HARNESSING THE AFFORDANCES OF INTERACTIVE TABLETOPS FOR COLLABORATIVE ACTIVITIES

A thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy in the School of Information Technologies at The University of Sydney

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Abstract

Interactive tabletops are large digital horizontal surfaces, often multi-touch, and due to their size, likely to be integrated and embedded in their surrounding physical environment. This form of single display groupware can provide new forms of support for collocated individuals to work together. Tabletops combine a natural around-the-table setting, encourage face-to-face awareness, with support to work with digital information. These devices unlock new ways to enable small-group work and collaboration.

Currently, relatively little is known about the potential roles of interactive tabletops and whether they can effectively support diverse and rich group-based activities. Notably, there are gaps in understanding their effectiveness compared with other single display groupware, such as widely available interactive whiteboards. This is particularly the case for groups of three or more, where issues of orientation and layout at the table start to become a challenge.

This thesis aims to gain an understanding of the place and the role of interactive tabletops for supporting small-group activities. This thesis uses brainstorming as the main activity to study the effectiveness of the tabletop. Brainstorming is well-known and draws on different forms of group-work. It consists of two phases. The first is a rich divergent ideation stage guided by four principles: defer judgment, aim for quantity, verbalise and swiftly record ideas, and spark ideas from one another. The second aspect of brainstorming consists of a convergent categorisation and organisation phase. Generated ideas are evaluated, merged and any duplicates removed. Brainstorming harnesses the power of group collaboration when effectively done. However, as with many activities, people may fail to follow recommended practice – intentionally or not. Brainstorming thus provides a useful activity to explore how an interactive tabletop can support several different and interesting collaborative group processes. This thesis reports my exploration of how to support effective small-group collaboration at the tabletop. It presents this in two parts.

Part 1 reports on three chapters that explore rich collaboration with interactive tabletops and how they are used for small-group collaboration. Part 1 aims to gain insights into the ways a tabletop is used compared with alternative ways to do the same activity. A series of novel prototypes are designed, built and evaluated. Chapter 3 compares a tabletop with a non-digital whiteboard, with adults brainstorming in a lab setting. Chapter 4 compares a tabletop to both an interactive vertical display and an index cards setup. This study is part of a university design class for students learning how to brainstorm. Chapter 5 compares a tabletop with an interactive whiteboard as part of a museum visit by children, where children collect content using tablets and then come together to build a shared poster at the groupware devices.

Part 2 reports on two chapters that explore ways to scaffold collaboration at the tabletop. This is motivated by the studies in Chapters 3 and 5 from Part 1, which brought to light coordination issues and non-compliance with methods that people were instructed to use. Chapter 6 addresses this through the use of computer supported collaborative scripts through two lenses: facilitator-led, through the prescription of recommended practice; and team-led, through negotiation, discussion and debate. The chapter also explores support for reflection – using open learner models. Chapter 7 explores the use of a multi-session tabletop classroom. It focuses on the mechanisms required to support the needs of individual students, the group, and teachers. It deploys laboratory based prototypes to the wild, highlighting the challenges of complex longer term authentic studies.

The contributions of this thesis are: a greater understanding of how tabletop affordances can be harnessed to support small-group work and collaboration, the effectiveness of tabletops versus other forms of single display groupware, the role of computer-supported collaborative scripts, and validation of the work in real settings.
Acknowledgements

First and foremost, I wish to give my utmost thanks and appreciation to my supervisor Professor Judy Kay. This thesis would not have been possible without her keen insight and dedication. Throughout the years I have been privileged to be guided by such a thorough and attentive mentor. The result of which has led me to become both a strong problem solver and researcher. Her perseverance, enthusiasm, and patience is unmatched. Each step along the way, I was given the freedom to explore directions of my own choosing, with guidance and advice provided as needed. Her refreshingly positive outlook and grounding in real-world relevance have always been welcome, particularly with some of my more ambitious research proposals, experiments and undertakings.

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I would like to thank the developers from the Kivy community project (Virbel et al., 2011). This was a framework I ultimately built many of my applications on top of. It was an interesting tool to learn whilst simultaneously acclimatising to the Python programming language. The architecture was straightforward, which enabled me to rapidly prototype design concepts and associated tools.

I would also like to thank those not specifically mentioned by name, but who contributed to various peer-reviewed papers, either helping run experiments, interpreting results or proof-reading contributions. Additionally, I would like to thank those I met within the Computer Human Adapted Interaction (CHAI) Research Lab, the administrative team and the technical staff within the School of IT. Without the workshop staff and duty programmers, many of the studies would not have been possible, especially with moving large equipment and helping outfit experimental laboratory spaces.

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Overall, the thesis took a number of different directions over the years. It was not what I imagined when I first started. It has been a simulating and thoroughly rewarding journey. I have met many interesting people and have had many interesting experiences due to it. Thank you all!
Preface & Notes

Relevant Publications During Candidature

Peer-Reviewed Journal Papers


Peer-Reviewed Conference Papers


**Peer-Reviewed Posters**


**Peer-Reviewed Workshop Papers**


2. **A. Clayphan** (2013). “Scripting at the tabletop to improve collaboration”. In: *Workshop on Intelligent Support for Learning in Groups (ISLG 2013) at International Conference on Artificial Intelligence in Education (AIED 2013).*

3. R. Martinez-Maldonado, **A. Clayphan**, J.Kay (2013). “Towards the Integration of Collaboration Analytics and Interactive Surfaces”. In: *Workshop on Collaboration meets Interactive Surfaces at International Conference on Tabletops and Surfaces (ITS 2013).*


Peer-Reviewed Doctorial Symposium Papers


Peer-Reviewed Conference Symposia


Technical Reports


Sources & Original Work

This thesis describes the original work of the author. Any work or contribution that is not solely owned by the author is clearly marked and acknowledgement is given as appropriate. Original material arising from publications are cited within each chapter. The ‘Firestorm’, ‘ScriptStorm’ ‘ScriptStorm (Reflect)’ and ‘ScriptStorm (Classroom)’ systems were developed solely by the author.

Chapter 5 was based on the deployment and evaluation of *MuseWork* (a collaborative poster system) at the Australian Museum with real school groups. MuseWork was developed by Dr. Anthony Collins. My contributions were: jointly running all the evaluations; and later analyses over the data collected.

Chapter 7 was partly built on two classroom frameworks: *MTClassroom* and *MTDashboard*. These were developed by Dr. Roberto Martinez-Maldonado. These frameworks were jointly extended to encompass definable lesson plan workflows. My contributions were: joint design of the lesson plan specification; implementation; evaluation; analysis of results; and discussion of the teacher’s use of the system.

Human Ethics Considerations

All studies described were conducted with full adherence to the human ethics committee provisions. The most updated participant information statements, consent forms, questionnaires and related documentation can be requested by email.\(^1\) The following ethics protocols were used:

- Collaborative tabletop file system access in pervasive computing environments, (*Protocol No: 12560, First Approval Date: 23 March 2010, Ethics Reference Number: 2012/062*).

- Data Mining on the process of concept mapping at the tabletop, (*Protocol No: 13061, First Approval Date: 3 August 2010, Ethics Reference Number: 2012/1129*).

- Exploration of new foundations for core operating system user interface elements for tabletop interaction, (*Protocol No: 13275, First Approval Date: 2 November 2010, Ethics Reference Number: 2012/066*).

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Chapter 1

Introduction

Thesis Statement: This thesis explores how to harness the affordances of interactive tabletops, for small groups of collocated people to do richly collaborative activities such as brainstorming.

1.1 Motivation

An interactive tabletop is a horizontal interactive display that can support multiple users working together at a shared workspace which is an important class of single display groupware (Stewart et al., 1999). A motivating argument for interactive tabletops comes from the fact that conventional desktops and laptops have a significant limitation for group work. They typically have one channel for input (Myers et al., 2000). This provides an environment for a single-user to interact, perhaps even a pair of people to work together. But it is not well suited for groups of three or more. The use of a conventional single user device forces collocated individuals into particular layouts, for example side-by-side, or with people looking over one another’s shoulders, with one person using the technology at a time. This quickly becomes problematic when groups of three or more want to contribute simultaneously.

Interactive tabletops have the potential to support small-group work and collaboration (Evans and Rick, 2014). This is because they have relatively large display interfaces which can enable users to have similar opportunities for participation, with direct interaction with digital content, and this may promote mutual awareness and face-to-face communication (Dillenbourg and Evans, 2011; Muller-Tomfelde and Fjeld, 2012). Interactive tabletops are becoming increasingly more affordable, making it possible to explore their use for small-groups in classrooms and many other learning situations.

Table 1.1 introduces and defines tabletops in terms of a number of key characteristics for small group work (group use, touch interaction, mobility, large screen size, and reach issues). This helps highlight the place of the tabletop in the landscape of ways to interact with carried and fixed devices. The first column shows tabletops, the focus of this thesis. Next are large wall displays in the form of interactive whiteboards and large interactive vertical displays, because they share some of the characteristics of tabletops – and are another form of single display groupware. The remaining columns — desktops, laptops, tablets and smartphones, all represent classes of devices that are already in very wide use. The place of tabletops compared with these is important, as they help frame how this device is likely to be used. Moreover, the design of tabletop interaction should take into account a user’s existing knowledge and expectations. Each dimension is now examined to reveal the distinctive nature of tabletop interaction.

Group use is a fundamental dimension, characterizing a potentially valuable role for tabletops. While there has been some study of a single user with a tabletop (Wigdor et al., 2007), the potential to support small-group collaboration is one of its defining and very promising features (Dillenbourg and Evans, 2011; Evans and Rick, 2014). As the table shows, tabletops and walls differ on this aspect, since all the other device types are primarily for use by a single user at a time. The table shows the interactive wall as suited to group work. Although a wall might be used by multiple people at a time, it is much less personal than
<table>
<thead>
<tr>
<th>Dimension</th>
<th>Tabletop</th>
<th>Wall</th>
<th>Desktop</th>
<th>Laptop</th>
<th>Tablet</th>
<th>Smartphone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group Use</td>
<td>✓</td>
<td>✓</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Touch Interaction</td>
<td>✓*</td>
<td>✓*</td>
<td>x</td>
<td>x</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Mobility</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Large Screen Size</td>
<td>✓</td>
<td>✓</td>
<td>x</td>
<td>x</td>
<td>✓</td>
<td>x</td>
</tr>
<tr>
<td>Reach Issues</td>
<td>✓</td>
<td>✓</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

* while not all tabletops and walls are touch based, many are.

Table 1.1: Comparison of key characteristics of many device classes within a person’s digital ecosystem (the tabletop and wall refers to large single display interactive devices).

a set of people around a tabletop. Indeed, much of the deployed hardware for walls are single touch, which means that groups need to co-ordinate actions at the device.

**Touch interaction** reflects the nature of input to the device. While many tabletop systems have physical additions such as knobs (Jordà et al., 2007), cups, pens (Brandl et al., 2008) and keyboards (Microsoft, 2007; Jaco et al., 2014) to act as input methods, tabletops are particularly designed for direct touch interaction. This has been the focus of much research in exploring how to effectively manage text-entry methods considering input efficiency, space requirements, and ease of use (Hinrichs et al., 2007; Benko et al., 2009). Similarly, many walls are also touch-based (Smith et al., 2005), though many make use of digital pens (Slay et al., 2008) for input. Desktops and laptops are beginning to have touch screens, but primary use is still with a keyboard and mouse (or trackpad). Tablets and smartphones are touch, but are so much smaller than the tabletop and wall, that there are deeply different design considerations.

**Mobility** distinguishes the tabletop, wall and desktop as an embedded device that is fixed in one location. For the tabletop and wall, this follows from their size. If the tabletop is to be large enough to be used collaboratively, it needs to be large enough for several people to arrange themselves comfortably around the screen. This makes it inherently less portable than any of the personal devices, particularly the smartphone. The laptop may be better seen as portable rather than mobile (Woodruff et al., 2007). Importantly, the mobility of devices like laptops, tablets and mobile phones suggests that the user may want to be able to use them in conjunction with a tabletop.

**Large screen size** reflects working area available. Tabletops and walls typically range from 30-100 inches, making it feasible for a small number of people to work at the device concurrently (Ashdown et al., 2010; Müller-Tomfelde, 2010). Importantly, with existing hardware, the large screen is not necessarily always matched with the capacity to achieve high resolution (Ryall et al., 2006). Owing to cost, the typical resolution is still 1080p in the size range of 40-60 inches. While this is certainly better than a lower resolution – it can pose problems. Higher resolutions may be needed for: web browsing, where text readability is a concern; collaboration on written documents with hand-drawn annotations; and in command and control environments, where information is often densely packed (Ashdown et al., 2010). In the future, resolution is expected to increase with newer displays, such as high definition 4K screens, and the use of multiple projectors stitched together to create very high resolution surfaces (Ashdown and Robinson, 2004; Tuddenham and Robinson, 2007). For most hardware today, size and resolution are still competing goals, with the former often winning the trade-off.

**Reach issues** follow from two factors. One is the large size of tabletops, combined with the goal of direct touch interaction. This creates the need to consider a person’s reach across the table. In this respect, the design of interfaces for tabletop and large wall displays has to deal with the fact that a user may not be able to reach parts of the display area that holds digital artefacts that they wish to use. The desktop and laptop avoid this because they make use of a mouse (or trackpad). The tablet and mobile phone avoid
this problem because the screen is small. In addition, a second challenge is that reach interacts with social
custom conventions when a tabletop is used by multiple people. The space immediately in front of a person is often
defined as an individual’s ‘personal space’, used exclusively by that person during group collaboration.
As such, another user may not feel comfortable reaching into it (Scott et al., 2004). In addition, when
multiple people use the table, it may be socially unacceptable to lean across another person – further
impacting reach (Ryall et al., 2004; Pinelle et al., 2008; Clayphan et al., 2013a).

In summary, tabletops are quite different from the other device classes. Tabletops pose new design
challenges. It is also unclear, particularly for small-group use, the actual impact of the difference between
horizontal and vertical displays. It is therefore timely to build an understanding of the whole enterprise of
designing for this important new class of pervasive computing device. If interactive tabletops are to be
effective in their role as an embedded pervasive device, for use by people who normally use that space, the
support they can afford, especially for groups of three or more, needs to be better understood.

1.2 Tackling the Challenges

Brainstorming was chosen as the core activity to tackle the posed challenge of designing effective user
interfaces for small-group collaboration with this device. This is because brainstorming is a richly
collaborative group based endeavour (Osborn, 1953); it lends itself to igniting group creativity (Paulus,
2000); is well-known; and is a useful tool for decision making (McMurray, 1994), problem solving
(Brightman, 1980), and organisational processes (Nunamaker Jr et al., 1987). Brainstorming draws on
multiple forms of cognitive interaction (Brown et al., 1998), making it an ideal candidate for researching
interaction with collocated small-groups. Brainstorming consists of two phases. It starts with a freewheeling
divergent ideation phase (idea generation). It is here that group members generate, verbalise and record
ideas. Owing to social processes, ideas from each member are drawn on, as inspiration for new and linked
ideas. Categorisation and organisation of ideas then follows, in a convergent process encompassing review,
discussion and evaluation. This phase seeks to identify the most promising ideas. Figure 1.1 shows an
example of screenshots from each of the two brainstorming phases conducted at an interactive tabletop.

To be effective, idea generation relies on a small set of core rules to be followed: no criticism; unusual
and wild ideas are welcome; quantity is encouraged; and combination and improvement of ideas are
sought. When followed, group members are able to contribute in a criticism-free context leading to greater
participation and a higher output of ideas. The categorisation phase relies on open dialogue to support
discussion and evaluation. Given these aspects of the ‘rules of the game’ for brainstorming, which aim to

(a) Idea Generation Phase. This draws on a set of
divergent collaborative processes, where people generate
ideas, and also tap into each other’s ideas for inspiration.
Deferred evaluation is key.

(b) Idea Categorisation and Organisation Phase.
This draws on a set of convergent collaborative
processes, where people discuss, evaluate and make
judgement over the ideas generated.

Figure 1.1: A group of people brainstorming at an interactive tabletop.
promote a method for effective group collaboration, it is important to understand how a tabletop interface can be designed to support the rich and diverse set of small group interactions that need to occur for effective brainstorming to take place at a tabletop.

One of the key challenges for small groups working together is effective group co-ordination. In the case of brainstorming, this means that the group should follow recommended methods for both the divergent and convergent aspects of the activity. This thesis explores how to support this. It calls for a combination of effective user interface design with effective use of the particular affordances a tabletop offers (Jonassen and Rohrer-Murphy, 1999).

In order to tackle the challenge of effective group collaboration, this thesis explores computer supported collaborative scripts as an approach to draw on a tabletops’ affordances. Collaborative scripts define roles, activities and task sequences. The goal of a collaborative script is to trigger forms of interaction that may be unlikely to occur spontaneously (Kollar et al., 2006). This includes elaborating on content, explaining ideas and concepts, asking thought-provoking questions, facilitating effective discussion, as well as promoting argumentation and negotiation. When effective, a collaborative scripted approach offers support for participants and the coordination of the tasks required in an activity. Scripts build on regulating learner knowledge; provide processes to complement core activities; alleviate coordination concerns; and help foster group awareness.

In summary, this thesis is motivated by the affordances of interactive tabletops for supporting small-group work and collaboration. Brainstorming is used as the core collaborative activity driver, with exploration into collaborative scripts as a response to identified process needs.

1.3 Structure and Contributions

This section describes the remaining chapters of this thesis, highlighting the key contributions of each.

Chapter 2 contextualises this work by providing the background of previous research on horizontal versus vertical displays; brainstorming theory, principles, process gains and losses; and research on computer supported collaborative scripts.

Chapter 3 presents a user study designed to gain an understanding of how a tabletop can be used to support the brainstorming process. The study compares the use of an interactive tabletop with a conventional non-interactive whiteboard. The chapter:

- contributes a novel tabletop brainstorming system – Firestorm;
- examines the differences between a conventional and tabletop based method for group brainstorming within a lab setting;
- provides new understanding of how the affordances of tabletops can potentially be used to support collaborative activities;
- provides a set of design guidelines for creating tabletop interfaces to support brainstorming;
- provides motivations for the need for scripting to support important group processes.

Chapter 4 presents a user study comparing interactive tabletops and walls to support brainstorming as part of a real classroom exercise. Three separate learning environments are explored – an interactive multi-tabletop classroom, a learning laboratory with interactive vertical displays, and a design studio with index cards. The chapter:

- studies how real students use large interactive displays (tabletops and walls) compared with a more traditional method in a classroom;
• aims to fill gaps in the understanding of the effectiveness of interactive tables versus walls;
• explores whether tabletops provide better support for brainstorming than vertical displays;
• contributes insights into the use of different technologies and materials for brainstorming;
• contributes to understanding of the challenges associated with running studies in-the-wild.

Chapter 5 presents a user study to compare interactive tabletops and whiteboards when these are combined with carried portable devices for small group work in a Museum. The chapter:

• describes a novel poster-creation application – MuseWork;
• explores a design that integrates multiple forms of interactive surfaces, either interactive tables or walls, with tablets;
• is the first in-the-wild study of both interactive tabletops and whiteboards for class groups of children (aged 10–14) in collaborative learning groups of 3–7;
• provides yet more motivation for scripting to support group work, particularly for this age group and context.

Chapter 6 presents three studies which explore collaborative scripting. The first study uses an approach called scripted collaboration, which explores different forms of collaborative scripts for brainstorming at a tabletop. The second and third studies explore the potential and use of open learner models for reflection in conjunction with such scripts. The chapter:

• contributes a novel script-based tabletop brainstorming system – ScriptStorm;
• is the first to explore the notion of team-negotiated scripts for different tasks at the tabletop;
• demonstrates the role of open learner models using digital traces from individuals and the group in order to support reflection.

Chapter 7 presents the last study, which was part of a semester long undertaking in a multi-tabletop classroom. The study assesses assumptions of collaborative script design from earlier chapters. In addition, the chapter tackles ways to support the role of the teacher in the classroom, and the integration of other pervasive computing devices such as vertical displays, and a portable teacher’s dashboard. The chapter:

• is the first study of a multi-tabletop classroom integrating a diverse set of learning activities;
• explores an approach for designing, deploying and visualising teacher’s classroom lesson plans;
• shows how collaborative scripts can be used to scaffold learning exercises;
• validates collaborative script setting assumptions for the brainstorming activity made in earlier chapters which were evaluated in laboratory settings;
• documents the experience and lessons learnt from the semester-long use of multiple interactive tabletops in two real university courses.

Chapter 8 revisits the thesis statement, summarising the contributions and key insights for the thesis, and outlines several important directions for future work.
Chapter 2

Background

This chapter presents existing work that informs our understanding of how interactive tabletops can support small-group work and collaboration. This chapter focuses on three areas. The first area explores comparative studies of horizontal and vertical displays, examining how these devices have been used for collaboration, their input methods, the tasks examined, how the interfaces have accounted for multiple orientations, and the group sizes supported. This seeks to highlight gaps, and motivates research for needing to establish a clearer picture of the use of interactive tabletops for small-group work and collaboration. The second area focuses on brainstorming. This includes: a review of the theory of brainstorming; strengths and limitations of the classical brainstorming method; alternative brainstorming techniques; electronic brainstorming systems; and tabletop brainstorming systems. The last area looks at computer supported collaborative scripts. Collaborative scripts are defined, theory on scripting reviewed, and examples of how and where scripts have been used in-conjunction with interactive tabletops reported.

2.1 Horizontal and Vertical Displays

This section reports on key literature that compares horizontal and vertical interfaces for collaboration. Table 2.1 shows a high-level summary in terms of eight key dimensions: interface type (digital or non-digital); input method; task performed; multiple orientation considerations; posture; group size; experimental design; and the number of groups evaluated. These dimensions aim to unpack insights into current technology of two common types of single display groupware devices, and what this means for the research explored in this thesis. At the outset, the comments of Potvin et al. (2012) are echoed and reflected in the table, that there is currently ‘a very incomplete picture of the relative benefits and limitations of horizontal and vertical displays for collaboration’.

<table>
<thead>
<tr>
<th>Study</th>
<th>Digital (D) / Non-digital (ND)</th>
<th>Input</th>
<th>Task</th>
<th>Designed for multiple orientations?</th>
<th>Sit or stand</th>
<th>Group size</th>
<th>Experimental design / Num. groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rogers &amp; Lindley (2004)</td>
<td>D</td>
<td>Single pen</td>
<td>Travel itinerary planning</td>
<td>No</td>
<td>H–sit</td>
<td>3</td>
<td>Lab setting 8 (within subs)</td>
</tr>
<tr>
<td>Inkpen et al. (2005)</td>
<td>ND (Pens)</td>
<td>Route planning</td>
<td>No</td>
<td>V–either</td>
<td></td>
<td>2</td>
<td>Lab setting 6 (within subs)</td>
</tr>
<tr>
<td>Pavlovych and Stuerzlinger (2008)</td>
<td>D</td>
<td>Target acquisition</td>
<td>No</td>
<td>V–stand</td>
<td></td>
<td>1–3</td>
<td>Lab setting 4 (within subs)</td>
</tr>
<tr>
<td>Pantdi et al. (2009)</td>
<td>ND (V), D (H) ND–pens D–multi-touch</td>
<td>Concept Mapping</td>
<td>Yes</td>
<td>Either</td>
<td></td>
<td>9–10</td>
<td>In the wild 4 (between subs)</td>
</tr>
<tr>
<td>Potvin et al. (2012)</td>
<td>ND</td>
<td>Pens</td>
<td>Software design</td>
<td>No</td>
<td>Stand</td>
<td>2</td>
<td>Lab setting 10 (within subs)</td>
</tr>
</tbody>
</table>

Table 2.1: Summary of horizontal and vertical display orientation studies (H: Horizontal, V: Vertical).
Column 1 lists the research studies. Columns 2 and 3 indicate whether the vertical or horizontal conditions used digital interaction, and if so, whether they used pens, single or multi-touch. So, for example, the first study (Rogers and Lindley, 2004) had digital, pen-based interaction for both horizontal and vertical conditions. It is interesting only two of the previous studies involved digital interaction for both conditions (Rogers and Lindley, 2004; Pavlovych and Stuerzlinger, 2008). Column 4 provides a high level description of the collaborative task. It is important to study usage of tasks that are rich enough to provide valuable insights into interesting classes of collaboration. Most of these studies report on tasks involving quite complex collaborative activities. The exception is Pavlovych and Stuerzlinger (2008) in the third row which involved a very simple task.

The final four columns should be considered together. The first indicates whether the interface design was designed to account for users at different orientations at the tabletop condition. This is important because people tend to sit or stand around the table, and doing so enhances face-to-face interaction. Conventional desktop screen layouts may be effective for wall or whiteboard displays because all users view them from the same orientation. But the same interface at a tabletop may mean that people need to view and interact with text and other orientation-sensitive materials from unfavourable positions, even upside-down. This compromises easy scanning and reading of materials and affects the dynamics of interaction. This creates a new design constraint compared with vertical displays. Additionally, this may force people into a less natural layout, for example, side-by-side in a row. This is especially problematic for larger groups. Of the studies, only Pantidi et al. (2009) supported multiple orientations and coincidentally had group sizes larger than 3 people. In studies where people are standing, people can move freely as needed – this may counteract problems associated with orientation and reach. The last column, shows the number of groups in each study, the experimental design and importantly, it distinguishes lab studies from more authentic settings. All the previous studies except Pantidi et al. (2009), were conducted in a lab setting. Each of these studies are now discussed with main results highlighted.

An early and influential comparison of horizontal and vertical displays was conducted by Rogers and Lindley (2004). Groups of three used pen-based hardware, similar to current pen-based electronic whiteboards. Three conditions were examined: a horizontal display (Figure 2.1a); a vertical display (Figure 2.1b); and a combination of both. Each display had a single electronic pen, which participants shared. The task was to navigate to websites to find information, answering questions on a separate paper worksheet. Results reported higher awareness for the tabletop – likely due to being seated side-by-side and the use of the table ledge to fill in the worksheet. By contrast, the vertical display was plagued with problems of pen changeover and physical layout, particularly as participants sat away from the display, when answering the worksheet. When both displays were used together, each with a separate input pen,

![Figure 2.1: Rogers and Lindley (2004) – horizontal and vertical interface setup. Groups consisted of three people. A single electronic pen was used with each interface. Figures included with permission from the authors.](image)
the task was completed much quicker. The main conclusions from this study are: devices that encourage people to be physically near each other are likely to facilitate collaborative interactions, and the use of multiple input devices increases productivity. These findings are not all too surprising.

Inkpen et al. (2005) explored different factors on face-to-face group work: display angle, display size; the number of displays; and user arrangement. The authors found horizontal displays afforded the opportunity for people to arrange themselves in varying configurations: side-by-side; face-to-face; or at right angles to one another. Vertical displays were reported to afford glancing, allowing content to be quickly viewed. In addition, tilted displays were observed to provide better viewing angles, but were not conducive to group work. Four studies were conducted, each paper prototyped, one for each factor. A task of planning a route with a subway map was used. Pointing gestures; quantity of writing; partner gaze; on-task communication; preparatory communication and the ratio of activity between participants was recorded. Results indicated significantly more pointing gestures in the horizontal condition, significantly more preparatory communication in the vertical condition, and slightly more on-task communication in the horizontal condition (though not statistically significant). Five of the twelve participants commented that it was difficult to write at the vertical display. Analysis of physical movement indicated, for the horizontal display, people tended to remain seated, with half commenting, it was comfortable to sit and write. At the vertical display, where people stood, people moved around much more, with two people seeing this as a disadvantage, commenting on back and neck pain (an issue they saw as potentially important if the device was to be used for long periods). Despite these observations, when asked about display preference, participants were evenly split. Participants explained this as follows: the horizontal condition – “a natural surface for collaborating”; and the vertical condition – “easier to see everything” and “[it was] good for displaying and sharing ideas”. This suggests that while participants favoured collaboration at the tabletop, they also found aspects of the vertical display effective. It is noted that this work involved non-digital collaborative work with pairs; so caution is required in assessing the implications for the context that is the focus of this thesis, namely support for small groups of 3 or more people.

Pavlovych and Stuerzlinger (2008) studied the effect of varying the number of participants (1–3 people) on collaboration, as well as comparing different display orientations. This work was distinctive in two important ways. First, the task was a simple game where dots appeared on the screen and the goal was to point at each dot as quickly as possible (Figure 2.2a). Second, the interaction was based on each person using their own computer mouse or laser pointer (Figure 2.2b). One approach to collaboration involved speech to coordinate actions, another involved dividing the screen into regions – with the person closest to a dot, tackling it. The authors found pairs performed best and those in groups of three the slowest. For the effect of display orientation, the authors found a significant positive effect at the wall, with 51.2% of
Participants achieving higher scores. A 24.4% missed target rate was observed at the wall condition – but this was not statistically significant. The authors report that they were not able to tell if the frequency of communication correlated with overall success and acknowledged the limitations of the task, with such a simple form of collaboration. The authors state they were surprised at the finding for the wall condition, attributing this to the relative orientation and positioning of participants. As can be seen in Table 2.1, this study is different from most, in terms of the role of collaboration, the interaction and small groups. But it does give interesting results in terms of the better completion rates for the vertical condition.

Pantidi et al. (2009) conducted a study in an educational workshop. The study compared various low-tech and high-tech devices: post-it notes; pen and paper; a non-electronic wall with a projector; and a multi-touch tabletop. The study was ethnographic, involving a one-time breakout session with group sizes of 9-10 participants. The authors studied how different collaboration conditions supported creative exercises, with a focus on equitable participation. The breakout session was divided into three stages: (1) presentation and discussion of position papers; (2) production of a concept map; and (3) reporting back to others in the workshop. The authors found the wall and interactive tabletop to be the most problematic; with post-it notes best overall. At the wall, the group of nine split into three sub-groups, working on different themes of the problem, with one person in each subgroup tasked as a scribe. A major problem at the wall and tabletop conditions involved the transition between stages in the breakout session activity. For both tech conditions, participants were reluctant to move beyond the first phase – paper discussion, and this delayed later stages. In the tabletop condition, this was exacerbated as the tabletop was situated away from the discussion area (Figure 2.3a). So participants needed to stand up and walk to the tabletop. This led to 4 of the 9 participants deciding not to go to the tabletop. Another barrier was the need to learn how to use the software at the tabletop. However, those at the tabletop quickly learnt how to use the software and were able to work in parallel – not needing to take turns for interaction (Figure 2.3b). Across all conditions, where participants split into smaller subgroups of 3-4 people, higher levels of engagement were noted. The confounds of the tabletop condition made it hard to use. The main conclusions from this work seems to be that large groups are hard to keep engaged across complex activities.

Potvin et al. (2012) compared pairs working together at either a non-interactive horizontal (Figure 2.4a) or vertical surface (Figure 2.4b). The authors evaluated face-to-face contact, verbal utterances, and equity of physical and verbal participation. It was observed that the vertical condition gave better face-to-face contact; this is in contrast to the earlier work of Rogers and Lindley (2004). This may be due to the study involving pairs; as two people can easily interact at a whiteboard, and readily pause to speak to each other. The authors concluded that orientation had little impact on equality of verbal and physical participation, and user preference was equal for both orientations. It appears participants found it unnatural to stand over the horizontal display. The issue of posture again is raised as an important dimension to consider.

Figure 2.3: Pantidi et al. (2009) – interactive tabletop setup. Four people used the tabletop from a larger group of nine. The table was overhead projected and supported multi-touch. The height of the table required people to lean inward to the display. Figures included with permission from the authors.
The authors concluded that much more research is needed in the area of comparing different orientations for the support of collocated collaborative tasks.

In summary, the picture that emerges from all of this work, is that there is a need for more work to fill in the gaps in the conditions studied and a need to build a stronger understanding of the relative strengths and limitations of horizontal and vertical displays and how designers might address potential collaboration issues. The studies reported here, used varying classes of hardware as well as low-tech. Only one study (Pantidi et al., 2009) accounted for multiple orientations in the horizontal condition. This neglects the key difference in design for tabletops to account for the inherent need to support interaction by people at different orientations. The studies differed markedly in terms of the size of the groups, with 3 involving groups of 3 or less, and the one that had larger groups of 9-10 (Pantidi et al., 2009) actually resulted in people breaking into smaller sub-groups of 3-4 people. Other seminal work on group size for tabletop interaction (Ryall et al., 2004) has also focused primarily on groups of 2, 3 and 4 people. So the bulk of the previous work is dominated by studies of no more than 3 people. This is important because two people can easily sit side-by-side in collaborative work, even at a desktop. Even groups of 3 can sit in a row. This becomes less natural for groups of 4 or more. This leaves a gap in understanding the relative benefits for using horizontal and vertical digital displays for groups larger than 3 people. Two studies (Rogers and Lindley, 2004; Inkpen et al., 2005) point to benefits of the tabletop over the wall, especially in affective measures which suggest participants liked its face-to-face collaboration. Another two studies indicate the wall may be better, one for performance on a simple game task (Pavlovych and Stuerzlinger, 2008) and the other for non-digital software design with pairs (Potvin et al., 2012). The large groups (9-10 people) in Pantidi et al. (2009) give a very complex picture with many confounds for the tabletop condition. Together, these works suggest that the tabletop may offer benefits for the group sizes (3 or more members), the research in this thesis aims to support.

