the design of systems like MuseWork that provide rich learning based on enquiry and consolidating collaborative learning. As multi-touch large screens are becoming cheaper, our observations of more off-task activity and independent activity highlight the need to find ways to improve collaboration. Our study also demonstrates that most groups, with up to 7 children, could complete the MuseWork learning activity work at each device – though, we found this group size is already quite large.

Overall, our work provides a foundation for further exploration of a number of research strands. It points to the promise of future approaches based on personal tablets – some groups spontaneously adopted them in ways we had not expected. Falling hardware prices for tablets open the way for new forms of support for collaboration, based on personalisation and scaffolding collaboration. This could support student awareness of their progress and contributions, and this could also be available to teachers. Our work contributes to the understanding of the ways that large displays can support collaboration.

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