2.2 Brainstorming

Group brainstorming is a technique for facilitating creative ideation in discussion groups through reduction of inhibitory aspects of group problem solving (Osborn, 1953). Its popularity stems from the long-standing and pervasive need to improve the productivity of groups. Brainstorming is simple, easy to learn and has the potential to dramatically improve group output of creative ideas. A great deal of research (Parnes and Meadow, 1959; Johnson et al., 1968; Isaksen, 1998; Isaksen and Treffinger, 2004; Isaksen and Gaulin, 2005) has confirmed the effectiveness of group brainstorming. This section covers the theory and principles of brainstorming; process gains and losses associated with the brainstorming method; proposed solutions to problems; a survey of electronic brainstorming systems; and coverage on tabletop brainstorming interfaces.
2.2.1 Theory and Principles

Brainstorming was devised by Alex Osborn in the 1930’s as a creative problem solving approach. To improve the productivity of groups, idea exchange and sharing was identified as an important aspect of group interaction. This led to a process to formalise this interaction, with the brainstorming method defined. The original brainstorming method specified two phases: ‘an idea generation phase’ (also called a storming phase), where the goal is to elicit and construct as many possible ideas in a limited period of time within a criticism free environment; this is then followed by an ‘idea categorisation and organisation phase’ (also called a norming phase), which consists of convergent processes where generated ideas are discussed, evaluated, and duplicates removed. The idea generation phase is guided by four key principles:

1. **Criticism is not permitted.** Adverse judgement of ideas must be withheld until later. The purpose of the first phase of brainstorming is the generation of many, varied and unusual options.

2. **Unusual ideas are welcome.** The wilder the idea, the better: it is easier to tame down than to think up. Since criticism is temporarily ruled out, it is acceptable and desired that really wild and unusual ideas are shared.

3. **Quantity is encouraged.** As many ideas as possible is encouraged, as the greater the number of ideas, comes with it, an increased likelihood of quality ideas emerging.

4. **Combination and improvement are sought.** In addition to contributing one’s own ideas, participants should build on the ideas of others, either by enhancing an existing idea, or combining two or more ideas into yet another new idea.

Multiple studies have shown that groups generate more ideas when the guidelines of the brainstorming method are followed (Meadow et al., 1959; Parnes and Meadow, 1959; Johnson et al., 1968).

2.2.2 Process Gains and Losses

When the principles of the brainstorming method are enacted and followed properly, this can lead to a number of advantages for the group. Some of these, identified by brainstorming literature, include:

- **Idea Sparking.** A group member is able to use an idea from another member, in a way that the original author, did not, or could not of thought of, to create a new idea (Shaw, 1971; Hackman and Kaplan, 1974; Hill, 1982; Brown and Paulus, 2002).

- **Cognitive Stimulation.** Working as part of a group may stimulate and encourage individuals to perform better (Lamm and Trommsdorff, 1973; Dugosh et al., 2000; Dugosh and Paulus, 2005).

- **More Information.** A group as a whole has more information than any one member, which may help as stimuli in the ideation process. (Shaw, 1971; Lamm and Trommsdorff, 1973; Steiner, 1972).

- **Learning.** Group members may learn from and imitate more skilled members to improve their own performance in the group (Hill, 1982; Shepherd et al., 1995; Paulus et al., 2002).

Conversely, when brainstorming principles are not followed, with people seeking to disengage from the collaborative process, the method is susceptible to a number of issues. Some of these include:

- **Free riding.** When an individual believes their contribution is dispensable, where this may in part be due to the size of the group, with larger groups giving a greater sense of anonymity. Free riding lowers motivation and effort from individuals, and diminishes opportunities for sparking gains to be realized (Latane et al., 1979; Ruback et al., 1984; Albanese and Van Fleet, 1985; Diehl and Stroebe, 1987; Paulus and Dzindolet, 1993).
Matching of effort. Individuals working in groups, particularly where contributions are distinguishable, may compare and only match their performance to the minimum of the group. This issue interacts heavily with free riding. This issue appears when a participant only wishes to do the bare minimum; or alternatively wishes to ensure they are not being taken advantage of in the group (that is, making sure other people are not free riding off their contributions). The more people in the group that engage in this behaviour, the less output overall (Robbins, 1995; Paulus and Brown, 2003).

Evaluation apprehension. This is the fear of negative appraisal from others which may cause participants to withhold ideas from the group. This is particularly common in cases where groups have an imbalance of power, for example, managers and their employees (Shaw, 1971; Bouchard, 1972; Lamm and Trommsdorff, 1973; Hackman and Kaplan, 1974; Jablin and Seibold, 1978; Diehl and Stroebe, 1987).

Production blocking. This is caused by a delay in verbalising (or recording) an idea when it occurs. By not releasing the idea, it is likely to be forgotten or suppressed due to the feeling that the idea is no longer relevant or original at a later point in time (Lamm and Trommsdorff, 1973; Jablin and Seibold, 1978; Diehl and Stroebe, 1987).

Cognitive inertia. Ideas may move along one train of thought without deviating, because group members refrain from contributing wild or non-conforming ideas. This has an inhibiting effect on the performance of the group when the task is to generate many varied and unusual ideas (Taylor et al., 1958; Vroom et al., 1969; Bouchard et al., 1974; Jablin and Seibold, 1978).

Domination. Some group members may exercise undue influence or monopolize a group’s time in an unproductive manner (Jablin and Seibold, 1978).

According to brainstorming literature, ‘free riding’; ‘evaluation apprehension’; and ‘production blocking’ are particularly problematic (Diehl and Stroebe, 1987; Mullen et al., 1991; Isaksen, 1998; Isaksen and Gaulin, 2005). Moreover, research over 40 years suggests that ‘production blocking’ is the greatest inhibitory factor (Bouchard Jr and Hare, 1970; Lamm and Trommsdorff, 1973; Diehl and Stroebe, 1987).

2.2.3 Overcoming Productivity Barriers

To address potential issues with the classical brainstorming method, a number of new techniques, as well as minor amendments to the original method have emerged. These include:

Questorming. This is where a list of questions are formulated prior to a brainstorm session. The questions are used as input stimuli during ideation. The set of questions act as prompts to help steer the brainstorm, and to invigorate the group when idea production slows down (Roland, 1985).

Nominal brainstorming. This is a method where each group member ideates in isolation from other group members. The group then comes together for the idea categorisation and organisation phase. The rationale behind this method is: (1) people will not fear criticism (as no one is around to criticise); (2) free riding will diminish; and (3) production blocking will reduce since a person’s internal train-of-thought is not disrupted (Diehl and Stroebe, 1987). However, a side effect of this approach is the loss of group. As noted by Isaksen (1998), in his meta-review of more than forty brainstorming studies, for real life scenarios – “working in real groups is far more often the case, than working in contrived or randomly-assigned nominal groups”.

Brainwriting. This is a method based on message passing. The procedure is as follows: the first person writes (or sketches) an idea, and then passes it to their colleague. This colleague then reviews the idea, and creates another, and the process then repeats. This continues for a set number of iterations or until participants have run out of ideas (VanGundy, 1993; Lugt, 2002).
• **Allowing multiple scribes and/or input devices.** An amendment to the original method, is to allow concurrent recording of ideas in a brainstorming session. Amongst the various ways this can be achieved, some approaches include: giving each person their own pen and using a larger writing surface, using post-it notes, using index cards, and using networked digital devices. This combats the key issue of production blocking (Diehl and Stroebe, 1987).

### 2.2.4 Electronic Brainstorming Systems

Brainstorming has predominantly taken place without the use of computers, such as with pens and paper or with whiteboards. However, several computer-based systems have been built to support the brainstorming process (Gallupe et al., 1991; Valacich et al., 1992; Sosik et al., 1998). Naturally, as technology has become available, brainstorming has adapted to make use of new media and computer networks in support of the group. Electronic brainstorming addresses several problems associated with traditional brainstorming — by affording opportunities to parallelise input, and finding ways to reduce apprehension (Cooper et al., 1998). A survey of many early systems can be found in the review by Jessup and Valacich (1992). Two typical illustrative systems are described, to demonstrate the types of support afforded.

Cognoter (Foster and Stefik, 1986) is one example of an electronic brainstorming system that enabled collocated individuals to come and work together. Individuals had a separate computer, with a room configuration typically in the form of a U-shape (Figure 2.5a). Each computer screen allowed group members to place ideas or edit existing ones (Figure 2.5b). There was also a large wall display which could mirror private displays to facilitate whole-group discussion. Cognoter aimed to support individuals working together to organise their thoughts (Figure 2.5c), and to provide a structured meeting process with a ‘what you see, is what I see’ multi-user interface (Stefik et al., 1987). The design of Cognoter included features to encourage productive brainstorming, deletion was disabled during ideation; the length of ideas was restricted to short phases; and layout of ideas was not enforced. Cognoter attempted to promote parallel input and equal access for all and encouraged the brainstorming ‘rules of the game’ (see Section 2.2.1, pp. 12). After several years of use, the experiences of Cognoter were written up (Tatar et al., 1991). The authors reported that despite the system being innovative for its time, users encountered communication breakdowns with the system – largely stemming from an incorrect model of conversation in the original design of the interface. The authors reported for a number of instances, groups hardly talked at all, leading people to focus solely on their own ideas. There were even a few groups, who became so frustrated, they reverted to pen and paper while in the technology-enhanced meeting room. This points to two broad issues: a potential lack of face-to-face awareness imposed by enforcing collaboration through a particular tool or

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**Figure 2.5:** The Cognoter system. Collaborators sat at separate terminals in a U-shape/curved configuration. Each member had their own screen and there was a shared display at the front of the room. Cognoter allowed ideas to be entered by clicking anywhere on an individual’s computer screen. Cognoter provided an unconstrained approach to the layout of ideas. Figures sourced from Foster and Stefik (1986) and Tatar et al. (1991), included with permission from the authors.
channel, and the importance of interface design. Despite issues encountered with this early system, it still points to benefits of: parallelising input; the ability to store, print and recall ideas; the ability to re-arrange ideas freely; and a method for handling large numbers of ideas.

GroupSystems (Nunamaker et al., 1991; Valacich et al., 1991; Valacich et al., 1992) is another example of an important, early electronic brainstorming system. GroupSystems was foremost a group support system – with a series of networked computer workstations enabling group face-to-face support, with a computer-mediated electronic communication channel. GroupSystems supported the first phase of brainstorming – creative idea generation (Gallupe et al., 1991). GroupSystems was deployed within a special purpose room to support group meetings. The space configuration typically consisted of a U-shape or a tiered Harvard style format. Participants typed ideas at individual computers, these ideas were then displayed on each computer in real-time and (if present) on a large vertical screen at the front of the room. The interface offered tools to show different subsets of the larger idea pool, a way to cope with large numbers of ideas. Ideas were shown as lists with authorship kept anonymous, to reduce idea conformity and evaluation apprehension (although this setting could be configured). GroupSystems was designed to offer high process support and have a low task structure – meaning collocated groups were allowed to talk while in the room, announcing and discussing idea contributions as they wished. A review of studies in Nunamaker et al. (1989) and Valacich et al. (1991) found GroupSystems promoted effective group awareness with members reporting high levels of satisfaction. The system was effective for both small groups (3–7 people) and larger groups (12–20 people) (Dennis et al., 1990; McGoff et al., 1990; Valacich et al., 1992). These results are interesting, particularly as they compare to Cognoter. The findings appear to point to particular interface characteristics and also the freedom and styles with regard to the way the system could be used. GroupSystems offered three modes: chauffeured – where one person enters ideas for the group; supported – where all members enter ideas simultaneously and use both verbal and electronic communication; and interactive – where electronic communication is prioritised over verbal communication. These different styles allowed for the effective use and uptake of the system.

In summary, electronic brainstorming systems have a long history and have allowed new opportunities for idea creation. However the use of electronic brainstorming systems have often traded face-to-face interaction to enable other functionality (Stenmark, 2002). However, face-to-face interaction is highlighted as particularly important for team building and problem solving (Dourish and Bellotti, 1992). This has inspired researchers to continue to explore and research newer forms of technology, such as interactive tabletops, which are described next.

2.2.5 Tabletop Brainstorming Systems

Tabletop systems are multi-user horizontal interfaces for interactive shared displays. They implement around-the-table interaction metaphors allowing co-located collaboration and face-to-face conversation in a social setting (Shen et al., 2006). Because tabletops emphasize both situational awareness and group awareness, they are expected to support the brainstorming method with both cognitive stimulation (Dugosh et al., 2000) and social comparison processes (Dugosh and Paulus, 2005). The computerized support from a tabletop allows generated ideas to be easily captured and a natural gestural interface can be used for discussing and organising ideas as a group. Table 2.2 provides a high level overview of key tabletop brainstorming systems. Each system is now reviewed.

Hilliges et al. (2007) examined creative problem solving with pairs at a tabletop using the brainwriting method (see Section 2.2.3, pp. 13). Group members constructed ideas with a digital pen, writing on virtual post-it notes. Each note was placed in the center of the table. Prior to the addition of a new idea, previous ideas were reviewed. The system employed the use of a wall display for grouping ideas in the idea categorisation phase. The authors conducted an experiment comparing the tabletop interface to a
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Hilliges et al. (2007) & Brainwriting & 2 & Yes & Yes (but on an interactive vertical display) & Electronic pens 
Hunter & Maes (2008) & Custom & 4 & A custom method that combined both phases and used automatic web searches to provide idea suggestions & On-screen keyboard / single microphone 
Buisine et al. (2011) & Brainwriting (ideas not spoken) & 4 & Yes (ideas faced the author) & Yes & On-screen keyboards / written text input 
Schmitt et al. (2012) & Brainwriting (ideas not spoken) & 4 & Yes & Unknown (not reported) & On-screen keyboards 
Ioannou et al. (2013) & Brainwriting (ideas not spoken) & 4 & Yes (with personal devices – phones/tablets/laptops) & Yes & Personal devices 
Jaco et al. (2014) & ‘Search for Ideas in Associative Memory’ Theory & 4 & Both phases were combined. Ideas were created and connected by rope like branching structures. Ropes could be split and joined to other rope structures at any time. & Multiple physical wireless keyboards 

Table 2.2: Survey of key tabletop brainstorming interfaces and how each supported the brainstorming method.

Figure 2.6: Hilliges et al. (2007) – tabletop brainstorming system. Ideas are constructed at a tabletop (left), then categorised and grouped at an interactive vertical display (right). Figures included with permission.

pen and paper setup. No statistically significant difference was found for the number of ideas generated, however this is not surprising, given the chosen brainstorming technique (brainwriting), combined with the fact that ideas were hand-written on the tabletop interface.

Wordplay (Hunter and Maes, 2008) provided a system to support collaborative idea discussion (Figure 2.7). To make an idea, a participant spoke into a microphone or entered an idea through the use of an on-screen keyboard. The brainstorming technique consisted of both phases combined, and the tabletop was primed with a set of starter materials. The system linked with semantic knowledge databases, to facilitate idea production. In order to give importance to ideas, animation was used, for example, an idea would shrink if it had not been interacted with recently. No evaluation of the interface was reported.

Buisine et al. (2012) built a tabletop brainstorming system which used a combination of input methods: an on-screen keyboard for typing; and touch for handwriting (Figure 2.8). The authors measured task performance in reference to a corpus of all the group outputs. The authors mined for collaboration patterns and asked questions in reference to user satisfaction. The authors conducted a study comparing the tabletop system against a flipboard with pens. The authors found the around-the-table configuration led to increased performance relative to the flipboard condition. Additionally it was noted that collaboration was higher at the tabletop based on examining group equity. User comments indicated novelty and attractiveness of the tabletop interface were factors that increased peoples motivation for using the system.
Schmitt et al. (2012) designed a tabletop brainstorming interface to examine the effects of social pressure and time pressure on group creativity outputs. The study focused on the idea generation phase of brainstorming. The authors used the brainwriting method (see Section 2.2.3, pp. 13). Social pressure was implemented with a visual in the center of the tabletop (Figure 2.9a). This visual showed the number of ideas created, the rank, and relative contribution of each group member. Time pressure was implemented with a countdown timer, shown on both vertical sides of the object and on the top right corner (Figure 2.9b and Figure 2.9c). A traffic light metaphor was used to signal the time remaining, before the note locked and was sent to the pool of ideas in the middle of the table.

With regard to the quantity of ideas produced, a significant effect was found in terms of the social pressure mechanism with more ideas generated when the mechanism was used. There was also a significant effect of time pressure on the metric of unique ideas produced. No reported link between the social and time pressure mechanisms were observed. In terms of collaboration, results indicated conversation was not significantly influenced by time pressure, but with limited time, people did not stop to validate or check ideas as they did with the regular interface. For social pressure, it was observed that collaboration decreased, as measured by the number of unique ideas generated and the total amount of verbal interactions recorded. Hence, lower collaboration may have resulted in reduced cognitive stimulation and disrupted divergence and generation of unique ideas. This points to both benefits and limitations of the authors approaches for encouraging creativity.
(a) A group at the brainwriting tabletop interface. Participants use an on-screen keyboard with touch input to enter ideas.

(b) Social pressure. In addition to the number of ideas generated, the rank of the participant is visualised by both the size and colour of their quadrant.

(c) Time pressure implemented via a traffic light signal metaphor (top right, and on the vertical sides of each note).

Figure 2.9: Schmitt et al. (2012) – brainwriting (turn-taking) tabletop interface. Input was via direct touch to the screen. Social-pressure and time-pressure mechanisms were explored as potential motivators to facilitate the creation of more ideas. Figures included with permission from the authors.

Ioannou et al. (2013) built a tabletop brainstorming system for the purpose of mediating dialog between members on opposing sides of politically sensitive peace dialogs. They used the nominal brainstorming technique (see Section 2.2.3, pp. 13). In this study, during the ideation phase, each person created ideas on their own personal device in silence (Figure 2.10a). Following, in the categorisation phase, all the ideas were loaded to the tabletop, and presented one by one, inviting authors to elaborate on their proposed ideas (Figure 2.10b). No evaluation was reported.

(a) People generate ideas at their personal devices (laptops/smartphones). Ideas are not verbalised during idea generation.

(b) Idea categorisation at the shared interactive tabletop interface.

Figure 2.10: Ioannou et al. (2013) – tabletop brainstorming system. The nominal brainstorming method was used, where people created ideas at their personal devices in silence. Once completed, the ideas each from device were loaded to the tabletop for discussion. Figures included with permission from the authors.
Jaco et al. (2014) built a tabletop brainstorming system based on the theory of ‘Search for Ideas in Associative Memory’ (Nijstad and Stroebe, 2006). The model states that ideas in a brainstorm do not come one by one, but rather as rapid accumulations of semantically related ideas. The developed interface enabled users to link successive ideas together by means of a graphical chain, as well as splice and connect multiple chains together (Figure 2.11a). The authors compared this system to a regular tabletop interface (Figure 2.11b). The authors found visualizing associations between ideas enabled people to produce longer sequences of related ideas. Additionally, it was reported that the train-of-thought interface resulted in more original ideas being produced as judged by a subject matter expert.

![Train-of-thought brainstorming interface.](image1)

![Regular tabletop brainstorming interface.](image2)

**Figure 2.11:** Jaco et al. (2014) – tabletop brainstorming interfaces. Figures included with permission.

In summary, it is clear that brainstorming has a long history with several interface experiments supporting it. Notably most of the brainstorming experiments used modified brainstorming techniques. This motivates the need for research to consider how a tabletop interface can be designed to support the classical brainstorming method.

### 2.3 Computer Supported Collaborative Scripts

A key challenge for small-group work is promoting collaboration whilst ensuring learning objectives are achieved. Even with a novel pervasive device such as an interactive tabletop, groups can still withdraw from effective interaction (Daradoumis et al., 2012). Computer supported collaborative scripts are a potential solution, where they aim to structure interaction between individuals, as well as promote key activities to take place. For example, a script may define a process, whereby each group member speaks first, before peer commentary is allowed. Collaborative scripts aim to structure collaboration by assigning responses, roles and tasks to individuals, as well as define action sequences to promote effective group processes (Kollar et al., 2006; Fischer et al., 2007).

#### 2.3.1 Properties of Collaborative Scripts

Collaborative scripts stem from the research area of Computer Supported Collaborative Learning (CSCL). CSCL scripts are used as instructional scaffolds to structure the interaction between collaborators, enforcing certain activities in order to facilitate effective collaboration and collaborative learning (Weinberger et al., 2009). Collaborative scripting has been shown to be effective in promoting learning in face-to-face and remote contexts (King, 2007; Fischer et al., 2007; Dillenbourg and Jermann, 2007). The type of scaffold that scripts offer range from strict assignment of specific responsibilities and roles, through to more relaxed guidance on the setup of associated activities and the sequencing of these (Dillenbourg, 2002). Scripts may be designed for various purposes, such as, to foster the acquisition of declarative knowledge; and to
develop collaboration, argumentation and negotiation skills (Fischer et al., 2007). Collaborative scripts have been shown to help structure tasks and encourage desirable interactions (Weinberger, 2011) with “activities of learners coordinated and guided according to particular rules, implemented via respective tools in the learning environment” (Haake and Pfister, 2010). In addition, collaborative scripts can help groups organise information, as well as mediate groups when needing to reach consensus (Meier et al., 2007).

Dillenbourg and Tchounikine (2007) distinguish two script forms: Micro scripts and Macro scripts. On a micro-level, scripts guide the low level interactions of individuals by providing them with relatively detailed instructions about their roles, actions, tasks and activities that are intended to be performed (Kollar et al., 2006). By contrast, macro scripts are concerned with organisational issues such as the description of groups and activities and how possible learning activities can be linked (Weinberger et al., 2009). An important feature of macro-scripts for face-to-face collaborative learning is that the sequencing of activities is often made explicit by a facilitator or teacher, thereby ensuring learners receive clear instruction concerning when and how to engage in different tasks (Kollar et al., 2006). Some questions to help facilitators, teachers, and designers create macro scripts are: “Who collaborates with whom?”, “What is the group’s task”, and “What roles are to be distributed among individuals”.

An important and critical issue when designing a collaborative script is how coercive a script is (Dillenbourg and Tchounikine, 2007; Fischer et al., 2007; Weinberger, 2011). A balance needs to be found since “scripts that are too flexible may fail to induce targeted interactions; [and] scripts [that are] too rigid may spoil the richness of collaborative interactions” (Dillenbourg and Tchounikine, 2007). When a script provides too much intervention, this is referred to as ‘over-scripting’. The problem with over-scripting is that it takes away too much from the individual. This may reduce opportunities for productive collaboration to take place, as an individual may avoid engaging with the activity. Dillenbourg (2002) proposed a method he designed as ‘flexible scripting’ as a potential solution to the over-scripting problem.

Flexible scripting as the name implies, gives an adjustable amount of control to users. By allowing users to modify certain aspects, this aims to empower them to become more motivated and engaged with the activity. However, just like over-scripting, flexibility comes with risks. When designing a script, not every change should be made available to the individual (or group). This is because changing some settings of a script may result in certain activities not being triggered, making the script meaningless. Last, Dillenbourg and Tchounikine (2007) state that micro-scripts, by definition afford themselves low flexibility – as they already structure specific activities through a number of tasks. Macro-scripts on the other hand, being based on larger grained activities, are often better suited to introducing flexible mechanisms to provide choice for learners.

Collaborative scripts are built on several principles: regulate learning activities; provide complementary procedural knowledge; provide process-orientated instruction; alleviate coordination difficulties; and foster awareness. Ideally, a script should complement the internal script of a learner (Weinberger et al., 2005; Kollar et al., 2007; Weinberger, 2011). A person’s internal script is their procedural knowledge of how to perform and collaborate on a given task. Therefore, a script should ideally take into account the knowledge an individual already has. Those who are more experienced and hold well functioning internal scripts should be provided with a less detailed script, or no script at all, while those missing or having a dysfunctional internal script should be provided with a script with much more detail.

Overall, there are many examples of successful and effective collaborative scripts that have been deployed in the area of computer supported collaborative learning, with usage in face-to-face, blended and online environments (Dillenbourg and Jermann, 2007; Fischer et al., 2007; Fong et al., 2015). Recently, research has started to look at the use of collaborative scripts with interactive tabletops in collocated settings (Dillenbourg and Evans, 2011). Key work in this emerging area is now reviewed.
2.3.2 Interactive Tabletops and Collaborative Scripts

This section describes two important tabletop systems that have employed collaborative scripts — t-vote (a collaborative decision making system), and Digital Mysteries (a system supporting collaborative learning and thinking externalisation). These two systems have been chosen as they provide a strong overview of the potential of collaborative scripts in-conjunction with interactive tabletops.

Example 1: t-vote

t-vote is a tangible tabletop application for supporting decision making by children. The system was built for children visiting a museum (McCrindle et al., 2011). It uses tangible pawns on a tabletop interface and includes a scripted decision making process for multiple stages of voting (Figure 2.12). Tangibles were used instead of direct touch, being easy to physically manipulate and supported group awareness. The goal of t-vote was to help children find a shared topic of interest. The script consisted of the following:

• **Step 1:** Children initiate the activity by placing museum tickets on the tabletop (Figure 2.12a). The tabletop detects markers on the ticket underside and identifies which exhibit(s) each child visited. A countdown timer starts, the moment two tickets are placed on the table. The timer either waits for a maximum of another two tickets (four tickets total), or eventually expires. At which time, the voting procedure begins.

• **Step 2:** The tabletop brings up the topic associated with each ticket for the children to discuss as a group. Topics are laid out in outlined areas, each area containing supporting material related to the topic. A maximum of six topics are shown at any given time.

• **Step 3:** The system guides learners through several voting iterations until one or two topics remain.

1. The children are instructed to place pawns (represented as tangible blocks) onto topics they wish to discuss. Each child has three different sized pawns (Figure 2.12b) representing preference choices – the larger the block the stronger the preference. Each vote cycle has its own countdown timer. When the timer reaches zero, the system checks to see if all pawns have been placed. If any pawns have not been placed, the system asks that the missing pawns (tangibles) be placed.

2. After successful placement, the system calculates votes and eliminates topics with no votes or a small number of votes.

3. The system instructs the children to remove the pawns from the table by showing a message and flashing circles around each pawn.

![Figure 2.12: McCrindle et al. (2011) – t-vote, a collaborative tabletop decision making system. Students use physical artefacts to perform actions on the tabletop surface. Figures included with permission from the authors.](image-url)
4. This process is repeated until there is only one topic remaining or if there have been two sequential attempts on the last two items with equal votes.

- **Step 4:** The system shows the children more information about the selected topic.

This script is an example of a micro-script, as it decomposes the decision making process into tasks, instructing the children specifically what they have to do.

**Example 2: Digital Mysteries**

Digital Mysteries (Kharrufa et al., 2010) is a collaborative learning application designed for school children using an interactive tabletop (Figure 2.13). It is based on the paper-based learning technique called Mysteries (Leat and Nichols, 2000). The technique aims to develop higher-level thinking in which cognitive processes are made evident through the manipulation of data slips. Students are given a mystery with an open question, and a number of slips containing clues. Clues can be facts, background information, abstract ideas or red herrings (purposely misleading information). The technique makes use of the manipulation of the slips to induce and expose higher order thinking processes. To solve a mystery, students proceed through three stages: a reading stage; a grouping stage; and a webbing and sequencing stage.

Digital Mysteries was developed with an iterative process. Three iterations were tested with groups of primary school students, with each addressing design issues of the previous version. The hypothesis for creating Digital Mysteries was that the unique affordances on offer from interactive tabletops would better support small-group collaborative learning. This, in comparison to what traditional paper or regular-computer based tools could provide. Digital Mysteries was specifically built to: promote thinking externalisation; support meta-cognitive processes; and to enable deep learner reflection.

Each evaluation of Digital Mysteries was conducted in-the-wild. The first iteration with 4 groups focused on identifying shortcomings of the paper-based Mysteries. The digital implementation at the tabletop was similar to the non-digital version, with a set of basic actions: items could be moved, rotated and enlarged. Annotation capabilities were also provided to take notes on the background of the surface. The first iteration highlighted the need for more structure, as slips were often grouped without purpose, and the annotation mechanism had a major weakness – when slips moved, annotations did not. The second iteration with 6 groups focused on improving the representation of the slips. Three forms were introduced: a default size, an enlarged size; and an icon representation. The second interface provided tools to help with process externalisation – a grouping tool, a relation tool and a note tool. The grouping tool provided a container, where slips and other items could be placed into. The relation tool provided a sticky-tape mechanism to join two or more items. Once two items were joined, items moved as one. The note tool, allowed students to leave comments, and could be joined with other items using the relation tool. The second iteration implemented a form of scripting, replicating a sequence order previously seen for high performing groups. The third iteration (Figure 2.13) with 12 groups focused on motivating students to group slips a particular way, and added support for post-activity reflection. This was done to encourage students to be more aware of processes and problem solving strategies employed throughout the activity. The final Digital Mysteries scripted sequence is as follows:

- **Stage 1: Read the slips.** When the system starts, slips are shown as icons distributed across the table surface. Students need to enlarge each; this encourages students to read each slip. To ensure this is done, the following stage only starts after all icon slips are enlarged.

- **Stage 2: Group the slips** (Figure 2.13b). Students are provided with three tools: a grouping tool, a note tool and a relation tool. The tools make the students’ thinking visible to themselves and to others. This is to encourage discussion and explanation. The relation tool allows students to connect slips that are closely related using a sticky tape metaphor (Figure 2.13e–‘left-center’). The note tool
encourages students to record their thoughts, which can also be attached to slips. The grouping tool creates a rectangular area for slips to be placed into. When the grouping tool is selected, students are asked to create a name for the group. At this point the application stops all other forms of interaction to force the students in the group to create a descriptive name together for the grouping. This element was introduced, because, in earlier versions of the interface, it was observed that low achieving students did not name grouped slips, whilst high achieving groups did. Once students consider they have completed this stage, they select finish, and the interface checks that all the slips are placed in at least four separate groups. If this condition is not met, the system provides feedback asking for ungrouped slips to be grouped, or for more groups to be created.

- **Stage 3: Sequence and webbing of the slips.** Students are required to arrange the slips in a branched sequence showing the order of events and cause and effect relationships when creating their solution. Upon selecting finish, students are presented with an evaluation dialog (Figure 2.13c). The dialog shows three layout forms: piled; linear; or branched. The group then chooses which layout they believe is closest to theirs. If the choice is the branched sequence – the stage ends, otherwise groups are provided with feedback about different layouts and told to make modifications to their solution. This continues indefinitely until groups select the branched sequence from the dialog. This was done
as it was identified in earlier iterations that a branched sequence corresponded to a more complex
mental model of causation.

- **Post-Activity Reflection** (Figure 2.13d). This stage provides an abstracted replay of the whole session.
  Under the supervision of a teacher, feedback is provided. The aim is to promote self-regulation and
  metacognition. This stage is controlled through a reflection control panel, which allows scrubbing to
  any point in time from the activity. Once scrubbed to a point, materials appear on the interface
  and can be interacted with. This allows for process reflection.

The evaluation of the final interface (with 12 groups) provided evidence that the application increased
the likelihood of effective learning taking place, and that students demonstrated metacognition. The
interface successfully supported thought externalisation in each stage. For Digital Mysteries, the carefully
designed user interface coupled with a refined task structure over three iterations resulted in strong support
for effective small-group collaborative learning.

The evaluation of the three iterations led to the proposal of a number of design guidelines for
collaborative applications at tabletops: ‘structure the task’ – divide larger tasks into smaller ones, and
incorporate scaffolding in terms of instructions, feedback and reflection; ‘precede the task as a whole,
and each stage individually with a planning stage’ – give clear instructions and requirements at each
stage of the activity; ‘encourage externalisation’ – transform ideas into forms visible to others, and
provide a variety of cognitive tools to support decision making; ‘follow the task as a whole and each
stage individually with reflective feedback’ – encourage students to evaluate their progress, and provide
targeted feedback to students where possible; ‘balance interaction styles at the table’ – the ability to
switch between different modes of operation (e.g. single and parallel input) should be used to optimize
effective collaboration; ‘support abstract logging of events’ – this can be used with algorithms to identify
critical moments in the process for later reference and reflection; and ‘design for different ability levels’ –
this means the application should behave differently for high achieving and low achievement students,
for example, by providing different targeted feedback as appropriate. Overall, these guidelines show an
interrelationship with the principles of collaborative scripts – regulation of learning activities; providing
knowledge; providing process; aiding coordination; and fostering awareness.

### 2.4 Summary

The interactive tabletop is an emerging pervasive single display groupware device that has attracted
significant research interest, with many different hardware implementations now available. The software for
tabletops however, is still relatively immature, and there are many remaining design challenges, particularly
in relation to the ways to best support collaborative activities such as brainstorming at these devices.

This chapter has reviewed the state of the art for several key aspects that are important for harnessing
tabletops for rich collaborative tasks. First, it is observed that there is currently an unclear picture of
the relative benefits of interactive tabletops versus interactive vertical displays, and it is unclear how
interactive multi-touch tabletops can be effective with group sizes of three or more individuals. The
second aspect of this chapter explored brainstorming literature and brainstorming systems. A considerable
amount of literature has focused on the creation of augmented brainstorming techniques like nominal
brainstorming and brainwriting to seek improvement in the quantity and quality of ideas generated. Even
with current tabletop brainstorming systems, this leaves a rather large gap in the understanding of how
tabletops can be used to support the classical brainstorming method. The last aspect of this chapter
presented literature on collaborative scripts and provided key examples of tabletop systems employing
the use of collaborative scripts – highlighting their promise for supporting effective collaboration and
collaborative learning.
Part I

Rich Small-Group Collaboration with Interactive Tabletops
Part I: Rich Small-Group Collaboration with Interactive Tabletops

Introduction

The first part of this thesis covers Chapters 3, 4 and 5, which present a set of foundational studies for exploring rich collaboration with interactive tabletops. A set of novel prototypes are designed, built and evaluated to gain an understanding of how tabletops support small-group processes, small-group work and small-group collaboration. The first part of the thesis aims to uncover insights into the ways multi-touch tables are used compared with alternative ways of doing the same collaborative activity. The table below provides an overview of the chapters and the studies undertaken, with the key characteristics: the setting and experimental setup; participant demographics; the task; posture; number of groups and the group sizes examined. In total, over Chapters 3, 4 and 5, 142 people volunteered their time, with the outputs of 32 distinct groups examined.

<table>
<thead>
<tr>
<th>Ch.</th>
<th>Setting</th>
<th>Condition</th>
<th>Who</th>
<th>Task</th>
<th>Posture</th>
<th>Groups</th>
<th>Group size</th>
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<td>3</td>
<td>In-the-lab (Within-subjects)</td>
<td>Multi-touch tabletop vs Non-interactive whiteboard</td>
<td>Adults</td>
<td>Brainstorming</td>
<td>Standing</td>
<td>6</td>
<td>4</td>
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<td>Classroom environments (Within-class-groups)</td>
<td>Multi-touch vertical displays vs Index cards and pens</td>
<td>University students</td>
<td>Brainstorming</td>
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<td>3-4</td>
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<tr>
<td>5</td>
<td>In-the-wild Local museum (Between-subjects)</td>
<td>Multi-touch tabletop vs Single-touch whiteboard</td>
<td>Primary school children</td>
<td>Collaborative poster creation</td>
<td>Standing</td>
<td>12</td>
<td>3-7</td>
</tr>
</tbody>
</table>

An overview of the foundational studies for the first part of the thesis.

Chapter 3 introduces the Firestorm tabletop brainstorming interface and compares it with brainstorming at a conventional (non-electronic) whiteboard with multiple people each with their own marker pen. This is conducted with adults in a laboratory setting. The goal of this chapter is to explore tabletop affordances, including: ways to foster awareness; how to design effective interfaces that work from any orientation; support for egalitarian collaboration; and capturing of group processes. This chapter seeks to uncover individual and group behaviours and the differences between both mediums used for brainstorming.

Chapter 4 compares a multi-touch tabletop classroom to a multi-touch vertical display learning lab to an open design studio with pens and index cards. The study is integrated as part of an authentic university class, with a set of design computing students specifically learning the brainstorming technique as part of their set class. This chapter seeks to gain a deeper understanding of the differences between interactive horizontal and vertical displays, and the different affordances of each in support for small-group work and collaboration. Importantly the chapter raises the questions: ‘do SDGs provide benefits over conventional methods for brainstorming?’ and ‘do tabletops provide better support in terms of collaboration (both observed and perceived) and in the quality of ideas produced?’.

Chapter 5 introduces MuseWork, a system which makes use of both carried tablets and an embedded multi-touch tabletop and a single-touch whiteboard for inquiry and collaborative based learning. This study is set within an authentic setting at a local Museum, to accommodate school children as part of their regular school excursion trips. The work is undertaken with students aged 10–14, where the children first collect content using portable tablets and then come together and build a shared poster at the collaborative touch displays. This chapter furthers the work started in Chapter 4 with regards to horizontal versus vertical displays, and also sheds light from a class of people other than adults. This chapter posits that the tabletop with its multi-touch configuration (compared to a single-touch whiteboard) will likely give rise to: ‘higher levels of engagement at the table’; ‘higher task success’; and ‘a more positive group experience’.

higher levels of engagement at the table’; ‘higher task success’; and ‘a more positive group experience’.
Chapter 3

Foundations for Brainstorming
at an Interactive Tabletop

This chapter reports on a foundational study of the design and implementation of a tabletop brainstorming interface – Firestorm (Figure 3.1). Firestorm is evaluated against a conventional (non-interactive) whiteboard setup. The processes and results are analysed with the goal to uncover and better understand the ways a tabletop can support each of the phases of this group-based activity. The results from the study indicated Firestorm enabled rapid generation of ideas, as well as provided useful ways to categorise and organise ideas. Additionally Firestorm allowed capture of aspects of the group process, which was valuable for reviewing compliance with recommended brainstorming procedure. The contributions of this chapter are: (i) a set of design goals to support brainstorming at interactive tabletops; and (ii) insights into the nature of the benefits a tabletop affords for small-group work.

Figure 3.1: Examples of different groups using the tabletop brainstorming interface – Firestorm.

3.1 Introduction

As reviewed in Section 2.2, brainstorming can help a group of people generate original ideas, with new ideas inspired from earlier ones. When effective, brainstorming encourages egalitarian participation and enhances group collaboration. Brainstorming has predominantly taken place without the use of computers, relying on materials such as whiteboards, post-it notes, and index cards. Computer-based systems have

This chapter is heavily based on the following peer-reviewed publication:

i) A. Clayphan, A. Collins, C. Ackad, B. Kummerfeld, J. Kay (2011). “Firestorm: A brainstorming application for collaborative group work at tabletops”. In: International Conference on Interactive Tabletops and Surfaces 2011 (ITS 2011). ACM, pp. 162–171. I made significant contributions to all aspects of this work, leading the study exploration, building the tabletop brainstorming tool used (Firestorm), conducting the study, thorough analyses of the work (with input from Dr. Anthony Collins) and write up of the paper (with particular reference to Prof. Judy Kay for insights to the design goals and helping frame the discussion).
emerged to support brainstorming (Gallupe et al., 1991; Sosik et al., 1998; Valacich et al., 1992) and bring several advantages. Ideas can be captured and stored, and novel methods of categorisation on-screen can aid grouping ideas. However, computer-based systems often force groups to funnel ideas through a single input source, or distribute collaborators across multiple computers which can detract from valuable collocated interaction. Interactive tabletops, offer the potential to combine natural face-to-face discussion around a table with the advantage of computerised support.

The conventional brainstorming technique (Osborn, 1953) consists of two distinct phases. An initial freewheeling ideation phase is followed by a convergent categorisation phase. Brainstorming relies on a group being unconstrained and without criticism, to elicit as many ideas as possible. Like other activities, brainstorming is subject to issues (see Section 2.2.2) that can detract from its success. The most common are: free riding; negative criticism; and idea funneling (production blocking). Owing to these detractors, it is very important to consider how a tabletop can best be configured and utilised to support the different activity phases (ideation and categorisation) to promote effective brainstorming processes.

Several important aspects at the tabletop require careful consideration. The first is the means for entering ideas in the ideation phase. At a tabletop, this is challenging, where text entry has often been problematic, especially with on-screen keyboards (Hinrichs et al., 2007), and annotation with a pen or stylus is slow. Second, technology should not be distracting; this can occur if large amounts of interaction are required just to enter ideas. Third, the interface needs to support a small group of users working around the tabletop at different orientations so that they can face each other and can easily hear ideas announced by each other. Finally, the tabletop interface should foster awareness of group members’ actions, where collaborators can glance at the tabletop, to gain an overview of the pool of ideas already generated.

To explore the interface mechanisms required, Firestorm (a tabletop brainstorming interface) was conceived, driven by a series of design goals to take account of these issues. Firestorm utilises a large multi-touch tabletop, with each member having a separate physical wireless keyboard. The separate keyboards facilitate efficient text entry and discourage members from interacting with the display during the initial ideation. The interface is designed to support egalitarian interaction, not favouring any one particular orientation.

### 3.2 Design Goals for Tabletop Brainstorming

Drawing on the constraints and opportunities afforded by tabletop interaction, a series of design goals were identified. The aim was to support and enhance the brainstorming process compared with other methods.

**Design Goal 1: Support fast, concurrent idea generation.** It is important to design the interface so that users can generate a large number of ideas and to minimise production blocking (Diehl and Stroebe, 1987). It is critical to select an appropriate mechanism for idea entry (Hinrichs et al., 2007).

**Design Goal 2: Many ideas visible on the tabletop at once.** If the tabletop interface is to effectively support multiple users, it is important that many ideas can be represented on the tabletop at once. It is also important to ensure text is sufficiently large and legible at all times, so the group can easily see the current state of the brainstorm. This means the representation of the ideas on the tabletop needs to be designed carefully to minimise the space occupied by each idea while ensuring all ideas are legible.

**Design Goal 3: Don’t enforce orientations or territories.** The interface should enable users to work from whichever position they prefer at the tabletop; meaning the interface objects and physical keyboards should be moveable. While personal working territories are natural at a tabletop (Scott et al., 2004), people should be able to decide where they prefer to be and to easily move there if they wish. This means the interface should be designed so that, in the idea categorisation phase, each collaborator is free to touch any idea on the table, without feeling they are invading another user’s personal working space.
Design Goal 4: Foster awareness of ideas as they are generated. A challenge for tabletop design is to support people working from multiple orientations (Ryall et al., 2006), as is natural for a small group, working face-to-face. Further, the interface should foster group awareness during ideation, enabling collaborators to gain an overview of the ideas, to inspire new ones. As ideas are generated, they should be both highly visible and equally visible to all.

Design Goal 5: Make clear the creator of each idea. This design goal involves a compromise. One strong influence is the need to discourage free riding. Since this is an acknowledged problem for effective brainstorming, a way to counter it is to make each person’s output clearly identifiable. The tradeoff relates to benefits of anonymity which may help an individual feel freer to generate wilder ideas. This benefit seems rather small, given group members are actually at the table together and can see and hear the ideas being generated. They may well notice who calls out a very wild idea.

Design Goal 6: Support flexible grouping for idea convergence. Once the idea generation phase is completed and there are many ideas on the table, it is important that the interface provides flexible mechanisms for discussing and grouping the ideas for convergence (for the idea categorisation phase of the activity). Thus, the users need a way of quickly sorting new ideas. This may come in the form of gestures to support the selection and grouping of multiple items at once. It may also involve investigating alternative metaphors for representing collections of topics (for example, such as in the form of piles (Mander et al., 1992)). Another consideration is how idea groupings can be structured. A design goal is to provide a hierarchical interface, where multiple levels of nesting are allowed, enabling collections of related ideas that can be manipulated together with one interface action (for example, a whole part of the tree can be moved by dragging the parent).

Design Goal 7: Capture the group’s process and final outcome. In an electronic brainstorming system, there is the ability to capture each stage of the brainstorm, so that it can be saved and reviewed later. This can be useful in many contexts for a tabletop, to enable an ‘outsider’ to see how the group’s ideas evolved. For example, in a learning context, a teacher — who would be unable to monitor all the groups at once — is able to walk around to each group and replay the group’s process to see how it evolved, in order to give them feedback. This capturing of state would also allow the group to jump back to previous points (for example, to restore an idea previously discarded). Therefore, a key design goal is to capture as much information during the brainstorm so as to be able to harness it later on.

3.3 User View

This section provides an overview of the interface created to meet the design goals. Example screens from the evaluation study are used to describe the elements of the two brainstorm phases.

3.3.1 Creating Ideas in the Ideation Phase

At the beginning of the brainstorming session, Firestorm presents one text input note for each keyboard. The case of four users is shown in Figure 3.2, each with a keyboard and these users have placed the associated feedback notes in front of them, at the corners of the table. Keyboards were low-profile, wireless and came with full-sized keys. This allowed group members to move from their default locations if they so desired. The use of physical keyboards was selected as they support quick and accurate text entry, for the high proportion of users familiar with keyboards. Other options were considered – such as allowing users to write with their fingers. However, this is not particularly natural or quick and it is much slower than a keyboard, making it likely to disrupt idea generation. On-screen virtual keyboards were considered, but rejected as they are somewhat difficult to use, mostly due to a lack of tactile feedback – and need a large area to be used effectively, a problem for larger groups of users.
CHAPTER 3. FOUNDATIONS FOR BRAINSTORMING AT AN INTERACTIVE TABLETOP

Figure 3.2: Group 1 at the end of the idea generation (storming) phase. Notes are shown in a spiral in the middle of the table; the notes in the corners are linked to the physical keyboards. Colour denotes authorship.

Figure 3.3: Refinement of the size of the note element (left). It was found that ideas tended to be short, thus, a more compact representation was devised with text expanding/contracting to fill the size of a smaller note (right).

Each note appeared as a rectangular, single line post-it, based on the trials with an earlier interface, where multi-line text entry was rarely used (Figure 3.3). When a user typed on their keyboard, text appeared immediately on their corresponding note, resizing as appropriate to fit the fixed size container. Pressing return sent the note to a spiral in the middle of the table. This avoided favouring any particular orientation, enabling all collaborators to gain an overview of the ideas generated (Design Goal 2, 3 and 4).

For each user, many of the notes faced their orientation. Findings in Morris et al. (2006) suggest that short pieces of text that are facing away from users may still be read easily. After adding a new idea to the tabletop, the original note (linked to the physical keyboard) is cleared. Notably, the process of entering notes does not require the user to perform any action at the tabletop. The layout happens automatically. So the collaborators can remain focused on creating ideas and entering them with the keyboards supporting equality in participation. This design aspect ensured users faced the table and so, as they called out their ideas, they could hear each other.

The interface also coded each note according to the author with colour (Design Goal 5). In paper-based brainstorming, the handwriting on notes can be a subtle indicator of who wrote it. Colouring notes on the table shows ownership while avoiding the potential clutter of extra text indicating the author. It also enables each user to compare their notes with others’ contributions to the brainstorm (Design Goal 4). This was chosen to deter users from free riding.

3.3.2 Categorising, Evaluating and Grouping Ideas

After generating ideas with the physical keyboards in the idea generation phase, the collaborators can evaluate and group the ideas with the provided manipulation tools. All objects in the interface can be moved, rotated and resized. In addition, there is a flip gesture that enables a note to become a container or parent to other nodes. This was intended for grouping ideas, by placing them on the back of the note with a higher level idea (Design Goal 6). A flip is initiated by selecting a note from within the middle of one of its edges (the selection areas highlight when the user touches the note). Once flipped, the text of the note is displayed above, making it easy for other ideas to be placed on the flipped note – now acting as a container (Figure 3.4). Containers can also be nested to create deep hierarchies of ideas, for example, Figure 3.4 shows nine notes that have been flipped to provide containers for grouping ideas. Ideas within containers can be easily rearranged, as well as dragged-out and moved to other containers as required. The container can also be enlarged and rotated, which moves the notes contained within it. The side by side arrangement of notes within the container meant items are able to be easily read, and avoided issues of occlusion, which were present in the earlier interface (Figure 3.5).
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Figure 3.4: Group 3 at the end of the idea categorisation (norming) phase. Containers are made by flipping a note; in the figure there are nine containers/categories, each with a title.

Figure 3.5: Original note sizes were found to be problematic for encouraging visibility, with notable overlap issues.

Figure 3.6: A person making a ‘lasso’ gesture over a group of notes and then moving their finger on top of a container (left). After the person has held their finger over the container for more than a second, the ideas snap to the container (shown on the right).

Figure 3.7: A person making a ‘lasso’ gesture over a group of notes (left); when the person has held their finger over the background of the screen for more than a second, the ideas reposition themselves into a grid structure (shown on the right).

To discard ideas, a recycle bin (Figure 3.2–center) was provided, and was always present on the tabletop. It could be moved to any location and acted as a regular container. Like regular containers, users could drag ideas out of it, if they wanted particular ideas to be restored.

Given that users will need to organise many notes at a time on the tabletop, a lasso gesture was built as a support tool (Design Goal 6). To invoke the lasso, the user drags their finger around multiple notes, then moves their finger to the location they would like to move the notes to (Figure 3.6–left). After holding their finger still for about a second, the objects move to the location of the user’s finger (with associated animation). If the new location is inside of a container, the objects are placed into the container (Figure 3.6–right). Otherwise, the objects are arranged into a grid at the new location (Figure 3.7).

3.4 Evaluation

The aim of the evaluation was to assess the effectiveness of Firestorm. The study was predominantly qualitative, aiming to gain an understanding of how well the interface design supported brainstorming. At the same time, quantitative analyses compared the number of ideas generated (in the ideation phase) and their categorisation (in the convergent discussion phase).

3.4.1 Experimental Design

The experiments had a within-subjects double cross-over design, where each group completed a brainstorm using both the tabletop and whiteboard, with ordering balanced, with two tasks. Task A had participants brainstorm about ways to promote their country to increase tourism. Task B was to promote recruitment for a local university. The task assigned to each condition was varied in the experiments.

A whiteboard was used for the control condition (Figure 3.8). This had one very important difference from the tabletop; it gave users the freedom to write or draw anything where the tabletop allowed only
for text note creation and organisation actions. A major potential advantage of a tabletop comes from the constraints to interaction. This made it important to learn how the constraints imposed by the design affected brainstorming, compared to a very free control condition. Another important reason for the choice of the whiteboard control condition is that its large surface allows participants to write clearly. This should make the two conditions more comparable in terms of the awareness of idea generation. At the end of the ideation phase at the whiteboard condition, participants were given two printouts of their ideas, which was provided to aid the group in their categorisations. It also met the goal of capturing the group process (Design Goal 7). An essential aspect of the experimental design was to provide participants with two interface solutions, to facilitate elicitation of constructive advice about both.

A group size of four was chosen. This is a reasonable number for a group session, enabling a potentially large number of ideas to be generated. It is also a fair size for both conditions, based on current hardware sizes available — the tabletop can be used comfortably with two users on each of the longer sides of the table (or one on each edge), and the whiteboard is large enough to accommodate four users writing ideas simultaneously. The study was designed carefully so as not to favour either condition.

The experimental procedure began with a background questionnaire, to collect general information about the participants’ computer skills and past brainstorming experience. Following this, the participants were each given a task sheet that explained the problem they needed to brainstorm about — either promoting tourism for their country or driving recruitment for their university or local workplace.

Participants were given specific instructions about how to brainstorm: they were briefed on the rules of the brainstorming process, and told to spend 10 minutes on each phase, for the provided topic. Participants were instructed to do this to ensure they approached the task in the same manner for both conditions. While participants brainstormed, the experimenter retired to a separate observation room.

After the participants had finished the tasks, participants completed a post-experiment questionnaire. This had seven Likert-scale questions, asking about their experience (with a Likert scale of 1 to 7, where 7 indicated ‘strongest agreement’). Each question applied to both the tabletop and whiteboard; with scales arranged side-by-side for the two conditions, and space provided for free-form responses. Following, four general questions elicited qualitative feedback. The session concluded with a semi-structured interview that enabled the experimenter to clarify any observed phenomena.

### 3.4.2 Apparatus

The tabletop was a 46-inch multi-touch display with a 1080p resolution. This ensured text entered was legible even at small sizes. Each participant was provided with a low-profile wireless keyboard (with full-sized keys), which could be moved freely around the tabletop display and placed on the rim or an area
nearby when typing. The whiteboard was 65-inches but not interactive (Figure 3.8). Each participant was
given their own marker pen (enabling the potential for simultaneous use of the whiteboard). In addition,
a printer attached to the whiteboard enabled contents to be quickly transferred to a sheet of paper.

3.4.3 Participants

The evaluation had 24 participants (18 male, 6 female) organised into six groups (who knew each other),
with an age range of 20–54 (mean 26). The participants were predominantly university students studying
IT-related degrees. Eleven participants had other backgrounds: architecture, engineering, advertising and
business. From the background questionnaire, all participants used computers at least 11 hours per week,
and all rated themselves as being competent or above with a computer. Eighteen had used a tabletop
before, but for unrelated experiments. All participants had used a whiteboard before.

3.5 Results

Two forms of analysis were conducted. First was a qualitative study of the videos for the processes
participants used in each condition. Next, the products of the idea generation and idea categorisation
phases were analysed, interpreted in terms of the process results. The questionnaire responses were used
to support interpretation of other analyses and to learn how participants viewed the experience.

3.5.1 Qualitative Analysis

The processes employed during both activity phases is summarised in Table 3.1. For the idea generation
phase, grouping layouts were analysed at the whiteboard. This is important as comparisons of this against
the tabletop point to the effects of the constraints in the ideation format imposed by the tabletop interface.
In both conditions, videos were analysed to see if the groups had created ideas concurrently. Groups were
instructed to call out each idea so others could hear it and to write the ideas, working in parallel. For the
idea categorisation phase, again the layout forms were analysed in the whiteboard condition. In this phase,
groups were instructed to work collectively to discuss choices of categories and the ideas that belonged in
each. For both conditions, videos were assessed to determine if the group did this.

3.5.1.1 Whiteboard Processes

Table 3.1 shows two forms of layout observed: List – where ideas were placed in columns (Figure 3.8a) and
Map – where ideas were drawn as linked structures (Figure 3.8b). The Map strategy was incompatible
with the instructions given for ideation, as it involved discussion as each idea was added. Groups 1 and 3,
ignored directions and used a Map layout. In the post-interview, Group 1 reported deviation due to

| G1   | A/1  | Map  | ×   | Lists  | ✓   | B/2  | ×   | ✓   | A/1  | ✓   | ✓   | B/2  | ✓   | ✓   |
| G2   | A/2  | List | ✓   | Lists  | ✓   | B/1  | ✓   | ✓   | A/2  | ✓   | ✓   | A/1  | ✓   | ✓   |
| G3   | B/1  | Map  | ×   | Maps   | ✓   | A/1  | ✓   | ✓   | partly*|✓   |
| G4   | B/2  | List | ✓   | Lists  | ✓   | A/1  | ✓   | ✓   | Partly*| ✓   |
| G5   | A/1  | List | ×   | Lists  | ×   | B/2  | ×   | ✓   | ✓   |
| G6   | B/2  | List | ×   | Lists  | ✓   | A/1  | ✓   | ✓   |

* – Participants categorised ideas individually and discussed after.

Table 3.1: Summary of group actions at the non-interactive whiteboard and interactive tabletop for the two
phases of the brainstorm activity – idea generation and idea categorisation.
learning a mind-mapping approach in a prior design class and followed that practice instead. Group 3 was influenced by the first person who wrote on the whiteboard, who wrote sideways and connected ideas. The other groups (Groups 2, 4, 5 and 6) simply listed ideas in columns.

It was notable only 2 groups brainstormed ideas concurrently at the whiteboard. Four groups (Groups 1, 3, 5 and 6) used scribes, either a single scribe (Groups 1, 5 and 6) or two as a scribe (Group 3). This diverged from the recommended approach for idea generation and caused idea funnelling (production blocking). Ideas were limited by the speed at which a scribe could write and recall what was said. Scribe(s) were repeatedly heard re-stating ideas to confirm them. Participants remarked that the whiteboard had limited space, despite its large surface. Additionally, participants commented on feeling they were at the mercy of their scribe — “the whiteboard made for a far less open process, where ideas needed to be vetted before being written down” (3A).

In the idea categorisation phase, all groups (except Group 3) used a list approach. Typically, one group member would read out an idea from the printed list, and the group would collectively discuss and then decide where to put it. If it didn’t fit, they would create a new column for a new category.

3.5.1.2 Tabletop Processes

In the idea generation phase, Groups 2, 3, 4 and 6 worked concurrently. Eleven (from 24) participants commented the tabletop made it easy to enter information. Several commented on the tabletop supporting group work — “the tabletop was a better layout for concurrent use, we could stand around, facing each other, we could contribute independently” (3A), “the tabletop system promoted closer collaboration” (3B), and “using the tabletop made me more aware of what the others were putting into the brainstorm” (1B). Groups 1 and 5 did not brainstorm concurrently. Group 1 discussed each idea together, before entering it to the tabletop. Group 5 had members announcing ideas, but not all typed them at the same time – often one person waited for another to input the idea to the tabletop interface. Both these groups had used the whiteboard first, with a single scribe; this may have influenced their behaviour at the tabletop.

Notably, one Group 5 member entered a single idea and then proceeded to touch the tabletop for the last few minutes of the idea generation phase. This prematurely shifted the entire group to start categorisation early. The instructions specifically stated participants were not to categorise ideas during the initial ideation phase. This observation suggests the need for a future change, adding a constraint to ignore touch input during ideation, to align stronger with recommended brainstorming approaches.

For idea categorisation, all groups discussed their categorisation decisions. Several patterns emerged for the forming of categories. The two main approaches for category formation were: (1) the group would look at the tabletop as a whole, discuss the broad elements, and then add a new idea to the tabletop with a category heading of their collective choosing (Groups 2, 3, 4 and 5); and (2) the group would look at the tabletop, identify a broad term, flipping it to use as a category heading (Groups 1 and 6). To categorise ideas, groups either: (1) worked individually to place ideas into categories, then confirmed with each other about the grouping (Groups 2, 3 and 4) — shown in the table with a *; and (2) the whole group discussed each category, looked for similar items to place, and then repeated for the next category (Groups 1, 5 and 6).

3.5.2 Quantitative Analysis and Observations

Brainstorming literature (Osborn, 1953; Parnes and Meadow, 1959; Parnes, 1961; Diehl and Stroebe, 1987; Isaksen, 1998; Kaiser-Lee and Dzindolet, 1994) emphasises the importance of the number of ideas generated, as this appears to correlate strongly with quality. The number of ideas produced and the rate at which they were generated are now analysed. Table 3.2 shows the count of ideas for each condition after 3 minutes and after 10 minutes (the end of the ideation phase). Figure 3.9 shows the rate of ideation in minute intervals. A paired t-test over the entire ideation phase (10 minutes) did not reveal a statistically
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Table 3.2: The number of ideas generated after 3 minutes, and the number of ideas after 10 minutes (at the conclusion of the idea generation phase).

<table>
<thead>
<tr>
<th>Group</th>
<th>Task/Order</th>
<th>Ideas</th>
<th>Task/Order</th>
<th>Ideas</th>
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<td>9</td>
<td>B/2</td>
<td>11</td>
</tr>
<tr>
<td>2</td>
<td>A/2</td>
<td>25</td>
<td>B/1</td>
<td>35</td>
</tr>
<tr>
<td>3</td>
<td>B/1</td>
<td>12</td>
<td>A/2</td>
<td>26</td>
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<td>B/2</td>
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</tr>
<tr>
<td>5</td>
<td>A/1</td>
<td>10</td>
<td>B/2</td>
<td>15</td>
</tr>
<tr>
<td>6</td>
<td>B/2</td>
<td>16</td>
<td>A/1</td>
<td>27</td>
</tr>
</tbody>
</table>

Mean/SD: 16.5 (7.09) Mean/SD: 24.67 (8.96)

<table>
<thead>
<tr>
<th>Group</th>
<th>Task/Order</th>
<th>Ideas</th>
<th>Task/Order</th>
<th>Ideas</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A/1</td>
<td>24</td>
<td>B/1</td>
<td>93</td>
</tr>
<tr>
<td>2</td>
<td>A/2</td>
<td>72</td>
<td>B/1</td>
<td>93</td>
</tr>
<tr>
<td>3</td>
<td>B/1</td>
<td>27</td>
<td>A/2</td>
<td>63</td>
</tr>
<tr>
<td>4</td>
<td>B/2</td>
<td>56</td>
<td>A/1</td>
<td>85</td>
</tr>
<tr>
<td>5</td>
<td>A/1</td>
<td>39</td>
<td>B/2</td>
<td>29</td>
</tr>
<tr>
<td>6</td>
<td>B/2</td>
<td>29</td>
<td>A/1</td>
<td>48</td>
</tr>
</tbody>
</table>

Mean/SD: 41.17 (17.41) Mean/SD: 56.5 (26.69)

Significant difference between the two conditions (p=0.092). However, as it was observed that groups tended to slow down after a few minutes, the analysis was repeated for the first 3 minutes of ideation – and here, a statistically significant difference was found (paired t-test, t(5)=2.20, p=0.006, Cohen’s d=1.88) between the two conditions, with the tabletop outperforming the whiteboard. For both analyses (10 minutes and 3 minutes), no statistically significant order or task effects were found.

At the conclusion of the brainstorms, 4 of the 6 groups had more ideas at the tabletop than the whiteboard. By contrast, the count was higher for the whiteboard for Groups 1 and 5 – and this corresponded to the groups who did not write ideas concurrently at the table, indicating a likely order effect (for these groups). In addition, both of these groups completed Task B at the tabletop, which had a somewhat smaller overall mean than Task A (42.5 vs 55.17), though this was not statistically significant.

Groups 2, 3, 4 and 6 generated ideas at a faster rate at the tabletop. One cause for this was the scribe-effect and slow handwriting (mentioned by 11 people in the post-interview). For Groups 1 and 5, the effect of their discussion in the initial ideation phase is clearly evident. This appeared to limit idea production in both conditions. Group 2 slowed down only on the whiteboard condition after about 4 minutes. Group 3 had a steady rate of production in both cases but was slower for the whiteboard and this gap is large compared with other groups. Group 4 was similar to Group 3 but with a smaller gap. Group 6 began generating ideas much faster at the tabletop but after 2 minutes, slowed down considerably. The two most productive groups produced more ideas in the whiteboard condition than 3 of the other 4 groups in the tabletop condition, suggesting that handwriting speed was not the main cause of different ideation rates. Exploring this notion, even the fastest condition (Group 2 – Tabletop) saw 4 people create 90 terms, all quite short, over 10 minutes. This is a mean of 2.25 terms per person per minute, quite achievable by handwriting in parallel by 4 people at a whiteboard. Broadly, these counts and rates of idea generation indicate the tabletop was faster when used for free idea storming without discussion or review.

For the idea categorisation phase, the number of categories created by each group was analysed. Figure 3.10 shows the number of categories constructed with the mean number of ideas per category listed at the bottom of each column. There was no statistically significant difference found for either the number...
Figure 3.10: The number of categories created by each group in the second phase. Numbers at the bottom represent the mean number of ideas per category.

The categorisation of ideas made or the mean number of ideas per category observed for either condition. The number of categories was similar across conditions for Groups 1, 2, 5 and 6. Group 3 diverged for the tabletop condition with more categories, but the number of ideas per category was similar for this group (6 vs 7). Group 4 also had many categories, but the number of ideas per category grouping was much smaller than the whiteboard classifications (5 vs 11). This is due to the fact that Group 4, which had a large number of ideas (85) started their categorisation phase by making only a couple of categories initially, and spent a long time hunting for individual ideas to place into the two groups. Only after six minutes did the group change their strategy and in doing so, made many categories in an attempt to finish the activity. Notably Group 4 was the only team to not finish categorising all of their ideas.

The categorisations of ideas for ungrouped or wrongly grouped ideas were analysed. An informal analysis was conducted to assess if a category was reasonable, if it could be interpreted as addressing the core goal, and ideas were assessed as correctly grouped if a valid reason could be seen for its inclusion to that category. At the whiteboard, categorisations in Groups 2, 4, 5 and 6 were reasonable. Group 1’s categories were unclear, contributing to a growing picture that this group was less engaged and serious about the task than the others (this was confirmed by the video). Group 3 used a map to categorise ideas. While the linked ideas were appropriately grouped, several ideas were uncategorised. Their layout seemed to make it easy to fail to categorise all the ideas. This was another case where the freedom of the whiteboard seemed to have been less effective than the constraints of the tabletop interface.

At the tabletop, groups made reasonable choices of the categories and mostly did well placing appropriate ideas in these. All groups identified reasonable categories and mostly grouped ideas appropriately. Some ended with one uncategorised idea (Groups 1, 2 and 5). Several groups made good use of nested notes (Groups 2 and 4) and several used the recycle bin well to prune ideas (Groups 2, 5 and 6). All (except Group 6) used the lasso operation to initially select ideas from the pool in the middle, to re-orient ideas into a non-overlapping grid (e.g. Figure 3.6, pp. 33). Groups 1 and 5 further used the lasso to place items within containers. For the most part, ideas were reasonably grouped; exceptions were Group 1 having 2 of their 21 ideas out of place and Group 3 having several oddly grouped ideas in one category. Group 3 was notable for having some undeveloped categories. Participants volunteered free comments about categorisation at the tabletop, “ideas were easier to regroup” (1A, 1B, 1C, 4A, 5B, 5C) and “the tabletop was a more interactive way to communicate with my group” (1B). The most interesting ideas came from Groups 2 and 4, which had the largest numbers of ideas, which is in line with literature that states quantity tends to correlate with quality (Osborn, 1953; Diehl and Stroebe, 1987). Overall, it appears that the grouping mechanisms, including nested categories and the recycle bin were effective. In addition, the simple swipe action is likely to have contributed to ease of use, being far quicker and easier, than needing to re-enter the idea for categorisation. At the same time, tabletops may facilitate the collaborative stage more effectively by offering increased structure.
Table 3.3: Post-Experiment Questionnaire Results (Mean and SD). The Likert scale is from 1 to 7 (where 7 represents 'strongest agreement'). Items in bold are statistically significant at the alpha=0.05 level.

<table>
<thead>
<tr>
<th>Question</th>
<th>Whiteboard</th>
<th>Tabletop</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. I was able to represent my ideas about the topic</td>
<td>6.08 (0.83)</td>
<td>5.96 (1.08)</td>
</tr>
<tr>
<td>2. I was able to easily understand the core operations presented to me</td>
<td>6.58 (0.72)</td>
<td>6.46 (0.66)</td>
</tr>
<tr>
<td>3. I found the system made it easy to co-ordinate with other members of</td>
<td>5.83 (1.01)</td>
<td>6.00 (0.88)</td>
</tr>
<tr>
<td>my group to do each of the tasks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. I found it easy to use the system to do each of the tasks</td>
<td>5.96 (0.81)</td>
<td>6.08 (0.83)</td>
</tr>
<tr>
<td>5. I was able to understand how the system responded to my input</td>
<td>6.67 (0.70)</td>
<td>6.13 (0.80)</td>
</tr>
<tr>
<td>6. I was able to enter information in the system easily</td>
<td>6.17 (0.82)</td>
<td>6.42 (0.65)</td>
</tr>
<tr>
<td>7. I was able to enter information concurrently (that is, at the same</td>
<td>4.96 (1.73)</td>
<td>6.50 (0.72)</td>
</tr>
<tr>
<td>time as others) in the system</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3.3 summarises the post-experiment Likert questionnaire responses. In most cases, participants found both conditions similar. A Wilcoxon signed-rank test indicated that Question 5 (understood how the system responded to input) and Question 7 (able to enter information concurrently) were statistically significant ($p=0.006$ and $p=0.003$, respectively) at the 5% level. Question 5 favoured the whiteboard, comments linking this to familiarity with it, and Question 7 was due to the physical keyboards at the table, and the tendency for some groups to assign a scribe at the whiteboard.

Free-form responses indicated that the whiteboard had crowding problems, a reason for assigning scribes. Also, at the whiteboard, a full view is easier at a distance and some people felt uncomfortably close if they all were writing together. The participants commented positively on the tabletop for enabling all four of the group members to work simultaneously — “we all had uninterrupted access to the tabletop; the whiteboard had crowding issues at times.” (2C) and “the tabletop had a better layout for concurrent use, we could stand around it, facing one another; we could also contribute independently to start with.” (3A). One participant (5C) commented on limited workspace awareness imposed by the whiteboard, stating “each participant writing their ideas on the whiteboard simultaneously was not practical as duplication of ideas occurred.” Finally, the physical keyboards and appearance of notes on the tabletop was received well — “tabletop interface was easier to read and write on, creating more time [for us] to brainstorm.” (6A).

3.6 Discussion

The results are discussed in relation to the design goals, reviewing how well Firestorm met them and reflecting what the study indicates about the goals themselves. All sources of data are drawn on – outputs from each phase, video, observations, interviews and free-form responses. Table 3.4 summarises how Firestorm achieved the design goals. The study found most of the goals were met by the current design. The table also summarises reflections on strengths and ways that future versions of Firestorm can improve support for the brainstorming process.

The Firestorm design appears to meet Design Goal 1 (fast, concurrent idea generation), as the tabletop condition resulted in more ideas created in four of the six trials, with exceptions of Groups 1 and 5, who ignored instructions to avoid commentary and discussion of ideas during ideation. Key to efficient idea generation was the use of physical keyboards. The tabletop coincided with more ideas in the initial few minutes. Participants commented that the design of Firestorm as a whole supported concurrent idea generation. For example – “I’ve created more ideas on the tabletop, due to the feeling of not needing permission [from others]” (3D). Importantly, this support for fast idea generation appeared to enhance production of more good ideas, matching observations from Osborn (1953) and Diehl and Stroebe (1987) and is in line with recommended brainstorming practice.
CHAPTER 3. FOUNDATIONS FOR BRAINSTORMING AT AN INTERACTIVE TABLETOP

<table>
<thead>
<tr>
<th>Design Goal</th>
<th>Achieved</th>
<th>Reflections and Recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Parallel Ideation</td>
<td>✓</td>
<td>Idea generation mainly worked well. Consider making the tabletop non-interactive during ideation to ensure strict adherence to recommended brainstorming practices.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mainly achieved visibility of ideas. For ideation with many ideas, a refinement to the layout method may be required to increase idea visibility. For idea categorisation, refinement of the lasso gesture to be more intuitive.</td>
</tr>
<tr>
<td>2. Idea Visibility</td>
<td>partly</td>
<td>Retain central placement of ideas generated – as it worked well. For ideation with many ideas, a refinement to the layout method may be required to increase idea visibility. For idea categorisation, refinement of the lasso gesture to be more intuitive.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Awareness during idea generation was well supported with ideas highly visible.</td>
</tr>
<tr>
<td>3. No Territories</td>
<td>✓</td>
<td>Relative contributions were clear. Aesthetics can possibly be improved.</td>
</tr>
<tr>
<td>4. Idea Awareness</td>
<td>✓</td>
<td>Grouping worked well, including subgroups. Refine the lasso to support reorientation of idea groups and add an undo mechanism.</td>
</tr>
<tr>
<td>5. Accountability</td>
<td>✓</td>
<td>Was not available to participants. Add interface elements for reflection on process and products and re-conceptualisation of ideas.</td>
</tr>
<tr>
<td>6. Grouping Support</td>
<td>✓</td>
<td>Idea generation mainly worked well. Consider making the tabletop non-interactive during ideation to ensure strict adherence to recommended brainstorming practices.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mainly achieved visibility of ideas. For ideation with many ideas, a refinement to the layout method may be required to increase idea visibility. For idea categorisation, refinement of the lasso gesture to be more intuitive.</td>
</tr>
<tr>
<td>7. Process Capture</td>
<td>✓</td>
<td>Idea generation mainly worked well. Consider making the tabletop non-interactive during ideation to ensure strict adherence to recommended brainstorming practices.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mainly achieved visibility of ideas. For ideation with many ideas, a refinement to the layout method may be required to increase idea visibility. For idea categorisation, refinement of the lasso gesture to be more intuitive.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Awareness during idea generation was well supported with ideas highly visible.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Relative contributions were clear. Aesthetics can possibly be improved.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Grouping worked well, including subgroups. Refine the lasso to support reorientation of idea groups and add an undo mechanism.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Was not available to participants. Add interface elements for reflection on process and products and re-conceptualisation of ideas.</td>
</tr>
</tbody>
</table>

Table 3.4: Summary of achievement of the tabletop brainstorming interface design goals with takeaway messages.

The idea ‘notes’ appeared in the centre of the tabletop during ideation and were colour coded. This supported Design Goal 2 (Many ideas visible on the tabletop at once), Design Goal 3 (Don’t enforce orientations or territories), Design Goal 4 (Foster awareness of ideas as they are generated), and Design Goal 5 (Make clear the creator of each idea). Several participants commented positively on the notes’ readability, and being able to see their contributions, e.g. “I could visualise my contribution (from my colours), and it was inspiring to collaborate with others” (5D). Some members in Group 2, with its 93 tabletop ideas, noted that the ideas eventually overlapped in the idea generation phase and this impacted visibility. It is concluded the interface should be refined to overcome this. In the case of idea categorisation (the second phase of the activity), the interface enabled people to place ideas messily, with overlap. The lasso was one approach to overcome this, with 5 out of 6 groups using the lasso at the start of the categorisation phase to re-orient pooled ideas from the center into a non-overlapping grid.

The results indicate success for Design Goal 6 (Support flexible grouping for idea convergence), particularly in terms of the effective definition of categories by all groups and the appropriate grouping of most ideas. The lasso supported selecting several notes, placing them into containers and altering their orientation, two groups (out of six) made use of this feature. Flipping a note to create a container for a category was well used and participants commented about liking it. Ten participants (from 24) volunteered comments on liking the grouping mechanisms at the tabletop. The tabletop also made it easy to see if all ideas were categorised, as un-grouped ideas were more easily spotted.

The current interface captured process data (Design Goal 7 — capture the group’s process and final outcome). A free question about potential uses of captured process information indicated that participants did consider that it would be useful to go back and revisit key stages in the session. Although none identified an explicit stage, it may be useful for a more authentic context, where a group may consider multiple re-conceptualisations for their ideas. To do this, they may wish to return to the end of the ideation phase to define new categories and group ideas in these. Or they may wish to save one conceptualisation and then go about defining new categories and moving ideas into these. As a form of feedback, it is envisaged that support for a new phase — reflection, be added. In that phase, a group could review their actions in the session and the nature of their discourse. Additionally, data could be used to add temporal displays of group symmetry (Martinez et al., 2011), as real-time feedback.
3.7 Conclusion

This chapter explored the use of an interactive multi-touch tabletop to support the small-group activity brainstorming. A number of design goals were formulated, drawing on user interface affordances as influenced by the characteristics of the tabletop single display groupware device. Results for the ideation phase of the activity demonstrated: the integration of physical keyboards with the tabletop device enabled fast generation of ideas; pooling colour coded ideas in the middle of the table supported awareness, an unconstrained view for any orientation; and discouraged free-riding. Results from the categorisation phase found the mechanisms to support categorisation useful as well as the method for creating categories and assigning ideas to them. In short, this chapter, provided key insights of the effect of careful user interface design and how it helped facilitate small-groups of people to work together.

Firestorm was driven by a need to better understand how a tabletop could support small-group collaborative activities. Over the course of the iterative design and evaluation conducted, a number of key lessons were learnt. Firstly, a defining characteristic of an interactive tabletop is that it can constrain interaction, compared with the freedom of more manual approaches such as at a whiteboard or chalkboard. Firestorm was designed so that its affordances and constraints could be used to help overcome common pitfalls associated with the classical brainstorming technique. Firestorm largely met its design goals and provided good support for the different phases of the activity. At the same time, potential ways to improve the effectiveness of Firestorm were identified. For example, at the ideation phase, it may be valuable to explicitly disable tabletop interaction, so group members are encouraged to follow recommended approaches, with fast generation of ideas that are not discussed or judged. And, at the categorisation stage, an area of potential improvement is in formalising the two subtasks of category definition and of moving ideas into appropriate categories. Another possible direction for both phases is further harnessing the potential for the table to use captured aspects of the process. One role is to revisit earlier stages, for example, to reconceptualise structuring of the ideas, while another is to support learning about effective group interaction, perhaps with reflection.
Chapter 4

Learning to Brainstorm with Tables and Walls in the Classroom

This chapter extends the work of exploring the utility of single display groupware to effectively support small-group activities such as brainstorming taken to a classroom context. This chapter aims to gain a deeper understanding of the potential of single display groupware with real students using these technologies. This work is situated in an in-the-wild authentic setting, with three different classroom environments (Figure 4.1). The work described integrates with the classroom curriculum for a set of architectural design computing students, practicing and learning the brainstorm technique. This chapter explores the outcomes and processes of small-group work in terms of a set of key factors: cooperative participation; mutual awareness; output evaluation; and effects of the environment. This chapter builds on the foundation set in the previous chapter, which compared a tabletop interface with a non-interactive whiteboard in a lab setting. This chapter moves away from a controlled laboratory setup, to a real-world setting, in order to gain a deeper understanding and comprehension of how single display groupware can be used to support complex group processes. This includes taking into consideration the function and constraints of the classroom: including timing requirements and working within defined and non-negotiable subject learning objectives. The contributions of this chapter are: how students use large interactive displays (tables and walls) for small-group work compared with a more traditional method in the classroom; gaining a deeper understanding of the relative benefits of interactive horizontal and vertical displays; and furthering knowledge on how tabletops can support collaborative tasks (such as brainstorming).

Figure 4.1: Three classroom environments. Left: Interactive vertical displays. Centre: Multi-touch interactive tabletops. Right: Regular tables used for paper-based activities.

This chapter is heavily based on the following peer-reviewed publication:

i) A. Clayphan, R. Martinez-Maldonado, M. Tomitsch, S. Atkinson, J. Kay (2016). “An in-the-wild study of learning to brainstorm: comparing cards, tabletops and walls displays in the classroom.” In Proc. Interacting with Computers (Advance Access, doi:10.1093/iwc/iww001). I made significant contributions to all aspects of this work, defining the problem, building the different software tools used, planning the logistics for the classes, conduct of the studies and write up of the paper. The work was undertaken in A/Prof. Martin Tomitsch’s Interaction Design Studio class, where he was the lecturer-in-charge. The study was run with the help of Dr. Roberto Martinez-Maldonado and Ms. Susan Atkinson. Dr. Roberto Martinez-Maldonado and Prof. Judy Kay made solid contributions with helping write the final paper.
4.1 Introduction

Large display interactive groupware is becoming increasingly more affordable, making it possible to create classrooms with interactive surfaces on tables and walls. Interactive surfaces hold the promise to effectively support small-group work and collaboration (Evans and Rick, 2014). This is important because it has been demonstrated that small group work can activate valuable learning mechanisms (Deutsch, 1949; Johnson and Johnson, 1987; Koschmann, 1996; Dillenbourg, 1999; Chen, 2006). This is reflected in the common practice of group work in classrooms from K-12, to the tertiary level and beyond (Springer et al., 1999; Gillies, 2003; Barkley et al., 2014). Another important aspect follows from the important role of group work in diverse settings (Kozlowski and Bell, 2003; Kozlowski and Ilgen, 2006), with teams “the strategy of choice when organizations are confronted with complex and difficult tasks” (Salas et al., 2008). This second aspect has important educational implications, with the ability to work in a group being recognised as an important generic skill to build into the curriculum (Binkley et al., 2012; Darling-Hammond, 2012; OECD, 2011; OECD, 2013). Broadly, emerging technology has the potential to play an important role both in helping students learn subject matter and develop collaboration skills more effectively, by opening new channels of interaction with content and their peers.

This chapter aims to build on the understanding of the different ways that emergent single display groupware (SDGs) – namely interactive tabletops and interactive vertical displays/walls can support effective small-group work and collaboration. The work explored in this chapter is based on learning to brainstorm, an established method of group ideation (Osborn, 1953). It makes for an interesting case study because brainstorming is widely used and importantly was part of the investigated students’ standard curriculum and involves widely-used types of collaboration. For the classroom, the brainstorm starts with freewheeling divergent idea generation where group members call out their ideas and the ideas of each group member typically spark more ideas by others in the group. This is followed by convergent phases where the group reviews the ideas, organising and discussing them to identify the most promising ones.

This work made use of three different classroom learning environments to support small group activities. Figure 4.1 (left) shows one of the large collaborative learning spaces with a vertical display for each group. A key goal was to gain an understanding of the benefits of this form, over a conventional studio classroom without digital technology, such as the one shown at the right of the figure. In addition, both of these were compared with a tabletop classroom, shown at the centre of the figure. Relating this to the thesis statement of how to support small group collaboration, two research questions emerged:

1. Do SDGs provide benefits over conventional card-based methods for students learning to brainstorm?
2. Do tabletops provide better support for students learning to brainstorm in terms of the nature of the collaboration (both observed and perceived) and in the quality of the brainstorm outcomes?

Research into horizontal and vertical displays (as reviewed in Section 2.1) gives no clear answers, even from lab studies, much less from real-world classrooms, with all the associated curriculum and timing constraints of an actual university class. Currently, interactive vertical displays are already very widely deployed and used in many first-world classrooms, from elementary to university levels (Slay et al., 2008; Shi et al., 2012). There has been considerable research into the use and effectiveness of these vertical display forms (Higgins et al., 2007; Sweeney, 2010). Their use and associated research have almost been exclusively for whole-class activities (Smith et al., 2005; Betcher and Lee, 2009), rather than for small group work (Evans and Rick, 2014). The first research question presented is therefore important for studying already emerging SDG-enhanced classrooms like the one depicted in Figure 4.1 (left).

Interactive tabletops are much newer to classroom use (Dillenbourg and Evans, 2011). They have very recently been deployed to a few in-the-wild classrooms to conduct small-group activities (AlAgha et al., 2010; Do-Lenh, 2012; Martinez Maldonado et al., 2012; Kharrufa et al., 2013b). But little is
currently known about their effectiveness compared to interactive whiteboards or conventional classrooms for small-group activities. Because tabletops are horizontal, they seem to offer benefits over vertical displays for small-group collaboration. This is because learners can easily interact with digital content while maintaining mutual awareness and have natural face-to-face communication, both verbal and non-verbal (Betcher and Lee, 2009; Muller-Tomfelde and Fjeld, 2012; Potvin et al., 2012). The second research question seeks to unpack and explore this potential benefit of tabletops over vertical displays, extending the work started in Chapter 3 with the Firestorm tabletop brainstorming interface.

4.2 Literature on Classrooms with Interactive Tables and Walls

For both tabletops and walls, there have been few studies that have explored the use-case of multiple devices supporting multiple groups in the same classroom. This section overviews a number of classroom studies in an effort to better contextualise and understand the affordances and limitations of each.

4.2.1 Interactive Vertical Displays in the Classroom

There is currently a wealth of existing research based on the concept of one interactive whiteboard per classroom. The use of an interactive whiteboard in this context, has been examined in terms of: impact on pedagogies and learning practices (Sweeney, 2010); teaching strategies (Higgins et al., 2007); learning discourse (Murcia and Sheffield, 2010); student perception (Yáñez and Coyle, 2010); student engagement (Hall and Higgins, 2005); and collaboration (Lanzilotti et al., 2015). Even with widespread deployment of single interactive whiteboards in classrooms, researchers are divided on the value of their use (Smith et al., 2005; Higgins et al., 2007), particularly as they have been used for entire class activities (Fong et al., 2013; Evans and Rick, 2014), rather than for small groups. Only recently have there been proposals for the use of whiteboards for classroom small-group work (Mercer et al., 2010). This is also combined with a recent interest in new innovative learning spaces from a number of educational institutions (Stockert et al., 2012; Wilson and Randall, 2009; RMIT Learning and Teaching, 2015; UNSW Business School, 2015) to incorporate these forms of displays, to support small-group collaborative processes. With regard to multiple interactive vertical displays for small-group work, there is still much to consider.

4.2.2 Interactive Tabletops in the Classroom

Over a decade ago, Scott et al. (2003) proposed a number of guidelines for the use of single-tabletop applications for collocated collaboration, identifying affordances for the use of shared objects, physical user layout, and the possibility of leveraging learners’ digital traces. However, looking at multi-tabletop learning studies, there have only been handful (Hatch et al., 2009; AlAgha et al., 2010; Mercier et al., 2012; Martinez Maldonado et al., 2012; Kharrufa et al., 2013b), which have explored how both learners and teachers can be supported.

Table 4.1 overviews a set of key characteristics of prior tabletop classrooms. Figure 4.2 shows the setup of each. The studies range across primary, secondary and tertiary levels of education. Class sizes are from 12-20 students, predominately with 3-4 students per table. The last three columns relate to classroom management. Orchestration tools seek to enable a teacher to control aspects, such as: freezing the tables (so students attend to whole class activities), moving the application from stage to stage, sending messages to the tables (such as a warning of the approaching end of an activity); and sharing the content of one table at a wall display for all students to see (for class discussion and reflection). Awareness tools provide teachers with an overview of the state of each table; which can be useful as it may be difficult for a teacher to easily see all the tables. For the work explored in this chapter, an orchestration tool was used in a
modest sense to progress parts of the activity automatically, though no awareness tool or central display was used. These aspects are outside the scope of the work explored in this chapter.

One of the first and most relevant tabletop classroom projects was SynergyNet (Hatch et al., 2009; AlAgha et al., 2010; Higgins et al., 2012; Mercier et al., 2012; Mercier and Higgins, 2013). This had four multi-touch tabletops in a classroom setting (Figure 4.2a). This was used for experiments with elementary school students in extracurricular problem solving activities, such as answering mysteries based on text and graphical clues; and for tasks designed to enhance mathematical fluency. The classroom design also featured a non-interactive vertical display, which an individual table could be sent to, to be shared with the rest of the class, to support discussion. The teacher was given a dedicated control table, to visualise, interact with and manipulate each group’s tabletop. The research involved studies of video-recordings

![Figure 4.2: Tabletop Classroom Examples. All figures used with permission from the respective authors.](image)

<table>
<thead>
<tr>
<th>Study</th>
<th>Classroom</th>
<th># Tables</th>
<th>Students per table</th>
<th>Orchestration tools</th>
<th>Awareness tools</th>
<th>Central display (for sharing)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SynergyNet</td>
<td>Primary</td>
<td>4</td>
<td>3</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>AlAgha et al. (2010)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TinkerLamp 2.0</td>
<td>Primary</td>
<td>4</td>
<td>2-3</td>
<td>✓</td>
<td>✓</td>
<td>x</td>
</tr>
<tr>
<td>Do-Lenh (2012)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MTClassroom</td>
<td>Tertiary</td>
<td>4</td>
<td>4-6</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Martinez-Maldonado et al. (2012)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tables in the wild</td>
<td>Secondary</td>
<td>6-7</td>
<td>2-4</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Kharrufa et al. (2013b)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4.1: Summary of key interactive tabletop classroom setups.
to assess how tabletops supported collaborative interactions and the ways the teacher used the system (Mercier et al., 2012). Notably, this was a laboratory setting, with the students working on tasks outside their regular curriculum and the teacher was not involved in the activity design. Overall, the results pointed to the tabletops being effective in allowing groups to come to consensus quickly; and the teacher console was useful for orchestrating and monitoring the class.

TinkerLamp is an important early contribution by Do-Lehn (2012), even though it involved a somewhat different form of interface. Do-Lehn studied a classroom (Figure 4.2b) with four (non multi-touch) tangible tabletops in field trials within two vocational schools. These tabletops tracked fiducial markers attached to objects placed on the table. The learning activity was based on logistics training scenarios. The system provided the teacher with multiple ways to manage the classroom: a wall display showed task progress; there were ways to compare two groups’ answers; and paper cards with special fiducial markings were used to control individual tables. This study assessed its use for teacher orchestration to support learning.

MTClassroom (Martinez Maldonado et al., 2012), was the first study that involved the authentic use of a multi-touch tabletop classroom – with 140 tertiary students in their normal tutorial class (8 tutorial slots) with the class activity determined by the curriculum (Figure 4.2c). It featured individual user touch differentiation, enabling detailed learner activity capture. Core to the work was support for classroom orchestration. Five tabletops were linked to a private portable teacher’s dashboard. This is similar to SynergyNet, but the control device was portable. The dashboard had two roles: activity control (start, stop, pause, and share to a central wall display); and the real-time tracking and feedback of progress of each group. The research showed that collected learner information helped with awareness and facilitated managing the class, and the data captured was useful in assessing activity designs.

Tables in the wild (Kharrufa et al., 2013b), was an important authentic classroom study in a primary school that ran over 6 weeks. Students worked in groups of 2–4 at seven small tables (Figure 4.2d). Researchers observed student behaviour and teacher interaction. The teachers reported problems due to the independent operation of the tabletops, with no support to easily see the progress of each group. This study led to recommendations regarding the design of multi-tabletop classroom deployments (Kharrufa et al., 2013a). The distinguishing aspects of this study were its scale and authenticity and that it was conducted with class groups as part of their formal curriculum.

In summary, there is a considerable body of work on interactive whiteboards for entire class use. However, the first research into the classroom use of either tabletops or interactive whiteboards for small group activities is just beginning. This motivates the first research question, to consider how SDGs can support small group learning activities in classroom settings, comparing the SDGs against a conventional classroom’s group learning activity.

### 4.3 Study Design

To address the two research questions, an in-the-wild within-class-groups study was used to explore a curriculum component devoted to teaching brainstorming. Each of three tutorial class groups did three brainstorming activities, in each of the three learning environments: a conventional classroom, with small tables using index cards; a multiple vertical display classroom, and a multi-tabletop classroom.

The first research question focuses on comparing a conventional classroom against the SDG-enhanced classrooms. The related literature just summarised points to very few studies of SDGs in classrooms and none comparing the learning environment to a conventional classroom for the same activity. The second research question focuses on comparing tabletops and vertical displays. Here, too, the review of comparisons between horizontal and vertical displays (see Section 2.1) highlights there has been some work comparing SDGs, but little that has been in-the-wild and none in a classroom setting.
One important design choice for the study was for it to be in-the-wild. This allows the opportunity to gain insight into the research questions in a context that is as authentic a classroom setting as it could be. This serves to make the results more meaningful for informing an understanding of the ways that SDGs can serve small group learning in classrooms. As brainstorming was part of the curriculum, this context provided the perfect opportunity to study tabletop brainstorming (as introduced in Chapter 3), compared with an interactive whiteboard version and the previously used conventional classroom practice. The within-class-group design provided an opportunity to: reduce the effects of differences in ability and motivation between groups; and to satisfy the teacher that all students would have the same learning opportunities and experiences, ensuring perceived equity.

The first part of this section explains the detailed design of the study in terms of the aspects experienced by the students: the design of the learning activities; the design of the SDG applications, with both wall and tabletop versions carefully crafted and tested to be well suited to each device; and the overall series of events in the full three conditions experienced by each learner. The second part of this section explains the data collection design. This draws upon considerable literature about the evaluation of brainstorming, including exploring the nature and quality of collaboration, and how this was identified and assessed.

4.3.1 Curriculum and Class Context

The learning activity was designed to fit into the curriculum of a second year subject called “Interaction Design Studio”, a core subject within the Bachelor of Design Computing Degree. The subject consists of 6 contact hours per week, with three hours each week dedicated to studio work where students work either on small design activities or their design projects, supported by their teacher and tutors. Depending on the type of activity, the studio typically runs in different and sometimes multiple learning spaces. Class activities are generally designed to complement and build on lectures. These activities typically require students to work in small groups and end with a reflection session that involves the entire class.

For the week of the study (Week 6 in a 13 week semester), the studio activity in the curriculum aimed to help students learn and apply collaborative ideation methods. For this, the class was devoted to learning brainstorming to develop ideas to a given problem brief, and students engaged in a number of brainstorms. In previous years, the teacher had designed the class around a brainstorming session with index cards. As brainstorming plays an important role in interaction design, the teacher decided to use different learning environments and associated technology-enhanced tools to support the group activity. Importantly, the activities and the tools were designed and developed in close collaboration with the teacher to ensure the design of the classroom activities was crafted to make effective use of the technology-enhanced classroom settings. The activity was based on the established principles of brainstorming (Osborn, 1953) which the students learned about in a preceding lecture. Importantly for gaining insights about a range of small group collaborative activities, the brainstorm involved three main phases: (1) idea generation, in which students worked in parallel in a divergent group work activity, as they were encouraged to follow the principles of brainstorming: focus on quantity, withhold criticism, welcome unusual ideas, and spark off others’ ideas; (2) group categorisation and discussion of the ideas, a convergent and tightly interactive phase where the group worked together to combine similar ideas, to identify the most promising ones; and (3) group selection of the very best ideas, involving group consensus processes. Each of these calls for a different form of group work. Notably, the first phase is divergent, involving parallel generation of as many ideas as possible, employing processes such as cognitive stimulation (Dugosh et al., 2000), social comparison (Dugosh and Paulus, 2005) and group awareness (Dourish and Bellotti, 1992). The second and third stages are convergent, involving discussions and gaining agreement. So the design of the task ensured it embodied important and diverse forms of small group collaboration.
4.3.2 Topics

The teacher set three topics (Figure 4.3) for the class to brainstorm on (two of these topics had been used in previous years). Each topic was expressed as a problem, with an associated design challenge, as follows:

- **Topic 1**: to design a solution that helps students to remember their USB memory stick when leaving the computer or lab space.
- **Topic 2**: to design a solution that gives students better access to lecture slides and other materials provided by the lecturer.
- **Topic 3**: to design a solution that provides students with wayfinding information for lecture theatres and lab spaces while on-the-go.

![Figure 4.3: Descriptions of topics handed to students, including: the problem; and the posed challenge.](image)

4.3.3 Learning Environments Overview

All three learning environments described here were from the University of Sydney, Australia. The learning environments are provided to support small-group activities for a number of regular classes as requested by teachers. Each environment is now described, with the learning application used.

**Design Studio for Paper-Based Activities**: This learning setting was identical to that used in previous years, and consisted of an open flat space with re-configurable furniture. For the purpose of the activity, each group worked at their own separate table. Students worked in groups of 3 or 4. Students were issued with coloured index cards, each student using their own colour to enhance accountability. Students were asked to write their ideas and categorise them as required. For categorisation, students wrote the name of a category on a card and grouped the idea cards around it. Students freely decided on the length and form in which they wrote ideas (Figure 4.4).

**Multiple Interactive Tabletop Classroom**: This consisted of five interactive (46") tabletops with a keyboard for each user (Figure 4.5). The tabletops were in fixed positions, a physical classroom constraint. Each tabletop came with a system that could differentiate who was touching what part of the interactive display (Martinez-Maldonado et al., 2011; Clayphan et al., 2013a). The construction of this was grounded on principles of classroom orchestration and multi-tabletop settings as defined in Kharrufa et al. (2013a).

In this setting, students interact both face-to-face and side-by-side, and all group members have similar opportunities to interact with the surface. These interaction affordances, compared with the vertical display setting, positively impact the ways groups collaborate and generate ideas.

**Multiple Interactive Vertical Displays Setting**: Each group worked at a conventional table with an interactive (46") vertical touch-display (Figure 4.6-right). Each student was given a separate physical keyboard, so they could type ideas simultaneously and have these appear on the vertical display. As the
vertical displays were not moveable, the layout was carefully designed between the physical table (which was reconfigurable) and the interactive display. Several arrangements to position the table, wall and chairs were explored as shown in Figure 4.6 (left). The left layouts were with learners in a row, compared with the right layouts, where learners were around three edges of the table. Placing the table hard against the interactive wall was considered versus that with a gap for a standing area. Reachability, screen visibility and ergonomics were examined and informal trials with small groups were conducted. The final chosen layout was arrangement #4. This enabled students to sit in a semi-circle for the idea generation phase, gaining much of the benefit of being able to face each other (as in the tabletop condition). It also placed the vertical display at a comfortable reading distance for all — during the idea generation stage, when there was no need to interact with the touch-display. For the group categorisation and discussion phase, at least one student needed to stand to interact with the display. The space between the table and the display made it possible for several students from the group to stand at the display, to interact with it for the group discussion. An important merit of this layout is that the divergent phase (idea generation) was clearly marked; when it ended, at least one student needed to move (to stand and interact with the display) for the convergent discussion phase (idea categorisation).

4.3.4 Brainstorming Application Overview

For both the interactive vertical displays and tabletops, the same brainstorming application was used. The application was designed to work with both SDGs. The system featured an orchestration engine, where the teacher specified the classroom activity and the timing of the phases: ideation; categorisation;
and best-idea selection. This helped manage load on the part of the teachers, allowing the technology to automatically progress each phase. The interface used multiple physical keyboards. This afforded fast idea typing, avoiding known problems of on-screen touch keyboards and handwriting issues (Hinrichs et al., 2007; Jaco et al., 2014).

There was one difference between the configurations for the vertical displays and the tabletops. This occurred during the first phase (idea generation). As students typed the ideas, they appeared top-down on the vertical display (Figure 4.7). For the tabletop, ideas appeared around a circle in the middle of the table (Figure 4.8). This was done to allow readability of ideas across seating positions around the screen in each condition. The use of a digital avatar provided a link between the physical seated student and the display. After ideation, students could orient and move ideas however they wished. These particular layouts were informally tested for text readability and typing comfort (with a separate set of students) for each technology type.

4.3.5 Participants

Participants consisted of 51 students (31 male, 20 female) who attended the design studio in Week 6 (consent obtained the week prior during the regular lecture). Students were first asked a set of general background questions. Most (90%) were enrolled in the Bachelor of Design Computing degree, the remainder being from a study abroad program. Thirty-five percent of participants had used an interactive tabletop before (touch screen directories, art installations, and design projects), 46% an interactive whiteboard before (predominantly smartboards at school), and 22% had used both. No students had previously been exposed to the particular brainstorming software used during the study. However, 75% reported performing brainstorming activities in the past, as part of regular class activities.

4.3.6 Small-group Classroom Activity Design

The 51 students met at their regular classroom at the start of their studio and were divided into 3 equal sections (A, B and C), each section having 4 or 5 small groups, each with 3 or 4 students. Each section followed a predetermined ordering sequence for the learning environments and topics. This allowed each student to experience each environment, as well as each topic once in the total time of the studio. The topics were counterbalanced with the learning settings in such a way that each topic was discussed in all the environments (by different groups).

Table 4.2 shows the teacher’s activity plan with the sequence of technology and topics. Groups were formed randomly (a requirement by the teacher to prevent students forming groups with only their close friends). Each student was told their Section, Group and Colour (colour being the coloured avatar for the student in the tabletop and vertical display conditions; and the colour of the index cards). Each student then completed three brainstorm activities (within their group), one at each venue.
Table 4.2: The activity plan of the brainstorm study within the allotted 3-hour studio session.

As the venues were at different locations on the campus, groups had to walk between them, staying with their section (see Table 4.2, ‘10 minutes for walking between venues’). Each brainstorming session lasted approximately 30 minutes (in-line with previous years), with:

- 5 minutes for familiarisation with the learning space and a sample demonstration
- 5 minutes to read the design problem (as well as instructions for how to brainstorm)
- 5 minutes for idea generation
- 10 minutes for idea categorisation, discussion and grouping
- 2 minutes for writing down (on a special card) what the group considered their best idea from the session (for use later on)

After the three sessions, students filled in a post-experiment questionnaire, reporting their experiences of each environment and then all groups met back at a common lecture theatre, and shared their best ideas. Each topic was considered in turn by the teacher. A delegate from each group was given a maximum of 30 seconds to pitch the ideas to the rest of the class. The idea was then affixed to a non-interactive whiteboard. After all groups had presented their best idea on the specified topic, students voted by placing stickers, on the idea they thought was best. This process was repeated for all three topics.

The teachers’ design is illustrated with the example of Section A (see Table 4.2). The 4 groups, once formed, walked to the multi-tabletop classroom to work on Topic 1; after completing the 30-minute activity, they walked to the design studio to work on Topic 2 using index cards. Then they walked to the multiple interactive vertical display classroom for Topic 3. They finally went to a common lecture theatre to meet their teacher for the reflection activity, which involved the entire class.

4.3.7 Multiple Dimensions of Study and Sources of Evidence

Six dimensions of analysis were identified as ways to characterise the collaboration and the brainstorming. Table 4.3 lists the sources of evidence collected as linked to the dimensions. The first, idea generation, is the count of ideas generated. This is commonly used to assess brainstorming (Isaksen, 1998), as it follows the principle of brainstorming, that the quantity of ideas correlates with greater creative outcomes (Osborn, 1953). Mutual awareness refers to each person’s awareness of contributions by other group members. The design used colour coded ideas, enabling students to easily see who created each idea. Participation strategies refers to the degree of cooperation versus independent work; in the ideation phase, part of the power of the approach comes from taking inspiration from each other’s ideas. So cooperation in this phase means working as recommended so to enable fast idea generation and the potential to spark new ideas off each other. By contrast, working independently, without letting others see one’s ideas is against the spirit of the brainstorming technique. The next dimension is interest. This refers to student perception of the technology as increasing their engagement in the learning activity. This provides data about potentially different novelty effects of the different technologies. Next is learning space configuration, this is whether the setup of the space contributed to the forms of collaboration observed. Last, the quality of the ideas
Table 4.3: Multiple dimensions of study and sources of evidence (application logs and index cards; students’ questionnaires and ratings and systematic observations).

<table>
<thead>
<tr>
<th>Dimensions of study</th>
<th>Sources of Evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Application logs/cards</td>
</tr>
<tr>
<td>Idea generation</td>
<td>✓</td>
</tr>
<tr>
<td>Mutual awareness</td>
<td>✓</td>
</tr>
<tr>
<td>Participation strategies</td>
<td>✓</td>
</tr>
<tr>
<td>Level of interest</td>
<td>✓</td>
</tr>
<tr>
<td>Learning space configuration</td>
<td>✓</td>
</tr>
<tr>
<td>Quality of ideas</td>
<td>✓</td>
</tr>
</tbody>
</table>

was evaluated, in multiple ways: during reflection by the students voting; a separate ranking from the main teacher and two tutors; and a week later all ideas ranked by the main instructor and one tutor.

To understand the dimensions of the study, evidence was triangulated from three sources. Table 4.3 shows the relationship between these sources (Columns 2–4) and the dimensions that each targets (Column 1). The first source of evidence (Column 2) is the physical cards from the conventional class setting. For ideas from the touch interfaces, application logs were used. For the second source of evidence – observations (Column 3), 6 observers were involved in the data collection process. One observer was stationed in each learning space, and there was one observer assigned to each section. The stationary observer in the learning space recorded the dominant strategy employed in the idea generation and idea categorisation phases, as well as whether groups stood or sat. All stationary observers were briefed and undertook training on how to code teams. Writing space was also provided on the forms used by the stationary observers, to aid recording of the dominant strategy choice, as well as any notable observations. Strategy types were defined by the teacher and researcher team, to describe how individuals worked in the team together. Strategy types were not mutually exclusive. They were:

- **Co-operation** – where students appear to be actively working together.
- **Independent** – where students (or the majority of students) appear to be working alone.
- **Leader** – where a student (or students) took charge and directed the rest of the group.

The remaining three observers (the moving observers) were assigned, one to each section. They moved from one environment to the next with the students. They recorded the activity of each person, using three possible values:

- **Constructing** – if the student was observed creating an idea or having their hands on the technology.
- **Monitoring** – if the student was speaking or involved in the idea generation process without interacting with the technology.
- **Disengaged** – if the student was looking at other groups, distracted, or not paying attention.

Each observation recorded by the moving observers was systematically done every half-minute for each group – which meant the observer visited that group (stood back, not interjecting or disrupting the group), viewed what each participant was doing, recorded this observation on their sheet against the relevant code, and then moved to the next group. This meant one judgement per group was made every 2–3 minutes. In this way, the moving observers recorded multiple samples for each group during the whole activity. All moving observers were trained how to code the students.

Last, information was obtained from the students (Column 4). This was in the form of a post-experiment questionnaire. In most of these questions, students were asked to answer on a 6-point Likert scale (for
each learning environment if applicable) about each of the dimensions of the study (Column 1). They were also asked to optionally comment on their answers. Finally, students’ ratings of each group’s best ideas were captured as described in the previous sub-section.

4.4 Results

The posed research questions involve two inter-related comparisons: ‘Research Question 1’ compares the conventional learning condition against the groupware devices and ‘Research Question 2’ compares the tables and walls. This section presents the data collected in terms of the six dimensions identified. In the next section, the discussion of the results returns to the research questions. The design of the study aimed to ensure that there was data collected from the students about their perceptions for each dimension.

Table 4.4 summarises the Likert results from the post-experiment questionnaire.

<table>
<thead>
<tr>
<th>Question</th>
<th>Friedman test</th>
<th>Mean (SD) on Likert Data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Tabletops</td>
</tr>
<tr>
<td>Q1. I was able to represent my ideas about the topic?</td>
<td>$\chi^2(2)=5.75$</td>
<td>5.29 (0.69)</td>
</tr>
<tr>
<td>Post-hoc Wilcoxon signed rank tests with Bonferroni continuity correction, showed significant differences between:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>o Tabletops and Vertical Displays ($p=0.02, r=0.24$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>o Tabletops and Index Cards ($p=0.0147, r=0.25$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q2. I was able to easily understand what was required of me in order to complete the brainstorm?</td>
<td>$\chi^2(2)=1.86$</td>
<td>5.31 (0.64)</td>
</tr>
<tr>
<td>Post-hoc Wilcoxon signed rank tests with Bonferroni continuity correction, showed significant differences between:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>o Tabletops and Index Cards ($p=0.0147, r=0.25$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q3. The method of brainstorming helped me generate ideas?</td>
<td>$\chi^2(2)=3.78$</td>
<td>5.16 (0.67)</td>
</tr>
<tr>
<td>Q4. Overall, I was able to understand how the technology responded to my input?</td>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td>Note: As only two matched groups in this question, a Wilcoxon signed rank test was run (no effects found).</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q7. The technology/material increased my interest in the content of the learning exercise?</td>
<td>$\chi^2(2)=28.72$</td>
<td>5.04 (0.87)</td>
</tr>
<tr>
<td>Post-hoc Wilcoxon signed rank tests with Bonferroni continuity correction, showed significant differences between:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>o Tabletops and Index Cards ($p=0.0001$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>o Vertical Displays and Index Cards ($p=0.0001, r=0.43$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q8. The technology/material enabled me to participate more?</td>
<td>$\chi^2(2)=12.69$</td>
<td>5.34 (0.74)</td>
</tr>
<tr>
<td>Post-hoc Wilcoxon signed rank tests with Bonferroni continuity correction, showed significant differences between:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>o Tabletops and Index Cards ($p=0.00075, r=0.39$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>o Vertical Displays and Index Cards ($p=0.026, r=0.23$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q9. The technology/material supported collaboration (working together) within my group?</td>
<td>$\chi^2(2)=4.89$</td>
<td>5.28 (0.67)</td>
</tr>
<tr>
<td>Post-hoc Wilcoxon signed rank tests with Bonferroni continuity correction, showed significant differences between:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>o Tabletops and Vertical Displays ($p=0.015, r=0.26$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>o Tabletops and Index Cards ($p=0.05, r=0.2$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q10. Did you find the learning space (technology/ furnishings, etc.) supported the activity?</td>
<td>$\chi^2(2)=6.02$</td>
<td>5.02 (0.93)</td>
</tr>
<tr>
<td>Post-hoc Wilcoxon signed rank tests with Bonferroni continuity correction, showed significant differences between:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>o Tabletops and Index Cards ($p=0.0498, r=0.20$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>o Vertical Displays and Index Cards ($p=0.03, r=0.22$)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4.4: Post-Experiment Likert Questionnaire – Quantitative Results Summary (Significant items for $p < 0.1$ are shown in bold). Post-hoc Wilcoxon signed rank tests are reported for significant pairwise items. The Likert scale is from 1 to 6 (where 6 represents ‘strongest agreement’).
4.4.1 Idea Generation

Literature on brainstorming emphasises the importance of the number of ideas generated, and it is claimed to correlate with quality (Osborn, 1953). Table 4.5 summarises the number of ideas generated in terms of the mean and the standard deviation (SD) by groups in each section, across learning environments (tabletops; interactive vertical displays; and index cards) and for each topic (1 – USB, 2 – Lecture Slides, and 3 – Wayfinding). The bottom row of Table 4.5 shows that students generated fewer ideas when they were working with index cards (mean of 12 ideas) compared with the technology enhanced conditions (mean of 21+). The ranges between the learning environments were considerable, with Sections A and B following a general pattern of producing more ideas at the technological conditions than in the pen and index cards condition. Section B had the highest mean and standard deviation in each learning environment; in part, this was due to two particularly productive groups in that section.

<table>
<thead>
<tr>
<th>Topics</th>
<th>Learning Environments</th>
<th>Tabletops</th>
<th>Vertical Displays</th>
<th>Index Cards</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: USB</td>
<td>Section A</td>
<td>Mean= 25</td>
<td>SD= 6</td>
<td>Mean= 19 SD= 8</td>
</tr>
<tr>
<td></td>
<td>Section C</td>
<td>Mean= 18</td>
<td>SD= 7.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Section B</td>
<td>Mean= 15</td>
<td>SD= 6.9</td>
<td></td>
</tr>
<tr>
<td>2: Lecture slides</td>
<td>Section A</td>
<td>Mean= 10</td>
<td>SD= 1.6</td>
<td>Mean= 16 SD= 11.2</td>
</tr>
<tr>
<td></td>
<td>Section B</td>
<td>Mean= 28</td>
<td>SD= 11.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Section C</td>
<td>Mean= 9</td>
<td>SD= 1.6</td>
<td></td>
</tr>
<tr>
<td>3: Wayfinding</td>
<td>Section B</td>
<td>Mean= 27</td>
<td>SD= 12.8</td>
<td>Mean= 20 SD= 11</td>
</tr>
<tr>
<td></td>
<td>Section A</td>
<td>Mean= 19</td>
<td>SD= 3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Section C</td>
<td>Mean= 11</td>
<td>SD= 5.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mean= 21</td>
<td>SD= 11.4</td>
<td>Mean= 22 SD= 9.6</td>
<td>Mean= 12 SD= 6</td>
</tr>
</tbody>
</table>

Table 4.5: Mean number of ideas generated by groups for each topic in each learning environment.

A two-way ANOVA (factors: ‘Topic’ and ‘Learning Environment’) with type III SSs, threshold alpha=.05 was conducted. Students who did not take part in all three brainstorms – either due to late arrival or early departure from class were removed. A significant effect was found for the Learning Environment ($F(2,30) = 4.75, p < 0.05, partial \eta^2 = 0.24$). No other statistically significant main or interaction effects were found (alpha=.05) (i.e. Topic $p = 0.29$, and Topic:Learning Environment $p = 0.12$). Post-hoc Tukey HSD tests on the learning environment revealed the mean difference was significant for index cards and tabletops ($p = 0.035$) and index cards and vertical displays ($p = 0.024$). Levene’s test did not show a violation of homogeneity of variances ($F(8,30) = 2.04, p = 0.75$).

In the post-experiment questionnaire, students rated the statement: “Q2: I was able to easily understand what was required of me in order to complete the brainstorm” for each learning environment, on a 6-point Likert scale (from 1 to 6, where 6 meant ‘strongest agreement’) as follows: tabletops – 5.31; vertical displays – 5.22; and index cards – 5.3. No significant differences were found. This indicates that students considered that they understood the task, and could complete it for each learning environment. Additionally no significant differences were attributable to the brainstorm method employed at the three learning spaces (Q3: The method of brainstorming helped me generate ideas), nor in the understanding of how to use the technology (Q4: Understanding how the technology responded to input).

Overall, the tabletop and vertical display devices allowed students to create more ideas faster. To understand the features of the technologies that may have contributed to such an effect, results were triangulated with students’ responses, namely on: “Q1: I was able to represent my ideas about the topic”. Student ratings showed they preferred the multi-tabletop learning environment against both the vertical displays and the index cards (students’ rating: tabletops – 5.29, vertical displays – 4.92, and index cards – 4.73). The tabletop differed significantly from the vertical display (Wilcoxon signed rank test, $p = 0.02, r = 0.24$) and the index card environments (Wilcoxon signed rank test, $p = 0.0147, r = 0.25$). Thirty-nine students left an optional comment. For tabletops, 18 positive, 3 negative; for vertical displays, 12 positive, 3 negative; and for index cards, 9 positive, 3 negative. Students described some of the preferred
affordances of tabletops that they thought helped them work more collaboratively. For example: “the tabletop was the easiest to use because [we] could sit around it easily and discuss our work”; “[the] tabletop makes idea generation much faster than [the] vertical display because [we] don’t have to stand up”; and “[the] tabletop makes it faster for [us] to edit or add anything to the ideas”. This was also partially confirmed in “Q9: The technology/material supported collaboration (working together) within my group”, with the tabletops approaching a significant effect ($\chi^2(2) = 4.89, p = 0.087$) compared with both the vertical display and index card conditions.

Students’ free comments highlighted the benefits of both technological environments over the index cards, because the technology enabled them to generate more ideas by typing, compared with writing. Twenty percent of the students (10/51) commented that typing was much easier than handwriting. Students commented on the readability of the ideas, favouring the vertical displays, with comments such as: “the vertical display was the easiest to read, so I engaged really well with others’ ideas” and “the interactive displays supported us sharing and clarifying our ideas by displaying them together while the index cards did not force us to show/explain our ideas”.

### 4.4.2 Participation and Group Strategies

This aspect was studied in terms of three data sources: the student responses; and the observations from the two observer sets. Students were asked to answer the question “Q8: Did the technology/material enable you to participate more?”. Ratings were higher for the technology-enhanced classrooms: tabletops – 5.34; vertical displays – 5.04; compared with the index cards – 4.42. A Friedman test over 47 Likert responses revealed a significant effect ($\chi^2(2) = 12.69, p = 0.002$). Post-hoc Wilcoxon signed rank tests revealed significant differences between both the tabletops and index cards: $p = 0.0001, r = 0.39$; and the vertical displays and index cards: $p = 0.03, r = 0.23$. Of the 17 students who left a comment, there were: for tabletops, 7 positive, 1 negative; for vertical displays, 6 positive, 1 negative; and for index cards, 1 positive, 3 negative. Some student responses were as follows: “[I] instantly [saw] other team members’ contributions [at] the interactive displays [which] helped me to generate more ideas. When [the] index cards [were used], ideas were kept to oneself more” and “the displays made it very easy to contribute ideas”.

An interesting observation (noted on review of the ideas) in the index card environment was that 4 students from 2 groups, all from Section C (the first to use the index cards), took time to draw and sketch ideas, for example drawing a wireframe of a mobile application. This was also reflected in the comments “[index cards were] more flexible for drawing ideas, but hand-writing is slow”; and “[index cards gave us the] freedom to sketch”. It was only this first index-card group who did any drawing, which might indicate a possible order effect of the conditions, as the SDGs did not support drawing. While it would have been possible to provide an open-based platform for drawing on the SDGs, it was decided to not do this, as literature (Hinrichs et al., 2007) pointed to annotation on SDGs as problematic and difficult for large group sizes (the same reason as to why drawing was not supported in the earlier tabletop brainstorming interface in Chapter 3). Notably, some students kept index cards to themselves, as in Figure 4.9. In such cases, with the student looking down at the card to create an idea, it is likely that they stopped observing what other group members were doing.

Table 4.6 summarises the observations by the stationary observers, for the dominant strategy each group employed. The observations confirm that most of the cases of students working independently happened in the index cards setting. The entry ‘leader’ indicates a point when one person took charge to direct the group. In fact, for this ideation phase, both the tabletop and wall display resulted in cooperation in almost all cases; for the index cards, just 5 of the 13 groups displayed such cooperation. The strategies employed during the discussion phase were predominately cooperation for all learning environments.
Table 4.7 summarises data from the moving observers from each section. The table shows the percentage of the observations (recorded at 30 seconds intervals) in the categories: constructing, monitoring, and disengagement. The means for each environment were similar. This supports the conclusion that students in the technology conditions generated more ideas in the same period, rather than this being an effect due to the students themselves. In particular, students in the index cards condition, who spent 50% of their time constructing ideas, were on average only 60% as productive, in terms of the number of ideas generated, when compared to the two technology-enhanced conditions.

<table>
<thead>
<tr>
<th>Section/Group</th>
<th>Tabletop</th>
<th>Interactive Vertical Displays</th>
<th>Index Cards</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>Cooperation</td>
<td>Cooperation</td>
<td>Cooperation</td>
</tr>
<tr>
<td>A2</td>
<td>Cooperation</td>
<td>Cooperation</td>
<td>Independent</td>
</tr>
<tr>
<td>A3</td>
<td>Cooperation</td>
<td>Cooperation</td>
<td>Independent</td>
</tr>
<tr>
<td>A4</td>
<td>Cooperation</td>
<td>Cooperation</td>
<td>Independent</td>
</tr>
<tr>
<td>B1</td>
<td>Cooperation</td>
<td>Cooperation</td>
<td>Independent</td>
</tr>
<tr>
<td>B2</td>
<td>Cooperation</td>
<td>Cooperation</td>
<td>Independent/Leader</td>
</tr>
<tr>
<td>B3</td>
<td>Cooperation</td>
<td>Cooperation</td>
<td>Cooperation</td>
</tr>
<tr>
<td>B4</td>
<td>Cooperation</td>
<td>Cooperation</td>
<td>Independent</td>
</tr>
<tr>
<td>B5</td>
<td>Independent</td>
<td>Independent</td>
<td>Cooperation</td>
</tr>
<tr>
<td>C1</td>
<td>Independent</td>
<td>Cooperation</td>
<td>Independent</td>
</tr>
<tr>
<td>C2</td>
<td>Cooperation</td>
<td>Cooperation</td>
<td>Independent</td>
</tr>
<tr>
<td>C3</td>
<td>Cooperation</td>
<td>Cooperation</td>
<td>Cooperation</td>
</tr>
<tr>
<td>C4</td>
<td>Cooperation/Leader</td>
<td>Cooperation</td>
<td>Cooperation</td>
</tr>
<tr>
<td>C5</td>
<td>Cooperation</td>
<td>Cooperation</td>
<td>N/A (group late to class)</td>
</tr>
</tbody>
</table>

Table 4.7: Behaviour proportions observed for each learning environment during idea generation.

### 4.4.3 Mutual Awareness

The impact of each learning environment on students’ mutual awareness was examined. Students were asked about the way the physical spaces affected their participation in their groups and their awareness of others’ contributions. First, for the multi-tabletop environment, students highlighted that the technology allowed them to work face-to-face while, at the same time, all students could type or touch the interface. Students described this as follows: “the tabletop allowed everyone to contribute and discuss more” and “the tabletops were best because you are facing everyone”. Students mentioned that working around the same interface gave them a better sense of team and being aware of others’ actions (similar to that as reported in Rogers and Lindley (2004)). In the words of one student: “it was easier to see everyone else’s ideas and help generate my own on the tabletop, as you could flip and move the ideas”. The vertical displays made it easier for students to quickly read all ideas at once; by contrast, some tabletop text was upside down for some students. This aspect of the design was intended to spur discussion, with individuals moving and reorienting ideas as needed. Students saw the vertical display as better suited for shared awareness of the group ideas, a finding supported by Lanzilotti et al. (2015). A student described this...
as: “for the vertical display, the team was able to clearly see the ideas; the tabletop wasn’t as effective; index cards was also good but it could get messy at times”.

Some students (15/33), commented on disadvantages of the index cards – referring to illegibility of handwriting, and how that made it hard to both present and interpret other members’ cards. In terms of awareness, one commented: “index cards [were] hard to read with different handwriting”. Additionally, students noted that handwriting ideas were slow, and so index cards did not allow them to participate as much as they would have liked to. Student comments also referred to the need to focus more on writing than sharing their ideas. One student described this as: “[when using index cards] we spent more time writing/drawing rather than talking about our ideas”. By contrast, another student indicated that this was a positive affordance of using paper; they said they could “write out ideas without other people seeing them until you’re finished”. However, this violates the goals of the collaborative activity (as per the method taught by the teacher). The data from Table 4.6, already discussed, confirms this disadvantage of the conventional classroom for collaborative work.

Overall, students perceived that the learning environments had different affordances for mutual awareness. Tabletops were seen as enabling the whole group to work directly with the digital content and discuss ideas face-to-face. In the discussion phase, the readability problems of text, due to orientation, encouraged more equal interaction with the ideas, regardless of who had created them. Interactive vertical displays offered an unconstrained view of the entire set of ideas; but in the discussion phase, less equal interaction with the content was observed. The paper-based setting allowed students flexibility to write and sketch ideas but this made it harder to share and stay aware of others’ contributions.

### 4.4.4 Level of Interest and Disengagement

To measure the level of interest during the learning activity in each setting, students were asked to rate and comment on the statement “Q7: The technology/material increased my interest in the content of the learning exercise”. For both the tabletop and vertical display environments, the mean response was 5.04 (agree); compared to the index cards, which was 4.08 (somewhat agree). A Friedman test over 49 Likert responses revealed a significant effect ($\chi^2(2) = 28.72, p = 0.000001$). Post-hoc Wilcoxon signed rank tests showed the difference was significant between each of technology-enhanced settings and the index cards (tabletops and index cards: $p = 0.0001, r = 0.39$; and vertical displays and index cards: $p = 0.03, r = 0.23$).

Of the 17 students who left a comment, there were: for tabletops, 10 positive, 0 negative; for vertical displays, 9 positive, 0 negative; and for index cards, 0 positive, 4 negative. Students explained their answers as follows: “writing [on index cards] was messy and tiring/ demotivating”; “not a good presentation for others”; “lost interest in writing, stayed demotivated”; and “I hate writing”. By contrast, other comments indicated that students found the technological conditions well suited to the task, explaining this as follows: “interesting medium = more idea flow”; “ideas flowed for the tabletop”; “the layout and medium [tabletop] to support the work was professional and inspiring, paper was boring and tiring”; “interesting medium [vertical display] allows flow of creativity whereas boring paper and pen is demotivating and tiring”; “the technologies made the exercise more engaging and more of a group effort”; and “[the] vertical [display] and tabletop were engaging and we felt like a group... the cards made me feel more isolated”.

Triangulating this evidence with observations made by the moving observers, some disengagement was registered for all the learning environments. Table 4.7 shows that there was no significant difference in the number of times students were observed to be disengaged (5%, 1% and 1% of the observation samples for tabletops, vertical displays and index cards settings). While it may not be evident from the particular disengagement measure used – which recorded levels at discrete time intervals (meaning 2 or 3 observations for each individual over the course of the ideation), the qualitative feedback appears to suggest that the new technologies were welcomed, and enhanced students’ interest.
### 4.4.5 Learning Space Configuration

For the study, the teacher adapted each space so that up to 20 students could work at once (3–4 students per group). Students were asked to rate and explain their response to the following: “Q10: Did you find the learning space (technology/ furnishings, etc.) supported the activity?” The ratings showed students preferred both the technology-enhanced learning environments (average student Likert rating for the tabletops and vertical displays, 5.0) compared to the regular studio space (index cards, 4.6). This result was statistically significant, confirmed with a Friedman test over 47 Likert responses ($\chi^2(2) = 6.02, p = 0.049$). Post-hoc Wilcoxon signed rank tests showed significant differences between the tabletop and index cards ($p = 0.049, r = 0.20$) and between the vertical displays and index cards ($p = 0.03, r = 0.22$).

For all of the learning environments, students never attempted to alter the learning space configuration of the activity. The comments from students confirmed satisfaction with the default layouts: “Seating us together in 4’s helped.”; “[the] tabletop had a good connection between generating ideas and having them displayed instantly in front of you”. However, a problem with the vertical displays was observed for collaboration. Figure 4.10 illustrates this for a group where three students stood near the board, excluding one student. It is noted, however, that in this case, the vertical display was very effective for the three people shown, the group size for earlier work explored by Rogers and Lindley (2004). Other groups adopted a strategy with a conductor at the display (Figure 4.11) with all actively participating. It is noted that in a classroom, a teacher would be able to see these behaviours at a glance, and this would provide an opportunity to coach students into better collaboration practices.

![Figure 4.10: Interaction with ideas at the vertical display – a student left behind.](image1)

![Figure 4.11: Interaction with ideas at the vertical display – with a conductor.](image2)

### 4.4.6 Quality of Ideas and Creativity

The last activity of the day was reflection and sharing. As described, each topic was explored by the teacher, with each group given 30 seconds to pitch their best idea(s) from each topic to the class (30 mins overall). These were then voted on by the students, producing a ranking of the ideas. A week after the study, three instructors (the teacher and two tutors) from the subject independently ranked the submitted top ideas. They were given a sheet with the ideas printed on them. The instructors used criteria of originality, innovation and practicality to rank the ideas (equal ranks were allowed). On average (after standardizing the different rank ranges), instructors agreed on the same ranking 55% of the time, whilst students when compared with the teacher-in-charge (the main lecturer) agreed 47% of the time. Instructors gave 28 ideas a top rank (8 ideas from topic: ‘usb’; 9 from topic: ‘lecture slides’; 11 from topic: ‘wayfinding’). Across the learning environment conditions, the average numbers of top ranked ideas selected were: 2.3 (tabletop), 3.7 (vertical display) and 3.3 (index cards). With these small numbers, it is interpreted as a spread of ideas coming from each condition. The top ideas selected by the teacher in
charge were: “USB acts as both a log-in and log-out key/token” (Section B, Group 5 – Index Cards); “A service similar to Facebook timeline that allows you to search items posted during the course of the semester including all material posted by the lecturer” (Section B, Group 3 – Vertical Display); and “Augmented reality – shows you a 3D map that helps users determine location” (Section A, Group 4 – Vertical Display).

Overall, there was no relationship between the learning environment and creation of top ideas.

To further examine quality, the teacher-in-charge (the main lecturer) and one tutor rated all of the ideas from the day’s session (approximately 750+ ideas). They used the same criteria for quality (originality, innovation and practicality) but instead this time, used a rating scheme between 1 and 5 (5 being best). The measured weighted Cohen’s Kappa (squared weights) for the ratings by the two raters was 0.31 (95% CI: [0.23, 0.39]), indicating a fair agreement (Landis and Koch, 1977), though this is likely influenced by the subjective nature of the task, with difficulty in assessing open ended ideas. The raters very sparingly awarded scores of 4 and 5 (less than 4% overall). For this reason, these scores were analysed as the ‘better ideas’ from the day’s activity. For each learning environment, the average of 4 and 5 scores was 1.08% (Tabletop), 1.34% (Vertical Display), and 1.21% (Index Cards). A Kruskal-Wallis test revealed no significant differences. When the topics were analysed, the majority of high scores came from the USB topic, with an average of 3%, as opposed to 0.3% for each of the other two topics. This indicates that the USB topic dominated, by an order of magnitude over the two other topics. There was no link between topic and learning environment. For example, the 4 and 5 score frequencies for the USB topic were: 6 from the tabletop, 8 from the vertical display and 7 from the index cards.

4.5 Discussion

This section has three parts. The first reflects on the study design and its impact on the results just reported. Then each of the two research questions are considered in turn, with key findings summarised.

4.5.1 Reflections on the study design, strengths, weaknesses and implications

The study design was within-class-groups and situated in-the-wild; each of these drove many fine grained decisions. Some of the decisions related to the design of the interfaces and the learning spaces chosen. One of the most important design decisions was the choice of data to collect to answer the posed research questions. This drew on a combination of log data, observations and student answers to Likert-scale questions with additional comments. The implications of these aspects are now discussed.

The within-class-groups study design meant each group practiced each task, experienced each learning environment, and tackled each problem, although different groups did them in different orders. This approach, like most of other related work summarised in Table 4.1 (pp. 46), is effective for studies involving small numbers of participants, with this study having 51 students, in 14 groups across 3 classroom environments. Ideally, the three tasks would have been strictly comparable. In terms of the numbers of ideas generated, summarised in Table 4.5 (pp. 55), this appeared to be the case. However, the rating of all ideas by the lecturer and tutor’s assessment gave most for the USB topic, with 3% compared with 0.3% for the other two topics. This may be a confound for topic comparability or, as will be discussed below, may be due to the difficulty of assessing the quality of ideas.

The commitment to the study being in-the-wild study was made, as this contributes to the meaningfulness of the results for real learners in future classrooms that may incorporate SDGs. Some of the aspects that contributed to the authenticity of the learning environment are now noted. Participants had a clear understanding that they were in a classroom, learning a skill within the curriculum. There was also authenticity in the time constraints, with the study needing to fit within the set prescribed class schedule. The choice of the brainstorming activity fit within the regular curriculum and its established
subject learning objectives. The conventional class condition was authentic; in fact, it was identical to one of the practice sets of the established tutorial schedule from previous years.

Reflecting on the choice of application, brainstorming was a valuable case to study. It is well suited to single display groupware support. In terms of generality of the findings, brainstorming is a rich collaborative activity, with a divergent idea generation stage and convergent later stages. So, it afforded the ability to assess diverse aspects of collaboration, both in observations and in light of student comments.

However, the in-the-wild nature of the study imposed limitations. It created time pressures, and there was data lost for part of the idea categorisation phase, as the moving observer in the first brainstorm in the vertical setting failed to do the individual observations. So, this intended analysis had to be omitted. Kharrufa et al. (2013b) reports this as a risk of in-the-wild classroom studies. This may have also been an explanation for the observation that only the first group in the conventional classroom did any drawing, while all the others simply wrote text. Initially, it was thought that this may well have been an order effect (with the student experiences at the SDGs encouraging them to continue using only text for the brainstorm with cards), but the teacher later remarked that under time pressure, they may have slipped when giving the instructions to each group, encouraging drawing for the first group only.

It is noted that with a limited number of observers, reliability measures for the stationary and moving observers was not possible. Although all observers were trained on how to code the groups, observations are limited to what was captured according to the defined coding schemes. In short, this is a trade-off between what students’ data could be captured and the constraints imposed by running the collaborative task in a real classroom in-the-wild. Understandably, this limits these collected aspects.

As described in the study design, considerable care was taken with regard to the layout and seating for the learning environments, particularly the vertical condition. While the conventional and tabletop classes lent themselves to students sitting around the table, the vertical condition required some careful design choices. In all conditions, students sat around a table for the idea generation stage.

The potential effects of the brainstorming interfaces are now considered, particularly whether the design favoured one condition. The interface was carefully designed for each orientation, with care taken to avoid any potential bias. The tabletop version had been refined over several studies (Clayphan et al., 2011a; Clayphan et al., 2014b; Clayphan et al., 2016) and an explicit design goal was to make use of the tabletop’s features for users to sit around the table, face-to-face. For the vertical condition, informal testing and refinement of the interface took place. The study design also took careful account of this potential confound, with a series of questions asking students to explicitly compare the three settings. Students gave similar scores to both the vertical display and tabletop for being able to understand what was required to complete the brainstorm, represent ideas and being able to participate.

Of the six dimensions identified, two were specific to brainstorming: the count of ideas and the assessment of the quality of ideas, especially for those identified as best by the students and the teachers. Much of the work on brainstorming reports the first, partly because it is very easy to do but also because large numbers of ideas are claimed to enhance creativity (Osborn, 1953). It is unusual for brainstorming literature to attempt to analyse the quality of the ideas produced (Isaksen, 1998). The approach here was based on three analyses. The first and second were based on the students’ and three teachers’ assessment of those ideas the groups had chosen to share as their best. The third analysis involved two teachers scoring all ideas generated. In all cases, there was no difference across conditions and only weak agreement between coders. For example, the Kappa agreement between the two teacher’s ratings in the third case was only 0.31. This analysis had the USB higher than the others by a factor of 10. If valid, this is unfortunate; it was hoped a potential learning effect might have emerged with the last brainstorm producing better results. But the dominance of the USB topic may have masked that for this analysis. Overall, considerable effort was put into assessing the quality of the brainstorm results, but the results seem to mainly point to the difficulty of doing that.
Last, the study was prone to novelty effects, especially for the direct data from the students in the questionnaire. This is because the study was different from typical classes even for these students. The students moved to 3 different rooms, and used two forms of technology that are not the norm in classrooms. Students were also well aware that they were involved in a study, having been presented with the study description and consent materials a week prior, and they would have been very aware of the presence of the observers. This clearly has implications for authenticity. It is indisputable that tabletops are more novel than vertical displays and both are novel compared with the conventional index-card condition. Even with 35% reporting prior experience with a tabletop, the novelty effect is likely to have affected student ratings. This has implications for both research questions.

4.5.2 Research Question 1: Do SDGs provide benefits over conventional card-based methods for students learning to brainstorm?

Briefly, the key results for this research question was that technology-enhanced classrooms did provide benefits over the conventional classroom for several key indicators.

- Students created more ideas, a result that is considered important for brainstorming (Osborn, 1953).
- The typed, rather than handwritten ideas, had benefits in terms of sharing as they enhanced readability for all group members, with greater satisfaction at the rate and ease of production. This is also confirmed in Pantidi et al. (2009) and Jaco et al. (2014) who also noted impacts of hand-writing illegibility as a factor affecting collaboration.
- The visibility of all the ideas in the single display groupware conditions is likely to have helped spark new ideas, a finding reported by Jaco et al. (2014).
- Each group worked collaboratively in the single display groupware conditions, whereas in the index card classes, this was achieved for only 5 of 13 cases.
- The single display groupware devices increased students’ attention and interest in the activity, although this result is particularly prone to the novelty effect.
- Students perceived that the technology-enhanced classrooms enabled them to participate more and helped support collaboration.

In contrast to these results, there did not appear to be benefits in terms of:

- The number of top ideas coming more strongly from the SDGs.
- Observations of higher levels of constructing and monitoring behaviour from the SDGs.

4.5.3 Research Question 2: Do tabletops provide better support for students learning to brainstorm in terms of the nature of the collaboration (both observed and perceived) and in the quality of the brainstorm outcomes?

For this research question, the key differences between the tabletops and interactive walls were only on the measures from the student questionnaires.

- For mutual awareness, the students reported the interactive tabletop was better because it provided better support for face-to-face interaction.
- Two aspects were close to statistical significance in favour of the tabletop: the ability to represent ideas \( (Q1, p=0.056) \); and the technology supporting collaboration \( (Q9, p=0.087) \).

But the tabletops and interactive walls proved to be equally effective on many counts.

- Similar numbers of ideas were created.
- Similar numbers of top ideas from each technological condition.
• The observers assessed similar levels of: collaborative work and time spent within each of the participation strategies (constructing, monitoring and disengagement).

This study points to design considerations for creating future classrooms that support small-group collaborative learning activities by incorporating horizontal interactive displays.

• Horizontal displays create a design challenge for readability of all the ideas for all users. This was tackled with an egalitarian layout, with ideas in a circle around the table, making similar numbers of ideas correctly oriented to each user. This was intended to spur students to move the ideas and talk about them in the convergent categorisation and discussion phase.

• The position of students around the tabletop favoured egalitarian participation, with all naturally placed to interact with the interface, reducing the risk of students being excluded as was observed in the vertical condition. The recommendation is ‘design for egalitarian use’ and for devices where orientation cannot be guaranteed ‘design for orientation independence’.

• The tabletop, being visible to the teacher only when they are quite close, is likely to reduce teacher awareness of each group in the class. Thus a recommendation is to find a way to provide information to the teacher. A recommendation in the work of Kharrufa et al. (2013a) suggests that teachers be provided with group indicators via a private personal channel.

This study highlights particular benefits and considerations for creating future classrooms that support small-group collaborative learning activities that incorporate the use of vertical interactive displays.

• It has been demonstrated that, with careful design of the vertical layout, it is possible to utilise learning spaces that enable students to do brainstorming, a complex collaborative task effectively.

• Students found the vertical orientation facilitated engagement with the ideas of other members of the group, by affording quick readability.

• The design of the vertical display condition meant that the first stage of the brainstorm involved seated work for idea generation; this meant that a teacher (and other students) could readily scan around the room to view the progress of each group.

• The entering of ideas via individual keyboards at the vertical display mitigated the need for a complex method for registering and recording ideas. This meant students had a clear view of group contributions (without any of the readability issues encountered at the tabletop).

• A limitation was that not all students were able to interact with the surface (for the categorisation and discussion phase). There was not enough room for groups of four at the vertical display; this points to the need for strategies to address this problem, for example structuring the activity and scaffolding it to facilitate full participation. A recommendation is ‘design activities and spaces together for egalitarian use’.

4.6 Conclusion

The study in this chapter set out to gain insights into whether the use of interactive tables and walls could support the activity of small groups engaging in learning to brainstorm, compared with each other and with a conventional method of brainstorming without electronic support. This work was undertaken with an authentic learning activity within an authentic classroom context, with established subject learning objectives. The work is novel on several levels. It is the first to:

• compare vertical and horizontal multi-touch displays; previous work involved older pen interaction and mixes of digital and non-digital interaction,

• compare vertical and horizontal displays in an authentic classroom setting,
• compare these with the conventional classroom, and
• conduct the study in an authentic class setting with realistic class-group sizes of 3–4 students.

The brainstorming interfaces were carefully designed for each of the horizontal and vertical conditions to make good use of the different affordances of each. The interfaces adapted support for ‘interpersonal interaction’, ‘appropriately arranged users’, ‘simultaneous user actions’ and ‘user accountability’ (Scott et al., 2003; Kharrufa et al., 2013a). This is in contrast to previous work (Rogers and Lindley, 2004; Pantidi et al., 2009), which exhibited an assortment of design related issues (e.g. devices physically situated far from users, ergonomic problems, and technology imposed sharing limitations). A core contribution of this work is adding to the currently very small body of work on the ways that horizontal and vertical single-display groupware support collaborative activities.

Although no previous work had compared modern multi-touch displays; when this work began, prior literature (Rogers and Lindley, 2004; Inkpen et al., 2005; Pantidi et al., 2009) pointed to an expectation that the tabletops would give better support for collaboration in both the ideation and discussion phases than the vertical displays. The results here are particularly important in terms of the promise shown for interactive vertical displays. This may have been due to the careful design of the learning spaces with the interfaces and tuning the application to make effective use of the vertical orientation. Given the demonstrated effectiveness of the vertical displays, they seem particularly promising for supporting small group work and collaboration. Vertical displays can be placed around the classroom, with desks, wireless keyboards, and other devices moved nearby as needed. They have the merit of orientation familiarity, which can enable user interface designers to draw on established design knowledge. They also offer potential for teachers and learners to see the activity across the class. Moreover, careful design of the physical layout can facilitate some face-to-face interaction around an accompanying table, as in the classroom described here.

A core contribution of this chapter was the set of dimensions identified for studying collaboration around vertical displays and tabletops in the classroom. The first, the number of ideas generated is particularly important for the divergent ideation phase of brainstorming; it may be relevant to the divergent phase of other collaborative activities. The last, the quality of ideas; is important in assessing the outcomes of collaboration, although it is difficult to do, and influenced by a complex set of factors such as each group member’s background and motivation. The other dimensions were mutual awareness, which highlighted the intimacy of the tabletop and readability at the vertical displays; participation strategies, which showed how students accounted for technology/material affordances and limitations, level of interest and response to the learning space configuration. Multiple sources of evidence were drawn on: application logs and the index cards themselves; external observations; student questionnaire responses; and expert scoring of the outcomes. This approach is valuable for future studies of surface technologies intended to support collaboration in the classroom.

The results reported reinforce the importance of effective user interface design to leverage on capabilities afforded by both technology and the surrounding environment. This chapter highlighted affordances offered by different forms of single display groupware which can be considered when creating new learning designs. For this work, the technology helped create more ideas, but on quality, the outcome was not as strong as was expected, based on the literature claiming that quantity correlates highly with quality. The results also point to the potential benefit of a hybrid setup with both a tabletop and a vertical display, enabling the devices to complement each another, mitigating limitations of either device.

In summary, this work has provided key insights from an authentic setting, and is a key step towards the further understanding of how to make effective use of different single display groupware for supporting small group work and collaboration in educational contexts and settings.
Chapter 5

Harnessing Interactive Surfaces for Inquiry and Collaboration

This chapter is the third in the series exploring the potential of interactive tabletops to support rich small-group collaboration (Figure 5.1). This chapter investigates this with MuseWork, a collaborative museum worksheet and poster system. This chapter explores interactive surfaces in an in-the-wild setting at a local Museum with two visiting primary schools. A between-subjects study is conducted with 67 students with group sizes ranging from 3–7 learners. Designed with the museum educators, the learning activity and associated tool were crafted to support informal small-group collaboration, providing opportunities for active learning – with exploration of objects and cooperative social experiences. This included an inquiry phase to explore the museum exhibits and galleries with a portable tablet completing a worksheet aligned to the state syllabus, followed by a convergent collaborative phase, where students came together, shared collected materials and constructed a poster on an interactive tabletop or whiteboard. The output of which was taken back to school. MuseWork was built to run on two SDG devices which are becoming more readily available – single-touch interactive whiteboards and multi-touch interactive tables, the first of which are already heavily adopted in many educational institutions. This work complements the in-the-wild study of Chapter 4 (of which brainstorming was explored), taken to a new collaborative learning activity, collaborative poster creation. This is important so as to provide breadth in exploration, in understanding the potential of emerging pervasive devices in support of small-group work. The learning activity was designed to be genuine and integrate with the needs of the curriculum, with tasks related to knowledge acquisition and sharing. The work in this chapter aims to further close the knowledge gap with regard to

![Image of students using interactive surfaces](image)

**Figure 5.1:** Groups assembling a poster with information collected from their private tablet devices.

Aspects of this chapter were partly based on the following peer-reviewed publication:

i) A. Collins, A. Clayphan, J. Kay, J. Horder (2012). “My Museum Tour: Collaborative Poster Creation During School Museum Visits”. In: *Workshop on Educational Interfaces, Software, and Technology at CHI 2012*. This paper proposed a research agenda for using single-display groupware and tablets in museums to support collaborative learning activities.
the effectiveness of using interactive horizontal and vertical displays. The work in this chapter explores this with a focus on the children’s group participation, evaluating task achievement and observed group behaviours. This is done to establish an understanding of the extent to which the interactive surfaces were able to be harnessed, in support of real-world small-group activities, and what this means in general for single display groupware.

5.1 Introduction

Reiterating the thesis statement — to explore how to harness the affordances of interactive tabletops, for small groups of collocated people to do richly collaborative activities, this chapter takes to exploring this in a museum setting with primary school children as part of their regular excursion visits, in group sizes of 3–7 students. This provides insight into aspects not covered in Chapters 3 and 4, namely the exploration with a class of people other than adults; the investigation of the use of SDGs in a more open in-the-wild setting; and the use of SDGs with larger group sizes.

Museums are important and a well-respected source of educational and cultural resources (Cox-Petersen et al., 2003). Museums serve as diverse learning environments for students to take part in activities outside of a formal class, though are still typically linked to a curriculum. Museums have “the potential to engage students, to teach them, and to stimulate their understanding” (Gardner, 2011). Museums are often early adopters of new technologies, providing a test-bed and platform to offer collaborative experiences that can assist learning processes through hands-on interaction. Furthermore, it has been shown, that social interaction at museums can enhance cognitive processes (Blud, 1990). This fits well with the established position of museums in providing engaging learning experiences (Falk and Dierking, 2000; Kisiel, 2003; Falk, 2006; Griffin, 2007; Falk and Dierking, 2012). For school visits, a museum offers a rich environment for inquiry learning that draws on the museum exhibits (Block et al., 2012; Davis et al., 2013; Chu et al., 2015; Ma et al., 2015; Lee et al., 2015). One widely used and valuable approach to structuring class group learning is to provide students with a worksheet (Kisiel, 2003; Mortensen and Smart, 2007).

Current widespread carried devices such as mobile smartphones and tablets have the potential (Bowen et al., 2008) to play an important role in inquiry based learning (Linn et al., 2003; Bell et al., 2010; Sharples et al., 2014). These devices play two significant roles in supplementing a traditional worksheet. First, learners can hold a form of worksheet that acts as a guide as they explore museum galleries, and second, they enable learners to easily record images, sounds and text as they study and explore the different exhibits. One goal of this work was to explore the integration of these with SDGs, by designing a system that made use of tablets for these roles.

This chapter presents the design and evaluation of MuseWork1, a system to make use of both carried tablets and embedded multi-touch interactive tabletops and single-touch vertical displays to support small class groups visiting a museum. While there has been considerable use of interactive surface displays in museum exhibits, such as those reviewed in Geller (2006) and Michael et al. (2010), none have been used for class groups in combination with tablets to provide a combination of both individual inquiry learning and collaborative learning in the museum. MuseWork was created with support for three main elements:

1. A tablet device to guide students working individually, or in pairs, to explore the museum exhibits to discover answers to broad questions, and to collect materials discovered;
2. A collaborative activity using SDGs to support sharing and joint creation of a response to the worksheet’s questions; and

1Acknowledgment: MuseWork was built by Dr. Anthony Collins, as part of a collaboration between the Smart Services Co-operative Research Centre and the Australian Museum. My contribution was jointly helping run the studies, as well as having a major role in the evaluation, analysis, and write-up of the work. The design of MuseWork is described, so to contextualise its use relative to the other foundation interfaces reported (in Chapters 3 and 4).
3. The museum experience contributing to the students broader school learning. This means museum teaching staff are involved with the design of the worksheet and it links with the formal state syllabus, and the activity in the visit should link with other classroom activities.

The chapter seeks to extend the analysis started in Chapters 3 and 4 with regard to the way large screen interactive devices can be used to support small-group collaboration. This chapter explores the use of a multi-touch interactive table against a single-touch interactive whiteboard. Three hypotheses were formed to guide exploration in unpacking the use of the SDGs, these are:

1. Groups at the tabletop will display higher levels of engagement than those at the whiteboard.
2. Groups at the tabletop will be more effective in completing the poster to meet the worksheet criteria.
3. Students at the tabletop will report a more positive experience.

Each of these hypotheses was influenced by literature pointing to an expectation that the tabletops will provide better support for collaboration (Rogers and Lindley, 2004; Inkpen et al., 2005; Pantidi et al., 2009). The hypotheses were also informed by the different technology forms, with single-touch restricted to only the vertical condition. This chapter provides an opportunity to compare findings with those from Chapter 4, which used multi-touch SDGs for both conditions. This seeks to provide an informed understanding of the relative benefits of both tabletops and walls as used for small-group work.

The next section looks at the design goals underpinning MuseWork. This is followed by a section on collaborative learning systems in museum settings (to place and contextualise MuseWork), followed by the user view, the evaluation, the discussion, and then the conclusion.

5.2 Design Goals

The broad intention for designing MuseWork was to create an engaging experience for learners, based on a variant of a conventional paper-based worksheet learning activity, as well as integrating this with a shared social experience at a set of large interactive touch displays. Activity worksheets were drawn on as inspiration as they have been shown to be a useful mechanism in providing a scaffold to guide learners in the acquisition of new knowledge (Kisiel, 2003). From the outset, the design team included the learning services department of the museum. Three design goals were formulated based on constructivist and collaborative learning principles (Jonassen, 1999). These are:

- **Design Goal 1:** To support the student’s exploration of the exhibit gallery to gather materials to answer the questions in a worksheet, that makes use of a portable tablet. This part of the class-group experience was based on inquiry-based learning, where the museum environment provides a “display of rich and authentic objects, and limited guidance, [which] all support a learning approach of active inquiry and engagement” (Vavoula et al., 2009).

- **Design Goal 2:** To support a collaborative learning activity, where learners share information from the earlier gallery stage, making use of a shared touch display (either an interactive tabletop or whiteboard), to curate a new joint artefact, in the form of a poster that answers the worksheet. This part of the design explored how to harness the potential of interactive tabletops and whiteboards for sharing, collaborating, assimilating, and synthesising information from the students’ carried devices. This presented an opportunity for students to be in close proximity to one another, hands on the technology, and share and construct knowledge together as a group.

- **Design Goal 3:** To link the entire process back to the classroom and syllabus. This involved several elements. The worksheet itself was designed by museum staff to align with the state syllabus. The MuseWork design allowed the teacher to provide materials that would be available at the collaboration
stage; enabling a teacher to provide materials to link earlier activities from their class. Finally, the completed poster for each group could be sent back to the school for subsequent class use. This creates links between activities in-and-outside of the classroom. Falk (2006) notes the importance of this, as “events unfold for the individual after the museum visit”.

5.3 Literature on Collaborative Museum Learning Systems

While there have been many studies with interactive surfaces in museum settings (Geller, 2006; Michael et al., 2010), few have featured an both an inquiry based data collection phase and a small group collaborative phase. This section overviews a number of key collaborative learning systems in museum settings. These studies were chosen as they feature a similar design to MuseWork: they involve the collection of data and then make use of it; all involve primary school students; and all were set within a museum context.

Broadly, museums have often been early adopters of new technology to enrich the experiences of their users. Table 5.1 provides an overview of a number of different collaborative learning systems used with students in Museums over the past 10 years. The first column lists the system name and main reference. The next column shows information about the students in the evaluation studies; with the number of students and their age. The third column summarises the technology used. In all cases, the students gathered information using a small portable device, including various types of phones and tablets.

<table>
<thead>
<tr>
<th>Study</th>
<th>Students</th>
<th>Brief Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>uLearn</td>
<td>Mitchell and Race (2005)</td>
<td>8 students (Ages 9) Used mobile phones to retrieve extra information on exhibits (Note: not a smartphone).</td>
</tr>
<tr>
<td>Museum Detective</td>
<td>Thom-Santelli et al. (2006)</td>
<td>80 students (Grade 3) Used a hand-held Dell PDA device in pairs. High level of on task behavior observed.</td>
</tr>
<tr>
<td>MyArtspace</td>
<td>Vavoula et al. (2009)</td>
<td>23 students (Ages 13-14) Information collected via mobile phones, automatically uploaded to the web, for later use in the classroom.</td>
</tr>
<tr>
<td>MuseumScouts</td>
<td>Wishart and Triggs (2010)</td>
<td>225 students (Ages 10-19) Learners collect information at the museum via smartphones to later create an interactive multimedia teaching presentation to their fellow students.</td>
</tr>
<tr>
<td>Zydeco</td>
<td>Kuhn et al. (2012)</td>
<td>54 students (Ages 11-13) Data collected on smartphones, then a collaborative phase with tablets where scientific explanations are built up using all the collected evidence.</td>
</tr>
</tbody>
</table>

Table 5.1: Collaborative learning systems in museum settings.

The uLearn system (Mitchell and Race, 2005) explored the use of a mobile phone and fiducial tagged exhibits to discover information about certain museum artefacts. The study assessed how learners were able to use the camera capture facility to learn more about the exhibits and objects in the museum. Unfortunately, reflecting the state of the art of the time (~2005), results were dominated by technical difficulties in taking a photograph. The study did point toward a need for more facilities, such as note taking, and the ability to record audio to complement the pictures taken.

The Museum Detective (Beyond just the facts: Museum detective guides; Thom-Santelli et al., 2006) was built to support students as they explored the museum. It aimed to guide the learning activities of school children with a hand-held PDA device. It did this by prompting students with questions and clues to uncover hidden information. The evaluation study involved third graders from a local school. This compared 80 students using handheld devices with 60 students using pen and paper. The objectives of using the technology were: (1) to improve interactivity and engagement over the pen and paper Museum Detective activity; (2) to help students visualise the context of different times and places; and (3) to
introduce students to technology in a museum. The authors concluded that the hand-held device worked well as a replacement for the classic worksheet, and required less prompting in later classroom sessions when students were asked to recall information from the museum session.

Myartspace (Vavoula et al., 2009) was a mobile-phone service to support inquiry-led learning while children were in the museum. It enabled students to gather information from tagged objects, take pictures, record sounds and type comments, based on questions on a worksheet. It automatically stored items, making them available on a website for later learning activities. This website supported viewing, sharing and organisation. Back in the classroom, students created personal galleries and presentations based on the collected data. The study demonstrated Myartspace was effective in enabling students to gather information and provided support for reflection as well as other learning opportunities.

MuseumScouts (Wishart and Triggs, 2010) explored how schools and museums could use interactive technologies (smartphones and web based authoring tools) to support learning. MuseumScouts was deployed to 27 schools, with 14 projects involving 225 students and 25 teachers. MuseumScouts enabled students to collect information during museum visits, and then use this information later in the classroom to create interactive multimedia presentations and quizzes – both to facilitate peer learning. The evaluation revealed different outcomes across schools and countries, with higher uptake and integration when activities were aligned to actual class lessons as part of the curriculum.

The final system is Zydeco (Kuhn et al., 2012). This used mobile devices (smartphones and iPads) to help students to engage in science related inquiry activities, integrating classroom aspects and informal learning. It had three components: (1) a website where students set up and accessed investigation questions; (2) a phase for collecting annotated multimedia data from a museum; and (3) a phase for constructing scientific explanations using both the personal and peer data collected. The evaluation study involved 54 students (aged 11-13), from three different classes, to explore a local history museum. Students spent 1 hour collecting data in the museum, and then 4 hours (1 hour a day, for 4 days) to create scientific explanations, using a tablet application. Students worked in pairs. In total, 54 students collected 434 pieces of data – 327 photos (75%); 98 photos with an audio note attached (23%) and 9 audio notes (2%) – which is 8 pieces of data per student on average. The scientific explanation phase was done at the tablet device, where students accessed their peer’s data sets. For accessing peer data, the authors found that tagging was valuable for annotating data, which facilitated search. Pictures were found to be used more than audio. This work contributes to research on how to support finding and utilizing personal and peer-collected data for educational activities. It presents one of the first studies on the ways students, particularly those new to science inquiry, thought about and utilized large quantities of annotated peer-collected image data, with an effective interface for exploring the data and creating explanations on tablets together. This work was later extended as part of the EvoRoom project (Lui et al., 2014a; Lui et al., 2014b; Lui, 2015), which supported learners with real-time immersive and reactive visualisations on large interactive whiteboards – using content collected from each learners portable device to help foster community discourse and inform inquiry. Zydeco was authentic, involving a rich activity that was grounded on sound pedagogic principles. It called for sustained work, over several days. It was framed around constructing scientific explanations. These aspects make it very rich but also mean that it may not fit gracefully with the needs of a typical school visit to the museum, where the classroom teacher may wish to use the visit in other ways.

In summary, this section has characterised several systems that have similar aims to the design goals of MuseWork. All involve forms of information exploration and learning inquiry at a museum. They explore various forms of technology for this phase at the museum, with various forms of guidance. In all these systems, only the information collection phase was done at the museum. Any consolidation activities were completed back in the classroom. The design goals of MuseWork called for a more complete and contained experience at the museum, involving both collection of information and some consolidation.
5.4 User View

During design consultations with the museum learning staff, poster creation was chosen for the collaborative phase with the interactive displays. This was due to its generic applicability with different exhibits and its potential for diverse forms of small group collaboration – with the likelihood of discussion being required and facilitating a need for consensus building processes. The generic nature of the activity also allowed it to be repurposed as required for different visiting schools and not be affected by exhibit changes.

5.4.1 Information Gathering Phase

For this phase, students used a portable tablet (an iPad). When there are more students than iPads, students worked in pairs. Figure 5.2 shows the introductory screen of the tablet interface. The tab at the bottom of each screen has buttons for switching between: (a) photo capture, (b) note creation, and (c) the worksheet. Figure 5.3 shows one of the worksheets designed by the museum staff, to match one set of the state’s syllabus learning outcomes. Students could readily refer back to this worksheet as required.

When the photo tab was clicked (Figure 5.2–a), the collection of images already taken was displayed to the student (Figure 5.4). To take a photograph, the student needed to tap on the ‘+’ button (top-right). Once an image was taken, students could add a title to the resource, by ‘dwelling’ over the picture (a long press action). Figure 5.5 shows a student using the camera to take a photograph of an emu. The note tab (Figure 5.2–b) worked in a similar manner.

5.4.2 Collaborative Phase

After students finished exploring the exhibit, they moved to a space with the interactive surfaces. Students were instructed to start the collaborative poster creation phase by first taking turns to share the materials collected. Students could do this either by sharing materials from the photo or note screens of their iPads. Each iPad was pre-configured to send content to either the tabletop or whiteboard. The groupware interfaces supported touch actions to arrange, rotate, and resize elements. Next, students were encouraged
to work together to create the poster. Figure 5.6 shows an example toward the end of the poster creation phase. There was flexibility in the process of making the poster. An example of a typical sequence, from the time the students have shared their material onto the interactive display is now described.

First, students decide on the poster background they want from the container shown in Figure 5.6–b. The student then drags the background to the main screen area. The widget holding the backgrounds may then be moved by the student to the ‘black hole’ (Figure 5.6–a) as it is not needed any more. To create the poster, the students discuss and agree on the pictures and notes to be placed on the poster, ‘dragging’ items onto the poster background as needed. During discussion, students can create new notes. They can do this in two ways. They can use their iPads to create more notes, potentially working in parallel, and send them to the screen for placement on the poster, or they can create a note directly at the groupware device (Figure 5.6–f) and use a virtual keyboard (Figure 5.6–e) to input content to the note. Students may also use the application menu, shown in Figure 5.6–d to bring up additional tools. There are tools to create titles, text boxes (similar to notes) and containers. To use them, students simply drag them from the menu. Figure 5.6–c shows an example poster with the title “Animals of the sea!”.

![Figure 5.4: The photo tab. The top right (+) button activates the camera.](image)

![Figure 5.5: A student taking a photo of an emu.](image)

![Figure 5.6: User view of the interactive tabletop/whiteboard 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; (c) a poster in construction; (d) the application menu to activate poster elements (containers, title and text boxes for the poster, keyboard and export tools); (e) on-screen keyboard (sourced from the application menu); and (f) a text box.](image)
5.4.3 Linking Back to the Classroom

The design of MuseWork had two elements to connect to the classroom. The first, the collaborative phase at the interactive display could be primed with materials that a teacher provides. This enables a teacher to discuss the topic in class, in preparation for the museum visit. The second, is an export tool (Figure 5.6–d) which saves the poster for later classroom use at school – as both a web-page and as a PDF document. The web-page version of the poster can later be modified with existing web-page editing software.

5.5 Evaluation

The evaluation had two major goals. The first was to assess if MuseWork met the formulated design goals, and the second, was to explore the nature of interactive multi-touch horizontal displays versus interactive single-touch vertical displays for small group work, complementing the work started in Chapters 3 and 4. This led to the following four hypotheses:

- **Hypothesis 1**: The design goals, with either the tabletop (TT) or the whiteboard (WB) for the collaborative phase are met. This assesses whether MuseWork, as a whole, supports: the inquiry learning phase in the museum gallery, where individuals or pairs use tablets to gather relevant material to answer the worksheet (Design Goal 1); the use of either the whiteboard or tabletop to collaboratively create a poster that answers the worksheet (Design Goal 2); and the extent to which the museum activity linked back to the classroom (Design Goal 3).

- **Hypothesis 2**: Groups at the tabletop (TT) will display higher levels of engagement than those at the whiteboard (WB). This is based on literature (Rogers and Lindley, 2004; Inkpen et al., 2005; Pantidi et al., 2009) predicting that the tabletop will be superior to the vertical whiteboard and also the fact that the vertical display in this instance is single-touch.

- **Hypothesis 3**: Groups at the tabletop (TT) will be more effective in completing the poster to meet the worksheet criteria. This is based on tabletop affordances of: multi-touch; a larger perimeter enabling more students to interact (4 accessible sides); and opportunities for simultaneous face-to-face interaction. All of which promote the likelihood of increased effective parallel activity. This is compared with the single-touch whiteboard, where the children will likely need to manage turn-taking.

- **Hypothesis 4**: Students at the tabletop (TT) will report a more positive experience. Similar to the previous hypothesis, this is based on the notion that multi-touch at the table combined with the face-to-face interaction will lead to greater student satisfaction.

5.5.1 Participants

Two visiting school groups participated in the study for a total of 67 students. The first school group had 21 students (ages 10–12, mean 11.2, 33% male, 67% female), and the second school group had 46 students (ages 11–14, mean 13, 50% male, 50% female). Parental consent forms and working with children checks were completed ahead of the visit\(^2\). The teachers allowed the students to form their own groups. This resulted in all groups being single gender, which is common for students of this age (Underwood et al., 2000). This is the type of factor that arises in-the-wild, where a teacher has control of their class. It had the merit that students appeared to all be comfortable with their group members. From the background questionnaire, 10% of the students reported having used a tabletop before (unrelated to this work), and all students reported previously having used a touch-capable tablet.

\(^2\)Ethics protocol 12560 – ‘Collaborative tabletop file system access in pervasive computing environments’
5.5.2 Apparatus and Data Capture

Twelve iPads were used for the individual stage of the activity (six for each condition). The whiteboard was a 60" LCD-based SMART Board, with DViT technology for sensing touches (Figure 5.1a, pp. 65). While this hardware accepts up to two concurrent touches, the accuracy of the two touch mode was unsatisfactory, exhibiting many anomalies. So the SMART Board operated as a single-touch device (which it could do accurately and predictably). It was observed that students used the whiteboard with their dominant hand, and comfortably held the iPad in the other. The tabletop was a 46" display with 1080p resolution with a multi-touch overlay (capable of sensing up to 32 concurrent touches). The tabletop enclosure had a 10cm rim around the display where students could place their iPads. The tabletop was at a standing height appropriate for the students (Figure 5.1b, pp. 65).

The collaborative phase with the SDGs was video-recorded. In addition, the interface was configured to log all interface actions to support later video analysis. During each task, experimenters took notes according to a set of pre-defined criteria: task timing, student positions (at the display, away but engaged, away and disengaged), the use of the iPads during the collaborative activity, and any interface conflicts.

5.5.3 Experimental Design and Procedure

A between-subjects study design was used. This was dictated by the time constraints of the school visits – with just enough time for each group to use one of the large collaborative displays. Table 5.2 summarises the (broad) timing of the workflow for a visiting school.

<table>
<thead>
<tr>
<th>Time</th>
<th>Duration</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>00:00</td>
<td>5 mins</td>
<td>General introduction, task overview and tutorial for the iPad interface.</td>
</tr>
<tr>
<td>05:00</td>
<td>20 mins</td>
<td>Individual gallery activity.</td>
</tr>
<tr>
<td>25:00</td>
<td>5 mins</td>
<td>Interactive display interface tutorial, and reminder overview of this part of the task.</td>
</tr>
<tr>
<td>30:00</td>
<td>20 mins</td>
<td>Collaborative practical activity on the interactive display.</td>
</tr>
<tr>
<td>50:00</td>
<td>10 mins</td>
<td>Background and post-experiment questionnaires.</td>
</tr>
</tbody>
</table>

Table 5.2: Timing plan for the activity stages.

Gallery Activity Introduction

Upon arrival, students gathered in the main activity room and were welcomed by the Museum Learning Services staff. Students were given tablets for the self-guided activity. The activity (on the worksheet) was then explained. Next, students explored the gallery, collecting photographs and creating textual notes to answer questions. This consisted of selecting animals of interest and recording details of the animals habitat, prey and predators.

iPad Tutorial

The experimenters gave a short tutorial on how to use each aspect of the iPad application, with a set of sample images and notes collected in an unrelated gallery. The students were asked to try each feature, to ensure they were comfortable before starting the real activity. This gave students confidence in using the iPad and an opportunity to move beyond the novelty of the system. The tutorial consisted of:

1. Viewing the worksheet for the activity just explained by the Learning Services staff.
2. Taking a new photo in the photos tab (using the ‘+’ button).
3. Giving the new photo a title (pressing the “Edit Title” button).
4. Deleting a photo (pressing the “trash can” icon).
5. Composing a new note in the notes tab (using the ‘+’ button).
6. Deleting a note (pressing the “trash can” icon).

Individual Gallery Activity

For this 20 minute activity, students explored the gallery with their iPads, capturing information as needed for the worksheet tasks. Figure 5.7 shows the floor plan of the exhibit the students explored.

![Figure 5.7: Floor-plan of the ‘Surviving Australia’ exhibit, which the students explored with their iPads.](image)

Interactive Display Interface Tutorial

Upon returning to the main activity room, students split into two groups, one at the whiteboard (WB), and the other at the tabletop (TT). The whiteboard and tabletop were at opposite ends of the room. A short interface tutorial was given by the experimenter at each device, where students were asked to try out each introduced feature. There was one difference between the tutorials in the two conditions. Due to single-touch input at the whiteboard, groups were told that only one finger at a time could be in contact with the whiteboard. A ‘rosize’ gesture combining both rotate and resize was demonstrated at the whiteboard as the means for enlarging and rotating images. On the tabletop, a 2-finger ‘pinch’ gesture and ‘rotate’ gesture was demonstrated instead. At the conclusion of the tutorial, the interface was reset by the experimenter, ready for the main group activity.

Collaborative Poster Creation Activity

The experimenter instructed students to begin the poster creation activity, explaining its three stages. The experimenters stood away from the devices and took observations. The class teacher split their time between the two groups. The three stages were:

1. Share individual materials. Students took turns to send materials to either the tabletop or whiteboard.
2. Create the poster. Students placed materials on a poster background, adding extra poster elements, such as titles and notes. Students needed to decide which individual materials to include, and which to discard.
3. Reflection. Students were asked to reflect on their poster, adding a new note explaining what the chosen animals had in common.

At the end of the activity, the experimenter saved the poster, to send back to the school.
Post-experiment Questionnaire

The post-experiment questionnaire was designed to capture both qualitative and quantitative responses about the students’ experiences. It had 6 closed questions with a Likert-scale rating, and provided space for open responses to explain the ratings. The students were asked: how the displays facilitated sharing; awareness of other group members’ actions, enjoyment, usability, interface learnability, and satisfaction with the produced poster. Three additional open ended questions asked the aspects students liked, disliked, and for any other comments.

Background Questionnaire

The background questionnaire gathered demographic information (age, gender) and past computer experience. It asked the student’s average number of hours per week of computer use, and if they had any previous smartphone or tablet experience.

5.6 Results and Analysis

Students were observed by two researchers. On the whole, groups appeared interested and engaged with both the information gathering in the museum galleries, and the collaborative activity at the SDGs. Groups invested genuine effort in assembling their posters (such as those in Figure 5.8), taking care to select appropriate backgrounds, colours for notes, and arranging collected information to address the required worksheet tasks.

Table 5.3 lists the dimensions of analysis evaluated in the study. These are: physical participation, group disengagement, interface usage, student arrangement, task achievement and student feedback. These were chosen to provide a holistic picture in terms of the group processes, group work and group collaboration observed. Each analysis form is linked to the earlier stated hypotheses. Information to
support each analysis was drawn from the collected application logs, the researcher observation notes, video codings and feedback from the student questionnaires.

Table 5.4 presents the demographics of each group along with a set of key results from the application logs and video codings. Table 5.5 presents descriptive statistics for the tabletop and whiteboard conditions, with statistical tests comparing the two. The touches section (rows 4–6) of Table 5.4 report on touch events that successfully manipulated an object (e.g. move, rotate, resize). For the single-touch whiteboard, this logged data excluded attempted touches where another user was already manipulating an object. The ‘touches per minute’ row indicates rate of activity. This ranged from 74.31–102 touches per minute for tabletop groups, and from 20.31–42.72 touches per minute for the whiteboard groups. The ‘touches per minute / group size’ row standardises this activity by the number of people within each group. For this, the tabletop ranged from 12.39–19.05 touches per minute per person, and for the whiteboard, this ranged from 2.9 – 11.84 touches per minute per person. This measure is reported to put the different sized groups on equal terms with each other. The number of touches recorded at the tabletop is in-line with the work by Rick et al. (2009). The video section (rows 7–9) of Table 5.4 reports on outputs of the video codings completed by the two observers. Each observer used the following when reviewing each video: ATDISP – whether the students are at the display and able to reach the screen; AWDISP – if some students are engaged in the task but standing back from the display so as to let other students interact with the display; and ODISP – whether any students are sitting out of the activity completely, noticeably away from the display and not participating (in other words, disengaged). For the measure of touches per min per student and the video coding measures, these were tested for statistical significance (Table 5.5). The tabletop was found to be statistically higher for both the ‘number of touches per minute per student’ (ATDISP) and for the metric of ‘the percentage of time students were all at the display’ (ATDISP). The whiteboard was statistically higher for the metric of ‘students away from the display’ (AWDISP), as well as for students observed to be ‘sitting out of the activity’ (ODISP). The next subsections detail the results of the analyses undertaken.

<table>
<thead>
<tr>
<th>Dimension of study</th>
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<th>Questionnaire</th>
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<td></td>
<td>✓</td>
<td>×</td>
</tr>
<tr>
<td>Group Disengagement (H2)</td>
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<td></td>
<td>✓</td>
</tr>
<tr>
<td>Interface Usage (H1)</td>
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<td>✓</td>
<td>×</td>
<td>×</td>
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<td>×</td>
</tr>
<tr>
<td>Task Achievement (H2)</td>
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<td>×</td>
<td>✓</td>
</tr>
<tr>
<td>Student Feedback (H4)</td>
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<td></td>
<td>×</td>
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**Table 5.3:** Mapping of analyses with the hypotheses and collected data sources.

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</tbody>
</table>

**Table 5.4:** Data on each group, drawn from the device application logs and the videos.
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<table>
<thead>
<tr>
<th>Item</th>
<th>Tabletop</th>
<th>Whiteboard</th>
<th>Statistical Test</th>
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</thead>
<tbody>
<tr>
<td>(Touches) Per Min/Group Size</td>
<td>(15.19 (2.74) 12.39 19.05)</td>
<td>(6.09 (2.86) 2.9 11.84)</td>
<td>Welch's t-test: t(10)=5.1, p=0.0004, Cohen's d=2.97</td>
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<tr>
<td>(ATDISP) % at TT/WB</td>
<td>80% (9.02%) 71% 98%</td>
<td>40.67% (14.09%) 23% 66%</td>
<td>t(9)=6.59, p=0.0001, Cohen’s d=3.81</td>
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<tr>
<td>(AWDISP) % away</td>
<td>10% (9.02%) 2% 29%</td>
<td>47% (12.21) 30% 67%</td>
<td>t(9)=5.45, p=0.0003, Cohen’s d=3.15</td>
</tr>
<tr>
<td>(ODISP) % sitting out</td>
<td>0% (0%) 0% 0%</td>
<td>12.33% (9.6%) 0% 28%</td>
<td>t(5)=2.87, p=0.03, Cohen’s d=1.66</td>
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</table>

Table 5.5: Descriptive statistics over the SDGs. The numbers for the tabletop were statistically higher for ‘touches per min/group size’ and for ‘student coded at the display’ (ATDISP).

5.6.1 Physical Participation

Physical participation was measured by the number of touches registered at the SDGs. Table 5.4 shows there were more touches at the tabletop than the whiteboard (row 4). This was statistically significant at the p<0.05 level (t critical=1.99, t(65)=14.83289, two-tailed p<0.0001). The higher count for the tabletop groups is not surprising, as the device was multi-touch. Accounting for group size, the number of touches per minute per student was still statistically significant in favour of the tabletop (t(10)=5.1, p=0.0004, Cohen’s d=2.97). Some of this increased activity was attributable to some students tinkering with elements near them, rather than necessarily concentrating or collaborating with their colleagues. This kind of off-task behaviour is in line with work conducted by Kharrufa et al. (2013b) with tabletop class groups in-the-wild. However, some touches at the tabletop were due to effective, parallel work to select material for the poster. The lower averages for the whiteboard reflect that students needed to take turns to interact and contribute to the poster. For the initial sharing phase, this was a benefit since it made it natural for the student sharing their information to take control and gain attention of the group.

Group size also affected the number of touches. The smallest groups: S1-G1 (4 boys at the tabletop) and S1-G2 (3 boys at the whiteboard), each had the highest number of touches relative to group size (a mean of 19.05 for S1-G1, and a mean of 11.84 for S1-G2). The mean for the whiteboard group (S1-G2) was similar to three of the larger tabletop groups (S1-G4 (12.49); S2-G1 (12.7); and S2-G6 (12.39)). The largest group for the whiteboard – S1-G3 (7 girls at the whiteboard) had a low number of touches relative to their group size (2.9 touches per min per student), whilst the largest group for the tabletop (S1-G4 – 7 girls) had a relatively high number of touches per minute per student (12.49) compared with all the whiteboard groups (but was the second lowest figure over the six observed tabletop groups). For both conditions, a very strong negative correlation between ‘group size’ and ‘touches per minute / group size’ was observed (whiteboard: pearson’s r(4) = -0.92, p = 0.01; and the tabletop: pearson’s r(4) = -0.83, p = 0.04)). This indicates that in larger groups for both conditions, students did fewer touches. One partial explanation is that this may reflect members working more collaboratively, rather than working in parallel or playing. For the whiteboard this may also be attributable to some students being disengaged (coded as sitting out), lowering the overall group mean.

5.6.2 Student Arrangement

Student arrangement is reported using the video codings performed and the observation notes taken. Figure 5.9 illustrates the most common formations observed at each device. The tabletop in its configuration in the museum had all four sides accessible, this allowed it to easily accommodate all students from each of the groups (up to 7 students), standing face-to-face and these students were generally able to stay in the same position for the entire task if they wished. By contrast, the whiteboard provided a smaller direct interaction space. It was observed that up to a maximum of 5 students could collaborate effectively at the whiteboard concurrently. This forced students in larger groups to move away from, and then back to the
whiteboard. Students had to stand shoulder-to-shoulder, thus students were generally not able to stand in the same spot for the experiment (if they did, others may have been disadvantaged). It is unsurprising that different arrangement behaviours were observed between the two conditions.

The smallest groups, S1-G1 (4 boys at the tabletop) and S1-G2 (3 boys at the whiteboard) were easily accommodated at either device. For S1-G1 (TT), 89% of the time – all four students were coded as at the display (ATDISP), which is close to the 90% average over all tabletop groups. For S1-G2 (WB), the three students were coded at the display (ATDISP) for 66% of the time, and while this is smaller than the reported tabletop percentage, this was the highest among all the whiteboard groups and more than a standard deviation above the whiteboard mean of 40.67%. These results, for group sizes of 3–4, show that both the tabletop and whiteboard were effective for these group sizes. This is similar to the group sizes of the earlier studies in Chapters 3 and 4.

For the larger groups (6+ students), for tabletops, most groups stayed above 90% at the display within a session, with the exception of S2-G1 (6 boys at the tabletop) with 71%. For the whiteboard groups however, there was a significant drop, with a range of 23% to 50% (an average of 35.60%, when S1-G2 is excluded from the calculation). The whiteboard groups had a correspondingly high portion of students standing back from the display (AWDISP: 30–67%, mean 47%), however many students still participated while watching others. This is based on the experimenter observations that noted that some students stood back from the whiteboard display — often awaiting their turn — where some students walked off and stopped participating (showing signs of boredom and frustration as they did so) (ODISP: 0–26%, mean 12.33%). By contrast, no sitting out (ODISP) events were coded for any of the tabletop groups. Correspondingly, a lower number of students were coded as away in the tabletop condition (AWDISP: 2–29%, mean 10%). These aspects were found to be statistically significant between the two conditions in favour of the tabletop (Table 5.5–‘right most column’).
5.6.3 Group Disengagement

As there were no cases of sitting out (ODISP) observed at the tabletop, this section only reports on the whiteboard. The percentage of time that some students were coded as sitting out of the activity is shown in the last row of Table 5.4 (ODISP – % sitting out). The highest level of sitting out was observed from S1-G3 at 26%. This was a group of 7 girls, also the youngest participants (aged 10–12), and with the largest group size. Striking coordination problems were observed in the first two stages of the collaborative activity. These included students reaching over each other and trying to move their collected items on the display, resulting in touch conflicts. While no students were observed as dominating the whiteboard interface, frustrations were noted. For example, one participant from S1-G3, started the activity, gradually moved backward and, after 3 minutes, lost interest. She returned to the whiteboard later but only used it for 1 minute, when others stood away from the display and were talking with each other. This came out in her questionnaire feedback with: “people hogged it”. Similarly, another student in S1-G3 tried to participate early in the activity, but withdrew and stood away once the whiteboard became crowded. These observations reflect the fact that a group of 7 students working without explicit guidance is particularly difficult to self-coordinate with a single-touch whiteboard.

The second highest group with coded sitting out events was S2-G2 at 20%. This had 6 girls who stood close to the whiteboard, frequently reaching over each other at the beginning of the task. This poor sharing of the workspace caused some of the girls to stand back or sit down and not pay attention to what was happening. A group of 4 students dominated the display for the majority of the activity (Figure 5.10). For the final 7 minutes, the same 4 girls were the only ones interacting; with the other 2 having lost interest. Four of the six girls commented on single-touch as having an effect on group processes, for example: “we sometimes got in each other’s way and forgot that only one person could [touch the display] at a time”, “it all looked good in the end after some difficult problems with only one touching at a time.”, and “it wasn’t difficult, it was fun and really easy to use, but sometimes it was frustrating when more than one person tried to touch the screen”. Another student noted collaboration issues: “Everyone wanted to do their own thing and didn’t share well, they just wanted to do it themselves.”

S2-G5 had 6 boys at the whiteboard with 17% of the time in the session coded with some students sitting out. One member of this group was particularly dominant — he stood in the centre of the display and rarely interacted with his teammates throughout the session (Figure 5.11). This made it difficult for others to use the whiteboard display. The student in the center remarked that he had a very positive experience from his questionnaire feedback, whilst the remainder of the group reported problems with sharing and group processes. Notably, this group had the second lowest average number of students at the display during the activity (ATDISP: 32%).

Figure 5.10: S2-G2 (WB) – 4 girls at the whiteboard. 2 girls standing back – one with a partial view, and the other with an obstructed view (in red).

Figure 5.11: S2-G5 (WB) – 1 main user (in green) at the whiteboard for most of the activity.
S2-G7 had 5 girls at the whiteboard with a 10% coded rate of sitting out. This group was careful in the way they shared the display. This was the only whiteboard group where all participants shared the display (for part of the task), in the formation shown in Figure 5.9–Whiteboard (a). For this group, the total time when four or five students were at the display totalled 66 seconds (out of 17 mins), primarily for quick confirmation with group members when choosing what to do next.

Continuing with the whiteboard, cases were observed where students worked well together. For example, S2-G4 (6 girls) with 1% of time coded as sitting out and S1-G2 (3 boys) at 0% with no exclusion events observed. For the case of S2-G4, these six students 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. Then two other students periodically worked with her while others were using the whiteboard. Thus, students who were waiting their turn were able to remain active. There was also a frequent rotation of students at the display, providing interaction opportunities to those standing back.

These results suggest that, for this age group, the number of students that can be accommodated within the direct interaction space of the single-touch whiteboard display directly impacted the students’ arrangement and subsequent engagement within the activity. In this case, dominant students can pose serious problems, making it more difficult for other students to contribute. However, the effective management strategies of S2-G4, point to the potential benefits that might be realised with explicit teaching of strategies on how to effectively utilise the constrained display surface.

5.6.4 Interface Usage

The experimenters took notes throughout each of the trials. Three groups (S2-G2 – 6 girls at the whiteboard; S2-G3 – 5 boys at the tabletop; and S2-G4 – 6 girls at the whiteboard) adopted a strategy to carefully arrange collected materials on the display to support their discussions. For example, in S2-G3, students arranged all the collected notes and photos on the left and right sides of the display, so the poster background could be placed in the middle without occluding any of the collected materials.

Text entry on both displays was a problem with the larger groups, typically halting use for others while that person typed. Although both interfaces allowed multiple virtual keyboards to be present, at the tabletop the on-screen keyboard needed to be enlarged for effective typing, often protruding into the other students’ personal work areas. As the whiteboard was single-touch, the use of the on-screen keyboard, meant that rotating, resizing or placing objects on the poster needed to halt during its use. This indicates the potential complementary use of the iPads during the collaborative activity as a method to remain engaged and remove input blocking (Verma et al., 2013), which some groups did, for example: “some people were writing things on their iPad and put it on the tabletop” (S2-G3 (TT)). The complimentary use of the iPad in this way increases opportunities for all members to contribute (Mennecke, 1997). These observations also point toward a possible need for more explicit guidance for scaffolding collaboration, for example it was not apparent to all students they could use their iPads with the SDGs: “it would have been good to have more people able to use and type information (S2-G4 (WB))”.

5.6.5 Task Achievement

Table 5.6 shows the extent to which the final posters met the worksheet criteria. The worksheet asked for a photograph of an animal, its name, its habitat and a corresponding picture and name of its prey or predator. Rows in grey indicate where more than one item was not met. Two of the six tabletop groups’ posters met all the criteria, and one more group (S2-G3) met all but one. Of the three tabletop groups who did not meet more than half the criteria (S1-G4, S2-G1 and S2-G6), S1-G4 and S2-G6 showed a non-serious attempt at answering the worksheet tasks, with photographs of students next to the animal
CHAPTER 5. HARNESSING INTERACTIVE SURFACES FOR INQUIRY AND COLLABORATION

exhibits, but with a lack of explanatory notes on the final poster. S2-G1 had a deeper attempt, with a broader collection of animal photographs, however even its with 5 notes on the poster, these were vague and unrelated to the worksheet tasks, for example: “these are all awesome animals”. By contrast, five out of six groups at the interactive whiteboard met all criteria and one more group met all but one. The logs were examined from the iPads to see if the tabletop groups that did not meet the task objectives, had photographs or valid notes that could have helped them achieve the worksheet objectives. This appeared to be the case for two such groups – S1-G4 and S2-G6.

It is noted that the literature on small groups, indicates that high levels of collaboration are not always correlated with the production of high quality outcomes (Cohen, 1994). It is still striking that the tabletop condition was so much more strongly associated with posters that failed to meet 3-4 of the 5 worksheet tasks. This sort of off-task behaviour with tabletops has also been reported by Kharrufa et al. (2013b) who examined the use of tabletops in in-the-wild classroom environments. Using a Welch’s t-test to compare the coverage over the completed worksheet criteria for both conditions, an approaching statistically significant effect was found ($t(6)=2.3, p=0.06, Cohen’s d=1.33$), meaning that for these groups, the whiteboard did appear to have a higher task-related achievement. The near statistical significance effect was the still evident even when all but one item achieved was considered ($p=0.08$). For the final product, most groups had an assortment of photographs and entries that detailed their responses to the worksheet. Selected actual notes from the final posters from the student groups are shown below:

- S1-G1 (TT): “I pick the green frog. [There are] around 37 species of frog[s] found in the Sydney region. The green frog eats flies [and] water beetles.”
- S1-G3 (WB): “Habitat: Dry and forests. Prey: short faced kangaroos. Predator: none. The Tasmanian tiger was fierce and a predator to a lot of animals. It hunted mostly large animals. It looked like a tiger with stripes and had a large jaw.”
- S2-G2 (WB): “Penguins and Leopard Seals. Leopard seals are the penguins biggest predators. They are found in the Antarctic. Leopard seals are the only seals know[n] to eat other seals.”
- S2-G3 (TT): “Australia is home to 190 species of snake! 25 of them are toxic to humans and 20 of them are in the 25 most venomous in the world.”
- S2-G4 (WB): “Salt-water crocodiles are found in rivers in the top of Australia. The baby crocodiles feed on insects. Adult crocodiles eat wallabies, pigs and sometimes other crocodiles.”
- S2-G7 (WB): “Blue bottles prey on small sea creatures who fall into their long stinging tentacles.”
- S2-G8 (TT): “The blue markings on the blue-ringed octopus light up when it attacks or feels threatened!”

<table>
<thead>
<tr>
<th>Group</th>
<th>Cond.</th>
<th>Gender</th>
<th># ppl</th>
<th>Items on the poster # Images</th>
<th># Notes</th>
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<th>Habitat</th>
<th>Prey/Predator Name</th>
<th>Photo</th>
<th>Notes</th>
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</table>

Table 5.6: Poster assessment against the set worksheet criteria. Rows in grey indicate the group omitted 1 or more items from the final poster.
Possible gender effects were explored from the analysis of the final products, though no patterns were found. Other studies, such as Harris et al. (2009), have reported female groups having better on-task discussion and being more equitable in participation when using a single touch interactive display. In addition, the work of Underwood et al. (1994) also found that girls tend to be more sociable when working together, regardless of whether they are told to co-operate or not. However, for those studies, it may have been the type of task that favoured one gender over another. Of the 5 groups in this work that did not achieve all the set tasks, 3 were male and 2 female. For the case where more than one item was not met, 2 were male and 1 female (Table 5.6—‘rows shaded grey’).

5.6.6 Student Feedback

Table 5.7 summarises the Likert responses to the student post-experiment questionnaire. The scale was from 1 to 7, where 7 represented ‘strongest agreement’. On the whole, all but Question 3 (the group working together at the SDGs) was on the agree side of the Likert scale. The mean response for Question 3 was neutral. The high ratings observed for Q’s 1,2,4-5 may be partly due to the novelty effect of the interfaces. At least 2 students commented on as such: “the novelty of the situation and the use of technology” (S2-G4 (WB)) and “it was really enjoyable playing with the new generation of technology, I liked fiddling with all the new features.” (S2-G2 (WB)). However, it is also possible that the effective user interface design of MuseWork equally had a part to play, which a few students made note of: “it is really user friendly” (S2-G1 (TT)); and “there was easy connectivity between the iPad and [white]board” (S2-G7 (WB)). For each of the six questions, the responses between the tabletop and whiteboard were closely matched. There were no statistically significant effects found at the $p<0.05$ level. Students were particularly positive in their responses to Question 6 – ‘I enjoyed using the SDGs for the task’, with a rating of more 6 out of 7 for both conditions. Of the 61 students who left an optional comment for Q6, 23 students explicitly noted the interface as “fun” to use.

As part of the student questionnaire, two open ended questions asked for feedback on what students found to be the most positive and negative aspects of SDGs. The positive responses for both devices were balanced with comments such as: “awesome”; “very interactive”; and “easy and simple to use”. The negative responses however revealed issues of device sensitivity for SDGs: “if multiple people are touching it, it gets a bit spazzy!” (S2-G1 (TT)) and “it was easy to organise everything, but it took time to adjust, because it was very sensitive” (S2-G2 (WB)).

While not statistically significant, the response for Question 3 – ‘the ability to share on the tabletop/whiteboard without interrupting each other’ had the lowest score for both the tabletop (4.68/7) and whiteboard (4.12/7). Figure 5.12 shows the distribution of responses for Question 3. Notably, this

<table>
<thead>
<tr>
<th>Post-Experiment Questionnaire</th>
<th>Mean (SD)</th>
<th>Statistical Test (between-subjects)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1 I was able to easily load information from the iPad and send it to the tabletop/whiteboard for showing other group members.</td>
<td>5.93 (1.00) 6.24 (0.95)</td>
<td>$U = 351, Z = -1.76, p = 0.08, r = 0.23$</td>
</tr>
<tr>
<td>Q2 I was able to easily organise the objects on the tabletop/whiteboard to my liking.</td>
<td>5.39 (1.08) 5.12 (1.61)</td>
<td>$U = 464, Z = -0.03, p = 0.98, r = 0.00$</td>
</tr>
<tr>
<td>Q3 My group was able to effectively share the tabletop/whiteboard interface and not interrupt each other or get in each other’s way while working together.</td>
<td>4.68 (1.28) 4.12 (1.65)</td>
<td>$U = 548.5, Z = 1.28, p = 0.20, r = 0.16$</td>
</tr>
<tr>
<td>Q4 I was aware what my group members were doing through the task.</td>
<td>5.79 (1.15) 5.39 (1.52)</td>
<td>$U = 515, Z = -0.80, p = 0.42, r = 0.10$</td>
</tr>
<tr>
<td>Q5 I was satisfied with the outcome of my groups collaborative work at the tabletop/whiteboard.</td>
<td>5.63 (0.87) 5.34 (1.51)</td>
<td>$U = 443, Z = 0.18, p = 0.86, r = 0.02$</td>
</tr>
<tr>
<td>Q6 I enjoyed using the tabletop/whiteboard for the tasks.</td>
<td>6.39 (0.94) 6.06 (1.46)</td>
<td>$U = 496, Z = 0.80, p = 0.43, r = 0.10$</td>
</tr>
</tbody>
</table>

Table 5.7: Post-Experiment Questionnaire Results. The Likert scale is from 1 to 7 (where 7 represents ‘strongest agreement’). No items were statistically significant at the $p < 0.05$ level across the two conditions.
Tabletop

<table>
<thead>
<tr>
<th>Strongly disagree</th>
<th>Disagree</th>
<th>Somewhat disagree</th>
<th>Neutral</th>
<th>Somewhat agree</th>
<th>Agree</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>3</td>
<td>7</td>
<td>7</td>
<td>8</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

Whiteboard

<table>
<thead>
<tr>
<th>Strongly disagree</th>
<th>Disagree</th>
<th>Somewhat disagree</th>
<th>Neutral</th>
<th>Somewhat agree</th>
<th>Agree</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>3</td>
<td>6</td>
<td>4</td>
<td>11</td>
<td>4</td>
<td>2</td>
</tr>
</tbody>
</table>

Question 3: My group was able to effectively share the tabletop/whiteboard interface and not interrupt each other or get in each other’s way while working together.

Figure 5.12: Responses for Question 3 (ability to share the tabletop/whiteboard) as a clustered stacked bar graph. Bar width shows percentage response, giving a normalised view across conditions. The conditions are aligned on the neutral mid-point, highlighting the relative negative/positive % of responses. Of the 67 students, 54 responded (tabletop: 28 responses; whiteboard: 26 responses). Response counts are shown in each segment.

5.7 Discussion and Design Recommendations

The results highlighted interesting differences between the SDGs, drawing on student engagement and inclusion in the collaborative activity. The original hypotheses are now revisited with discussion.

Hypothesis 1: The design goals, with either the whiteboard (WB) or the tabletop (TT) for the collaborative phase are met. A key goal of the research was designing MuseWork to operate across different types of hardware; and this work reported on the use of MuseWork with two devices: an
CHAPTER 5. HARNESSING INTERACTIVE SURFACES FOR INQUIRY AND COLLABORATION

interactive multi-touch tabletop and an interactive single-touch whiteboard. This overlaps with a goal from Chapter 4, ensuring that the interface design is effective for that orientation. While the technology itself was novel compared to a manual way to doing the same activity, it was important that the students were able to engage in the activity to ensure that it had pedagogical value for either condition. Looking at the task as a whole (not just the collaborative whiteboard/tabletop activity), the materials collection process gave the students considerable freedom to explore topics they found most interesting. Students assessed this and the later collaborative creation of the poster as enjoyable, as indicated by the overall positive responses in Table 5.7. Importantly, the observations indicated positive results for learnability and usability of the interfaces, after just a brief tutorial.

Students took a great deal of care in both the collection of the media and the construction of the collaborative poster. The notion that the poster was an artefact to take away with them and put up on a wall (e.g. in the classroom) was different from the traditional paper worksheet. This provides an important connection between the museum visit and post-visit activities in the classroom. For example, a teacher may introduce further research activities on the topics summarised in the poster, or the posters can be made available to the whole class for later learning activities. The creative choices in making a visually appealing poster and thinking about the material collected individually, was well received, reflected in the Likert-scale and free-form questionnaire responses.

Overall, Hypothesis 1 was broadly supported from several forms of evidence: the student responses; student participation in each stage of the activity; and the success that the majority of groups demonstrated in meeting the worksheet criteria. However, the results also indicated that the children faced difficulties in sustaining egalitarian collaborative interaction at the interactive whiteboard.

Hypothesis 2: Groups using the tabletop (TT) will display higher levels of engagement than those at the whiteboard (WB). It was expected that the tabletop would be more favoured for engagement because of its larger size and also due to fact that larger groups were involved (up to 7 students). Engagement was defined as interacting with the display or collaborating with group members. The results at the SDGs highlighted very different working styles between the two conditions. At the whiteboard, students frequently stood back — relinquishing control to one or two students. This caused some students to disengage. This was influenced by the limited space at the whiteboard, where students needed to stand shoulder-to-shoulder at the display, and also influenced by the restriction of single-touch interaction. Together, these factors meant that only a subset of the group could effectively share the vertical display at a time.

The tabletop condition had students touching the display more throughout the experiment. Its multi-touch input and larger direct interaction space meant that all students could stand within reaching distance of the display. This provided more opportunity for each student to contribute to the activity, without needing to coordinate their actions with other group members. So students stayed at the display more than the students using the whiteboard condition. Strikingly, no students chose to sit-out of the activity when using the tabletop — a positive reflection on the levels of participation and engagement around the display. This matches findings in Rogers and Lindley (2004), where the face-to-face collaboration supported by the tabletop was found to promote participation and communication. Of course, that work was with adults. In the case here, with children, the tabletop also made it easy for the children to do parallel rather than collaborative work, which meant it is possible they were engaged at the display but off-task. This may have been a factor for the three of the six tabletop groups (S1-G4, 7 girls; S2-G1, 6 boys; S2-G6, 6 boys) whose poster did not meet half of the worksheet criteria.

The multi-touch interface had increased touch interaction compared to the single-touch whiteboard, but this did not noticeably improve task completion, as the task did not require independent, parallel work. Findings by Harris et al. (2009) suggest that students at a single-touch display will spend more time discussing to coordinate their interactions. While speech was not analysed, there did not appear to
be a difference in coordination-related discussion. It was observed that some students monopolised the interface, both at the tabletop and whiteboard and this caused some group members to lose interest.

The single-touch whiteboard was observed as more effective for groups who were careful in their sharing of the display. For example, S2-G7 (5 girls), spaced themselves to include all group members at the display at key stages throughout the experiment, exhibiting good levels of engagement. An alternative approach was exhibited by S2-G4 (6 girls), where members who were away from the display continued to work on their iPads, taking notes to support the group at the whiteboard.

This points to ways that the design of user interface might improve engagement at widely-available single-touch devices like whiteboards, by helping groups manage turn-taking. While these two groups showed clear signs of effective teamwork, for these students (aged 10–14) there may still be a need for more explicit guidance, so as to facilitate effective small-group work.

Furthermore, increasing structure of the activity may help reduce crowding at either display, ensuring all group members have the opportunity to contribute to the group artefact. Approaches such as multi-user coordination policies (Morris et al., 2004) and scripted interaction (Dijk et al., 2014; Fischer et al., 2007) are possible ways to foster the construction of effective group processes for students of this age.

Overall, Hypothesis 2 was broadly supported by the results on touch interaction, student positions, the numbers of students sitting-out and activity engagement.

**Hypothesis 3:** Groups at the tabletop (TT) will be more effective in completing the poster to meet the worksheet criteria. It was hypothesised that the tabletop, with its combination of face-to-face interaction, a larger perimeter with four accessible sides, and the use of multi-touch to permit synchronous input would help groups produce a poster that met all the worksheet criteria. The results however, did not confirm this, with three tabletop group posters failing more than one criterion, compared with zero at the whiteboard.

There is also a potential effect of group size for the success of the tabletop groups. Larger groups may have more difficulty coordinating and collaborating effectively. For example, S1-G4 (7 girls), spent time at the tabletop discussing who should do what, with comments like “let’s take turns touching”, and even voting on what to do. In the cases of S2-G1 and S2-G6, both groups of 6 boys, it was observed that they failed to discuss how to proceed on how to meet the worksheet criteria. These findings are similar to those reported in Birnholtz et al. (2007), who found for participants sharing a very large wall sized display – with multiple inputs (multiple mice), people tended to act independently (resulting in people often not knowing what others were doing) and when there was one shared input (a single mouse), a higher quality of discussion was observed (as everyone was aligned to task goals). Moreover, participants at the multiple input condition were more likely to act in their own self-interests. Here, again, this points to a potential need for greater scaffolds to support collaboration.

The results from this study highlight that it is not only the device that drives collaboration, rather it is the combination of the hardware with its affordances, user interface design, and the activity that result in certain group processes unfolding. Greater awareness of the particular challenges of each device class can help a designer provide the necessary support for the challenges users may face.

Overall, Hypothesis 3 was not supported because the tabletop groups were not more successful over the whiteboard groups in completing the worksheet tasks.

**Hypothesis 4:** Students at the tabletop will report a more positive experience. The tabletop was expected to provide a more positive experience for students, given its horizontal format, larger direct interaction space, affordances for face-to-face interaction and multi-touch. Drawing on the student questionnaire, the question “I enjoyed using the tabletop/whiteboard for the tasks”, the tabletop reported a mean score of 6.39/7 compared to the whiteboard with 6.06/7. Time and time again, students remarked that single touch at the whiteboard was an issue. This ranged from inconvenience: “we sometimes got in each other’s way and forgot that only one person could go at a time” (S2-G4) to annoyance – “when two
people touch the screen the wrong object would move and others were getting frustrated” (S2-G2).

The desire to work in parallel for the collaborative activity, meant that the whiteboard resulted in some students being excluded, and different feelings towards the experience relative to their peers. For example, two students in S1-G3 (7 girls) found their group members took more than their fair share of time on the technology: “everyone did not take turns and it made it a little unfair”. Similarly this occurred in other groups as well, such as with S2-G4 (6 girls): “arguing, stealing, each to their own”. At the tabletop however, having multi-touch did not translate into higher task achievement, and this may possibly be seen as a penalty of multi-touch, where the students did not have to co-ordinate or necessarily interact with one another in order to use the display.

These observations on experience, point to an agenda for the consideration of the careful design of each user interface to suit the orientation of the display, working within the constraints and affordances of each form. From the perspective of the students – equal time on the technology is a high concern. This is also particularly heightened, as students are visiting, and may not have regular access or another chance to use such technology again. An important consideration is therefore finding a way to effectively share each device. For both devices this points toward the need for tighter defined tasks (such as with the use of a collaborative script (Fischer et al., 2007) to expose certain group interactions) and/or extra scaffolds for the teacher to also support the students at the displays.

Overall, Hypothesis 4 was confirmed from students quantitative and qualitative feedback.

5.8 Conclusion

The study in this chapter explored the use of a system which involved both inquiry based learning and collaboration at two different shared large interactive displays (a tabletop and a whiteboard). The interfaces were designed to be effective across a range of SDGs harnessing the affordances of each to support small-group collaboration. The study used poster creation as the collaborative activity at the SDGs, explored with primary school students. This shed light on the following:

- the use of multi-touch interactive tabletops compared to single-touch whiteboards, and the effect of the affordances of each for small-group collaboration and in completing set tasks.
- the use of both displays in an in-the-wild authentic setting, with: variable time restrictions for each school, different group sizes (up to 7 students), and a real learning activity with actual objectives linked to the state syllabus.
- the need for more guidance and structure, either in the form of enhanced teacher support or possibly through the introduction of collaborative scripts, or multi-user coordination policies, to support more effective group processes for both large screen collaborative devices.

This study revealed differences on how students interacted with the tabletop and whiteboard. Physical participation, group disengagement, interface usage, student arrangement, task achievement and student feedback helped reveal this. More activity was registered at the tabletop, but this surprisingly did not translate into a higher level of task achievement. At the whiteboard which was single-touch, groups needed to take turns to manage the interaction with the display and one another, and while this resulted in some students becoming frustrated, it appears to have led to a higher rate of task success. The use of both devices highlighted issues with group co-ordination, and echo findings observed in Chapter 3 (with the brainstorming activity) with regard to off-task behaviour. This points to an agenda for a need to further develop ways to support small groups at these types of devices.

Furthermore, this work involved larger groups (up to 7 students) than either of the studies in Chapters 3 or 4 (which had groups of up to 4 people). Whilst groups of 3–4 students in this study
were able to self-manage themselves, groups of more than 4, faced extra difficulties – either due to compet-
ing self-interests (i.e. wanting to use the technology for themselves), or in the case of the whiteboard, not
physically being able to accommodate all of the group at once. This points to two items: the first, further
investigations are needed into the complementary use of extra devices as ways to reduce input blocking
and secondly the need for support to keep students on-track, on-task and collaborating effectively.

In summary, this chapter contributes to a greater understanding of the place of SDGs and how they
can be used to support small-group activities. It helped reveal that the affordances of tabletops do not
necessarily translate into greater outcomes over other SDG forms. In addition, this work, pointed to the
need for effective user interface design and the need for further support and guidance at these devices.
Part I: Rich Small-Group Collaboration with Interactive Tabletops

Summary

This first part explored the potential of using interactive tabletops to support small-group collaboration. The key findings from each chapter are presented below. The first two studies explored collaborative brainstorming which consisted of a divergent ideation phase, followed by a convergent categorisation phase. This called for different group processes. The third study explored collaborative poster creation, which involved an initial information gathering phase with portable tablets, followed by a collaborative phase at a tabletop or whiteboard. This required sharing, discussion and consensus group processes.

<table>
<thead>
<tr>
<th>Ch.</th>
<th>Setting</th>
<th>Condition</th>
<th>Who</th>
<th>Key findings</th>
</tr>
</thead>
</table>
| 3   | In-the-lab (Within-subjects) | Multi-touch tabletop vs Non-interactive whiteboard | Adults               | • The tabletop was useful for supporting brainstorming, enabling fast idea creation and providing effective ways to collaborate.  
• Some people did not follow the rules of the activity, highlighting a need for further task support at the table.  
• There is the potential to use captured aspects of the process. |
| 4   | In-the-wild in Classrooms (Within-class-groups) | Multi-touch tabletop vs Multi-touch vertical displays vs Index cards and pens | University students  | • The SDGs helped create more ideas, but on quality the outcome was not differentiated as expected (based on prior literature which stated quantity correlates highly with quality).  
• The tabletop saw a high rating for mutual awareness, providing better support for face-to-face interaction.  
• Similar numbers of ideas, and levels of participation were seen at both the tabletop and vertical display.  
• The results show particular promise for interactive vertical displays (which contrasts findings in previous literature). |
| 5   | In-the-wild Local Museum (Between-subjects) | Multi-touch tabletop vs Single-touch whiteboard | Primary school children | • Both SDGs were effective ways for individuals working in small groups.  
• For groups sizes larger than 4, both devices resulted in problems for collaboration. This indicates a need for collaboration guidance.  
• Both devices recorded aspects of off-task behaviour, stressing a need for scaffolding, particular for children of this age.  
• The whiteboard despite being single-touch had high task achievement, where this is partly due to technology forcing students to take turns to interact, both with the device and each other. |

An overview of the studies from each chapter with key findings.

The experimental setups compared the use of a tabletop to different SDG forms (single/multi-touch whiteboards) as well as manual methods. The participants in the studies included adults in groups of 3-4, and primary school children in groups of 3-7. These dimensions provide an interesting set to draw on for informing the use of tabletops for small-group collaboration. Overall, the emerging picture is:

- that SDGs, both horizontal and vertical have advantages over more conventional methods, be they vertical regular whiteboards (Chapter 3) or conventional cards (Chapter 4), where it is clear that this is partly due to the benefits of having multiple keyboards for creating many ideas.

- that with the careful design of the interface for both vertical and horizontal conditions, interactive vertical displays can be very effective for brainstorming (Chapter 4) even when the vertical display is single touch and the tabletop multi-touch (Chapter 5).

- that participants preferred the tabletop to the vertical display (Chapters 4 and 5) – with Chapter 4 showing this was reported as enhancing face-to-face interaction, and in Chapter 5 the comparison is more complex as the single touch of the wall display had a major effect in raising task success.

- there are indications that there would be benefits for providing scaffolds for collaboration, to address problems observed in the Chapter 3 study where some failed to follow directions, and in the Chapter 5 study where several groups of children had difficulty managing collaboration within their groups.
Part II

Exploring Methods to Scaffold Collaboration at the Tabletop
Part II: Exploring Methods to Scaffold Collaboration at the Tabletop

Introduction

The second part of this thesis covers Chapters 6 and 7. It looks at exploring ways to scaffold collaboration at the tabletop. The motivation for this is from observations from a subset of the studies explored in the first part of the thesis. It was observed in Chapter 3 with adults brainstorming in a lab that some failed to follow task directions, leading to off-task behaviour which affected the group and activity outputs. Next, in Chapter 5, with primary school students building a collaborative poster, several groups had difficulty managing collaboration within their groups. This led to a realisation that the tabletop has the potential to provide a new role, by providing scaffolds for collaboration. An overview of the work to explore this is shown below. Brainstorming was used as the main activity throughout, with a split between laboratory studies (Chapter 6) and longer-term in-the-wild classroom studies (Chapter 7). In total, over Chapters 6 and 7, 216 students were involved in the different aspects explored, with 55 distinct groups.

<table>
<thead>
<tr>
<th>Ch.</th>
<th>Setting</th>
<th>Focus</th>
<th>Who</th>
<th>Task</th>
<th>Posture</th>
<th>Groups</th>
<th>Group size</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>In-the-lab (Within-subjects)</td>
<td>Collaborative scripting</td>
<td>University students</td>
<td>Brainstorming</td>
<td>Standing</td>
<td>12</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Team negotiated vs preset scripts at the tabletop</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>In-the-lab</td>
<td>Open Learner Models to support Reflection</td>
<td>University students</td>
<td>Brainstorming</td>
<td>Seated</td>
<td>15</td>
<td>(over 2 classes)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Think-aloud on paper</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>In-the-lab</td>
<td>Scaffolded Reflection</td>
<td>University students</td>
<td>Brainstorming</td>
<td>Seated</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>with a tabletop and non-interactive screen</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>7</td>
<td>Authentic Classroom (Within/class-groups)</td>
<td>Teachers use of a dashboard to support lesson plans</td>
<td>Teachers</td>
<td>Brainstorming</td>
<td>Standing</td>
<td>4</td>
<td>class teachers</td>
</tr>
<tr>
<td>7</td>
<td>Authentic Classroom (Within/class-groups)</td>
<td>Collaborative scripting</td>
<td>Undergraduates</td>
<td>Brainstorming</td>
<td>Seated</td>
<td>24</td>
<td>3–5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Team negotiated vs preset scripts at the tabletop</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>7</td>
<td>Authentic Classroom (Between-class-groups)</td>
<td>Testing effect of activity assumption Ideas in center</td>
<td>Postgraduates</td>
<td>Brainstorming</td>
<td>Seated</td>
<td>9</td>
<td>3–5</td>
</tr>
<tr>
<td>7</td>
<td>Authentic Classroom (Between-class-groups)</td>
<td>Evaluation of a Role based Script</td>
<td>Postgraduates</td>
<td>Brainstorming</td>
<td>Seated</td>
<td>9</td>
<td>3–5</td>
</tr>
</tbody>
</table>

An overview of the studies exploring scaffolded collaboration at the tabletop.

Chapter 6 introduces ScriptStorm, which implements a form of scaffolding for collaborative brainstorming. This draws on collaborative scripts, as the scaffolding approach. The chapter starts with a study comparing two scripting forms: preset-scripts in the sense of a facilitator or teacher pre-selecting settings, and team-based scripts with group negotiation to select settings. The chapter continues with two studies exploring support for reflection – a think-aloud study, followed by the design, construction and deployment of a tabletop-based reflection system.

Chapter 7 reports on the in-the-wild use of ScriptStorm within an authentic multi-surface classroom environment, used with two subjects to support a diverse range of learning objectives. The use of ScriptStorm in this instance provides an authentic test-bed to analyse usability, report on real use and also explore the adaptability of the tool. The chapter reports on the classroom infrastructure ScriptStorm was deployed within and the different scaffolds used for each class week. This evaluates script assumptions, looks at group processes from a real environment, and helps reveal the role scripts have in support of rich small-group collaboration at interactive tabletop displays.
Chapter 6

Enhancing Brainstorming with Scripts and Reflection

This chapter tackles problems reported in previous chapters’ results where people failed to follow the guidelines for the collaborative task. This chapter explores collaborative scripts and models for reflection to support tabletop brainstorming. These approaches offer promise for addressing core challenges with collaborative activities because they should help group members realise the importance of recommended practice, remember to follow it at each stage, and to learn to work more effectively. This links to the thesis statement in developing ways to harness the potential of interactive tabletops.

Three studies are presented in this chapter. The first, focuses on a deeper form of support based on scripted collaboration. Collaborative scripts can “structure collaborative learning processes by specifying, sequencing, and distributing roles and activities across a group of learners” (Fischer et al., 2007). This work was motivated by observations from earlier studies which showed negative impacts of off-task behaviour. The second and third studies focus on reflection, looking at methods to enhance awareness of group processes and group products. This was motivated by a need to encourage people within groups to more deeply understand and appreciate the activities they are engaged with, with the expectation that this leads to more effective group work.

6.1 Tabletop Brainstorming with Collaborative Scripts

This section introduces ScriptStorm, starting with its design, to enhance the understanding of key processes involved in tabletop based small-group brainstorms. Then it presents the user view. The remainder of the section then describes the evaluation study design and results. Two collaborative script forms are explored with ScriptStorm: a preset script, where the interface enforces settings participants cannot alter, in the spirit of a human facilitator; and a team-based script, where the interface hands over control to the group. ScriptStorm is based on the notion that: the additional interface complexity of the script will be modest in terms of learning and usability; that both scripted forms of collaboration will support effective brainstorming; that scripting will motivate and encourage effective group processes; and, that the system will help facilitate rich group-based discussion.

6.1.1 Design Foundations for Scripted Tabletop Collaboration

This section explains the design approach taken to develop the collaborative script scaffolds to support brainstorming at the tabletop. This involved examination of three key items: (1) structure of the

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1Section 6.1 is based on the following peer-reviewed publications:

i) A. Clayphan, J. Kay, A. Weinberger (2012). “Enhancing brainstorming through scripting at a tabletop” In: Educational interfaces, software and technology: 3rd workshop on UI technologies and educational pedagogy (CHI 2012).

brainstorming method – probing into the different phases of the activity; (2) flexibility – what tabletop elements are used for each brainstorming phase and the constraints and direction a script should provide; and (3) settings – for each phase, establishing the right balance of interface elements to be configured, and establishing sound default parameters for these. For each of these, it was explored how to harness the tabletops’ affordances that might provide guidance, during the brainstorming session. Each aspect is now described in more detail.

Structure

The classical brainstorming method consists of two phases – *idea generation* and *idea categorisation* (Osborn, 1953). The first employs a highly *divergent* thinking process, intended to generate many different and interesting ideas. The second is a *convergent normative* phase where a group uses discussion to reach consensus for evaluating, organising, grouping and filtering ideas. The second phase involves two clearly defined subparts, ‘*category definition*’ and ‘*idea classification*’.

For the brainstorming process to be effective, it is important that groups follow recommended practices. To facilitate this, it is hypothesized that being informed of choices surrounding each activity phase and having input to the phase may aid with group processes. Thus the proposal is the addition of a negotiation stage before each core brainstorming phase (and for the case where a facilitator makes the choices, the group still being informed of the choices made). The aim is to encourage exploration and help with the understanding of recommended practice. For ScriptStorm, two workflows are proposed: the first, a *preset script*, which follows the model of a facilitator driving and leading a session, with settings specified in advance; and the second, a *team-based script* where groups take more control, with discussion and negotiation over aspects of each activity phase.

Flexibility

To consider the aspects for flexibility, affordances and limitations of interactive tabletops, literature on brainstorming, and literature on computer supported collaborative scripts was drawn on. A review of the design goals from the Firestorm tabletop brainstorming system (Section 3.2, pp. 30) was conducted which helped refine the design of the ScriptStorm interface. ScriptStorm was built around a revised set of design goals, as follows:

- **Design Goal 1: Regulate the activities for each activity phase.** This means identifying support needed for the tasks in that phase, identifying responsibilities of each team member, to promote effective group work. This design goal, aims to ensure that “activities of learners [are] coordinated and guided according to particular rules, implemented via respective tools in the learning environment” (Haake and Pfister, 2010). In the earlier Firestorm study, it had been observed that some group members failed to stay on task during idea generation. This led to less ideas being produced and also impacted other group members. Also, it was observed in the earlier study that during idea categorisation, the more effective groups had a leader who made sure discussion and debate took place when evaluating and reviewing idea outputs.

- **Design Goal 2: Foster collaboration.** This involves identifying methods to guide the activity and scaffold effective group interaction. This requires “sustaining mutual understanding, dialogue management, information pooling, reaching consensus, task division, time management, technical coordination, reciprocal interaction and individual task orientation” (Meier et al., 2007). For ScriptStorm, this is proposed by both informing the group of any choices made which may affect core tasks, and also potentially giving more control to the group.

- **Design Goal 3: Design for user control with scripting.** When a human facilitates group work, they can decide when to take a strong role and when to stand back. This design goal is intended
to allow a script to be configured by either a facilitator or the group themselves. The aim here is
to avoid the risk of over-scripting (Rummel et al., 2009), by making choices transparent, providing
explanation and descriptors as relevant. This also combats the issue of mismatches between the
script and the group/facilitator preferences (Dillenbourg, 2002).

- **Design Goal 4: Facilitate egalitarian control over the scripted elements.** This means
allowing equal control to each user for decisions about the flexible aspects of the script. This requires
providing interface elements for each individual in the group to enable effective and transparent
decisions to take place. The aim of this goal is to allow a voice for each group member. This allows
group members to discuss opinions, thoughts and rationale, take these into consideration, and then
decide on their input to the decision being made. This seeks to counter issues where one person may
attempt to take or assert control over the process.

**Settings**

For each phase, there are different aspects which can be used to support effective group interaction. Con-
figurable elements were identified. This drew on: the structure of the brainstorming method; experiences
from the earlier brainstorming tabletop study (Chapter 3); and the design goals just stated. The items
and the defaults chosen are now described.

**Idea Generation Phase**

The goal of this phase is to enhance creativity and generate many idea outputs, so the settings were
designed to avoid early idea evaluation as well as minimise production blocking. This led to a number of
design decisions.

- **Disable Touch Interaction (Design Goals 1 and 2, Default: Touch is disabled).**
  The option to disable touch during idea generation was made to discourage off-task activity, such as
  early idea categorisation. This follows recommended practice (Osborn, 1953). As the interface is
designed to use external keyboards as the input mechanism, this means there is no strong reason a
person should have to manipulate the interface during idea generation.

- **Colour Code Ideas (Design Goals 1 and 3, Default: Ideas are colour coded).**
  This option allows groups to choose whether to use colour for idea authorship. Diehl and Stroebe
  (1987) found identification led to a reduction in free-riding behaviour. On the other hand, anonymity
  may permit wilder ideas (Valacich et al., 1992; Pissarra and Jesuino, 2005). Offering both and
  explanations for their benefits allows a group to decide which is best for them. ‘Colour enabled’ was
  set as the default, based on the importance of equal (and visible) group participation.

- **Idea Orientation (Design Goals 1 and 2, Default: Ideas placed in a concentric circle).**
  This option allows ideas to be placed either in a concentric circle in the center or orientated toward
  the person who created the idea. The circle approach is likely better for people reading from different
  orientations (Ryall et al., 2006), and may reduce a sense of ownership and foster awareness of ideas
  generated by others. However, having the ideas near each author emphasizes the number of ideas
  created, and likely helps with reading their own ideas (at least for the ideas that can be seen).

- **Phase Duration (Design Goals 1 and 3, Default: Time set to 5 minutes).**
  This setting allows groups to create a plan for the time they wish to spend in a phase. ScriptStorm
  provided a slider from 2–10 minutes, and selections from each member were averaged (and then the
  floor taken). For example, if 2 people selected 10 minutes and another 2 selected 6 minutes, the timer
  was set for 8 minutes. If the time elapsed, a dialog was raised asking the group if they wished to
  continue in the phase (or stop, and move on to the next step).
Idea Categorisation Phase

The goal of idea categorisation is for group members to work together to evaluate, filter and organise ideas. This led to the following settings and associated design decisions:

- ‘Make categories first, then move ideas’ versus ‘Move ideas together, then define category labels for groups formed’ (Design Goals 1 and 2, Default: Make categories first).
  
The earlier Firestorm tabletop brainstorming study indicated groups took one of these approaches. This choice was made explicit for ScriptStorm. If “make categories first” was chosen, ideas were dimmed for 30 seconds, to encourage the group to focus on creating appropriate category headings. If “move ideas first” was chosen, the keyboards were disabled for 30 seconds, to encourage the group to interact with the ideas on the interactive display.

- Elect leader(s) (Design Goals 1 and 2, Default: Participant A is set as the leader in the preset script, no default is set for the team-defined script).
  
  Small group research indicates that groups perform better when there is a leader (Sosik et al., 1998). ScriptStorm permitted leader self-selection, which provided that person with additional interface controls. These were the ability to toggle the appearance of ideas (described above) and/or categories, as well as being able to enable/disable keyboard inputs. These were provided so a leader could focus the group onto certain aspects of the activity.

- Colour Code Categories (Design Goals 1 and 2, Default: Category colour enabled).
  
  A group could choose whether categories were colour coded to identify authors. The rationale is the same as per the colour coded ideas setting.

- Phase Duration (Design Goals 1 and 2, Default: Time set to 5 minutes).
  
  The rationale is the same as per described earlier.

6.1.2 ScriptStorm User View

ScriptStorm was built with support for the two core brainstorming phases – idea generation and idea categorisation. ScriptStorm also introduced a group reflection phase at the end of the activity. This drew on captured processes and outputs from the brainstorm by the interactive tabletop. It was felt that reflection could provide opportunities for the group to develop key metacognitive skills (Schön, 1983), as well as the construction of higher level reasoning skills over their group contributions (Azevedo, 2007).

An iterative approach was used to design ScriptStorm. This began with the formulation of its theoretical grounding, informing the design of a low-fidelity prototype (Clayphan et al., 2012c). The feedback from the early prototype and a set of further think-aloud studies contributed to the final design. The user view is now described in terms of what the participants saw in the final evaluation study.

ScriptStorm begins with participants arranged around the table, each person to a side (Figure 6.1 shows this for the case of 3 participants). A welcome message invites participants to start. Next, each participant is presented with a pre-task questionnaire (Figure 6.2). ScriptStorm then advances to the idea generation planning stage. In this, ScriptStorm shows a widget for each user (with initial defaults set) (Figure 6.3). For example, the first option shows that the system will ‘Disable Touch Interaction’ and it is set to ‘Yes’. Double tapping on any of the question marks on the left brings up a brief explanation of the option (Figures 6.4, 6.5, 6.6 and 6.7). The widget also indicates the keyboards are currently disabled.

Once group members have considered the settings, discussing and possibly altering them, they ‘Submit’ their selections. A confirmation then appears (Figure 6.8), which gives participants an opportunity to change their mind. When all group members have submitted their selections (Figure 6.9), the system computes the results and displays them in front of each person (Figure 6.10). When ScriptStorm is configured to use a preset script, this is the first screen they see. After the group has considered the chosen
settings for the upcoming phase, one person is required to press the central start button (not shown) to advance the system to the idea generation phase.

Group members now proceed to the idea generation phase, and create as many ideas as they can (Figures 6.11 and 6.12). When the allocated time has elapsed, a dialog appears (Figure 6.13) asking if the group wishes to ‘continue’ or ‘stop’. The team can also bring up the dialog (for example, to move to the next step early), with a long press on any of the clock timers (located in the corners).

The group then moves to the idea categorisation and organisation planning stage (Figure 6.14). This operates in a similar manner to the previous planning step. The explanations available from the question
marks are shown in Figures 6.15, 6.16 and 6.17. In ScriptStorm, any user can self-select to be a leader, providing functions for highlighting ideas and/or categories and controlling keyboard input. As before, once the entire team has submitted their selections, a summary is shown (Figure 6.18).

The group now categorises and organises the ideas (Figures 6.19 and 6.20). By default, in this phase, keyboards are set to create new categories. If a participant wishes to create an idea instead, they double tap their user avatar (Figure 6.21), bringing up a context menu (Figure 6.22). This provides options for switching between ‘making ideas’ and ‘making categories’. While in the idea categorisation phase, a person can edit any item by ‘swiping’ their avatar over it – this creates a link (Figure 6.23). Typing with the keyboard when linked to an object edits its content. This is useful if a person wishes to change something or to simply fix a spelling mistake. A similar ‘swiping’ mechanism is used for creating links between ideas and categories. Links between ideas and categories are shown with semi-translucent lines (Figure 6.24).
Ideas can be moved from one category to another. The simplest way is to swipe the idea over the desired category. Alternatively, a participant can double tap the item to invoke its menu (Figure 6.25), which holds a disconnect icon. In addition, the menu provides an option for deleting the object (which would send it to the nearest bin). Items can also be deleted by moving them to a bin. In ScriptStorm, no items were truly deleted; a long-press on the appropriate trashcan brought back removed items.

To help with clutter, two lightweight sorting methods are provided, invoked from the category menu (Figure 6.25—‘bottom-center’). These produce either a grid layout (Figure 6.26—‘top-left’) or an elliptical layout (Figure 6.26—‘top-right’), with ideas placed alphabetically, in a left to right or clockwise manner.
Once idea categorisation is complete, the group then moves to reflection (Figure 6.27). The group is provided with several different widgets to aid with reflection. These are: (a) a statistics widget – this reports the number of ideas, categories, links and touches from each phase; (b) a stage choices widget – this summaries options chosen from each phase; (c) an ideas and categories widget – this displays the ideas and categories produced, as well as a summary of the time spent in each brainstorming phase; and
Figure 6.27: Group Reflection Phase. Items: (a) the statistics widget (one for each group member); (b) the stage choices widget (indicating options selected for the brainstorm phases); (c) the ideas and categories widget (showing group products as well the time spent on each phase); and (d) the replay widget (which allowed the group to view any point in time of the brainstorm process).

Table 6.1: Post-Task Reflection Questions.

<table>
<thead>
<tr>
<th>Question</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1. I could work out how long each stage was.</td>
<td>?</td>
</tr>
<tr>
<td>Q2. I could work out how ideas were categorised.</td>
<td>?</td>
</tr>
<tr>
<td>Q3. I could work out the choices made by the group/facilitator.</td>
<td>?</td>
</tr>
<tr>
<td>Q4. I could work out ideas that I created.</td>
<td>?</td>
</tr>
<tr>
<td>Q5. I could work out ideas created by other people.</td>
<td>?</td>
</tr>
<tr>
<td>Q6. I could work out categories that I created.</td>
<td>?</td>
</tr>
<tr>
<td>Q7. I could work out categories created by other people.</td>
<td>?</td>
</tr>
<tr>
<td>Q8. I could easily see how much I contributed to the activity.</td>
<td>?</td>
</tr>
<tr>
<td>Q9. This activity helped me learn about idea generation in brainstorming.</td>
<td>?</td>
</tr>
<tr>
<td>Q10. This activity helped me learn about idea categorisation in brainstorming.</td>
<td>?</td>
</tr>
<tr>
<td>Q11. I found the information in the reflection stage useful.</td>
<td>?</td>
</tr>
</tbody>
</table>

(d) a timeline widget – this allows for reviewing any point in time, by scrubbing the widget like a video.

As part of reflection, participants are asked to answer a series of post experiment questions (Table 6.1) on the tabletop interface (Figure 6.28). Once each participant had submitted their answers, the system closed and a thank you message was presented.

6.1.3 Evaluation

The evaluation was designed to assess both ScriptStorm and the core idea that its scripting could improve tabletop brainstorming. ScriptStorm used the same brainstorming tasks as the earlier Firestorm study (from Chapter 3) – ‘Promoting Australian Tourism’ and ‘Recruiting Students to come to University’. While the different user populations for the studies limit true comparability, the design enables some comparisons, both quantitative and qualitative. The following hypotheses were constructed for ScriptStorm:

- **Hypothesis 1: ScriptStorm is learnable and usable.** This is a critical hypothesis because the addition of scripting, particularly the team-based script, brings with it additional interface complexity and the real risk that the interface will be difficult or tedious to use and that broadly, usability and learnability will be compromised.
• **Hypothesis 2:** *ScriptStorm is effective for brainstorming.* A central goal of ScriptStorm is to support effective tabletop brainstorming. This meant assessing both script forms that ScriptStorm provided – ‘the preset script’ and ‘the team-based script’.

• **Hypothesis 3:** *People consider that the collaborative script helped them learn how to brainstorm.* ScriptStorm was designed to help make people aware of decisions that should be considered in working as a group through the key phases of the brainstorming activity. The *preset script* enforced aspects that literature (Osborn, 1953) suggested were valuable, so that participants learnt how to brainstorm more effectively. The *team-defined* script relaxed restrictions, in the expectation that participants would consider settings, engage in discussion, and become aware of the importance of recommended group approaches. This hypothesis aimed to assess how users perceived these opportunities.

• **Hypothesis 4:** *People will prefer the team-defined script for the control it gives them.* The *team-defined* script has the potential for improving group processes. It was designed to avoid known risks of over-scripting and mismatches between user’s preferences and a restrictive script. This suggests it will be preferred.

**Experimental Design and Procedure**

The study featured a within-subjects design. A team size of three was used, allowing ample room for each participant. Each group completed two brainstorms. Task and ordering were counterbalanced. The order drew from one of the following three configurations:

- **T then T (T-T)** – A *team script* followed by another *team script* brainstorm.
- **T then P (T-P)** – A *team script* followed by a *preset script* brainstorm.
- **P then T (P-T)** – A *preset script* followed by a *team script* brainstorm.

The design aimed to assess the effect of giving control before and after a *preset script*. The case of a *preset script* followed by another *preset script* was omitted, as it was not needed for the hypotheses being tested. The entire experimental procedure consisted of the following:

1. **Introduction.**
   Upon arrival, participants completed a written consent form and background questionnaire, regarding demographics and previous experience with tabletop interfaces.

2. **Tabletop tutorial.**
   The experimenter gave a short tutorial of the tabletop interface, going through the different elements: the participant avatar; how to create an idea/category; how to edit items; how to link items; how to detach and delete items; and how to move from phase to phase. Participants were asked to try each feature – to confirm they understood each action.

3. **Brainstorming activity.**
   Participants were assigned a condition and a task (Table 6.2), given time to read the task and then asked to brainstorm. There was a pre-task questionnaire just before the start of each brainstorm. Upon completing the brainstorm, participants completed a post-task questionnaire. After a short rest break, another brainstorm followed, with the same procedure.

4. **Post-experiment interview.**
   The post-experiment interview was designed to gain quantitative responses about the participants’ experiences of the scripted tabletop interface. It consisted of four open-ended questions, asked to the group as a whole.
Table 6.2: Experiment Setup – Condition, Tasks and Order.

Apparatus and Data Capture

An interactive tabletop, Bluetooth wireless keyboards and a depth camera were used in the experiment. The tabletop had a 46-inch multi-touch screen (capable of sensing up to 32 concurrent touches), with a 1080p resolution. The tabletop enclosure was supported with a rim to rest the wireless keyboards on, as well as room for participants to place their palms. The tabletop was at a suitable standing height for all participants. The depth camera was a standard Microsoft Kinect, which used the CollAid system (Martinez-Maldonado et al., 2011) to link touches with individuals. The depth camera was mounted directly above the interactive display. Its stand was on the side of the tabletop that was not used by the participants. A video camera recorded each session. ScriptStorm logged all interface actions, both to support group reflection and for use with later video analysis.

Participants

Thirty-six participants were recruited from two nearby universities (22 male, 14 female) with an age range of 19–30 (Mean = 23, SD = 2.53). Participants had a diverse set of first languages (25 English, 4 Chinese, 3 Japanese, 2 Bengali, 1 Korean and 1 Romanian) and studied various degrees (12 Engineering, 8 Medicine, 4 Social Science, 4 Computer Science, 3 Medical Science and 1 Information Systems). Twenty-five were undergraduate students, with the remainder postgraduates.

On aggregate, people indicated that they used computers between 31–40 hours per week, rating themselves as competent or above. Six people had used a tabletop before, but for unrelated purposes. More than a third reported familiarity with touch based tablets. No students reported having prior experience with computer supported collaborative learning scripts.

6.1.4 Results

The results first report a combined analysis of the log data, with video and observer notes across the scripted planning stages, as well as the effects seen on the brainstorming phases. Then the results report the brainstorm outputs in terms of the tasks, and across the three sets of conditions (T-T, T-P, P-T), assessing the impact of the two script forms. ScriptStorm is then compared with the earlier Firestorm tabletop brainstorming system. Then, leadership in the idea categorisation phase is reported. Following, the results report on the reflection phase. Last, the results report on affective data from the various questionnaires. All of these cut across the hypotheses and give a rich picture of the ways that participants responded to both scripted forms.

Brainstorm Script Selections (Team and Preset Scripts)

Table 6.3 details the selections from the team-script / pre-script in support of each of the two core brainstorming tasks. The time spent by each group is also reported. Overall, the table shows that each group had different forms of engagement in terms of: discussion; exploring option explanations; and/or altering default settings. Figure 6.29 presents selected interactions from the planning stages.
**Table 6.3:** Overview of actual choices taken by each participant (columns: A, B, and C, where a grey shade indicates a selection other than the default, and a red border indicates the participant looked at the option explanation for that particular setting); the group outcome from voting process (column: Out, where an orange shade indicates a difference from the default outcome); the time spent in each planning stage in mins (column: Time); and whether the group engaged in some form of discussion during the planning stage (column: Disc?). For the preset script, cells are shaded yellow to distinguish it from the team-negotiated brains.
Group 3 (Team Script, Order 2, Topic B, Idea Generation)

C – What do you think about the ideas in the center like we had last time or should we have them just around our area?
A – Well, I think I prefer ideas near me, so then you know what you have done, in case I’m wondering if I already wrote down an idea.
C – Yeah.
Action: A changes her vote to put ideas near herself.
Action: C changes his vote to put ideas near himself.
B – Maybe we should have ideas in the center, since I won’t be able to see C’s ideas if the ideas are near ourselves, actually I’m not sure.
C – Oh yeah.
Action: C changes his vote to put ideas in the center.
B – I’m not sure why we don’t need touch interaction.
A – It’s the idea generation stage, we have no need to touch or move anything.
B – Oh, actually if we turn on touch, we can rotate items, if someone wants to see something.
C – Yeah, and if we do that, then we can have ideas near each other, and if someone wants to see something, they can just grab it.
Action: C changes his vote to put ideas near himself.
B – I’m fine with that.
Action: B changes his vote to put ideas near himself.

Group 4 (Team Script, Order 1, Topic B, Idea Generation)

A – What is touch interaction?
Action: All team members press the help button to find out what touch interaction means.
C – We are just meant to be making ideas, so I really don’t think we need to turn on touch.
A – I agree. Cool.

Group 1 (Team Script, Order 1, Topic A, Idea Categorisation)

C – Lets make categories first.
B – No I think we should move ideas first, so then you can see what you will actually organize
C – Okay, Yeah.
Action: C and B select the option to move ideas first.
<then in the idea categorisation phase>
C – Why is my keyboard disabled? (when C tries to make a category heading at the start).
B – Because we need to move ideas around first.
C – Oh yeah, whoops. I forgot. Thanks.

Figure 6.29: Example discussion from the brainstorming planning stages.

Of the 24 brainstorms, 16 brainstorms involved a team-script, and in 11 of these, participants actively negotiated and discussed option settings (for which 8 instances involved discussion with both planning stages (idea generation and categorisation), and 3 instances featured discussion only for idea categorisation). In 5 instances there was no discussion – but for 4 of these, individuals still explored the help explanations or altered at least one option setting.

The default settings in the planning stages were largely preserved, likely indicating sound defaults. There were two notable deviations. The first, half of the groups (G1, 3, 5, 8, 11 and 12) enabled touch for the idea generation phase. On review of the videos, some groups (G1, 3, 11 and 12) indicated this was because they wanted to be able to rotate ideas in order to be able to read them. This is an example
where groups wanted extra control over the interface to solve issues they considered as important. The second difference was related to stage duration (G3, 4 and 12). This occurred primarily in the second brainstorm where groups adjusted timing in relation to their experience from the first brainstorm.

Tables 6.30 and 6.31 provide an overview of the time spent in each planning stage for each condition. Time spent for the planning stages was modest, with the first planning stage ranging from 12s to 2min 47s, and the second planning stage ranging from 17s to 1min 29s. The time spent planning dropped for groups involved with more than one (team-script) brainstorm. This was statistically significant for the idea generation planning stage \((t(3) = 8.88, p = 0.003, \text{Cohen’s } d = 4.44)\) and the idea categorisation planning stage \((t(3) = 6.788, p = 0.007, \text{Cohen’s } d = 3.39)\). Choices made in the second brainstorm primarily mimicked those from the first. Interestingly, teams that started with a preset script for the brainstorm followed by a team-negotiated brainstorm (G3, 6, 9 and 12) spent longer initially discussing settings (on average 95s (SD=20s) compared to 65s (SD=52s)), however this was not statistically significant. Overall, it was found that the addition of the scripted components (selection and negotiation of option settings) did not substantially add to the overall activity time (less than 2 minutes on average).

### Quantitative Brainstorm Outputs

All three conditions \((T-T, T-P, P-T)\) involved a team-defined script, with T-T groups having control for both tasks, T-P groups having control for the first brainstorm, and P-T groups having control in the second brainstorm. Table 6.4 overviews the quantitative outputs from each phase (ideas, categories, link actions and touches). Table 6.5 presents descriptive statistics surrounding the different conditions around the number of ideas generated and conditions in the study.

For the tasks \((\text{Promoting Australian Tourism and Recruiting Students to a Local University})\), no statistically significant effect was found in terms of ideas generated – this indicates likely task comparability in terms of difficulty. Furthermore, no effect was found for the order of the brainstorms, highlighting that the counterbalanced design mitigated learning effects. Interesting cases are now highlighted.

Groups in the T-T condition, produced more ideas in the second task (statistically significant with \(p=0.03, \text{Table 6.5-’row 3’}\)). In fact, 9 of the 12 groups produced more ideas on the second task (exceptions were groups 3, 8 and 9). Groups 3 and 9 are now considered as interesting phenomena was observed. For group 3 \((P-T)\) in their first brainstorm they created more ideas than any other group (104 ideas in total). For their second brainstorm they created 49 ideas. The individual participant changes were – person A: 34 to 19; B: 30 to 19; and C: 40 to 11. These individual changes were statistically significant \((p=0.007)\). Comments left by this group indicate the change was due to how they perceived the second brainstorm, as opposed to an effect from the script, for example: “[in the first brainstorm] we just tried to create as many things as possible, just to see if we could” and “last time we made too much”. This indicates reflection. For Group 9 \((P-T)\), they had 77 ideas in the first brainstorm and 59 in the second. From video review, it was revealed this drop was due to a change on how they approached the second brainstorm, where they initially spent the first 30 seconds discussing the topic generally. Additionally, the

### Tables

#### Planning Stage – Idea Generation - Timing (mins)

<table>
<thead>
<tr>
<th>Condition</th>
<th>N</th>
<th>1st Brainstorm Mean</th>
<th>1st Brainstorm SD</th>
<th>2nd Brainstorm Mean</th>
<th>2nd Brainstorm SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-T</td>
<td>4</td>
<td>1:15</td>
<td>0:10</td>
<td>0:17</td>
<td>0:16</td>
</tr>
<tr>
<td>T-P</td>
<td>4</td>
<td>0:57</td>
<td>0:21</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>P-T</td>
<td>4</td>
<td>N/A</td>
<td>N/A</td>
<td>1:40</td>
<td>0:45</td>
</tr>
</tbody>
</table>

Statistically significant: T-T \((t(3)=8.88, \text{p}=0.003, \text{Cohen’s } d=4.44)\)

\(N\) refers to the number of brainstorm

#### Planning Stage – Idea Categorisation - Timing (Mins)

<table>
<thead>
<tr>
<th>Condition</th>
<th>N</th>
<th>1st Brainstorm Mean</th>
<th>1st Brainstorm SD</th>
<th>2nd Brainstorm Mean</th>
<th>2nd Brainstorm SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-T</td>
<td>4</td>
<td>0:49</td>
<td>0:14</td>
<td>0:25</td>
<td>0:08</td>
</tr>
<tr>
<td>T-P</td>
<td>4</td>
<td>0:53</td>
<td>0:12</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>P-T</td>
<td>4</td>
<td>N/A</td>
<td>N/A</td>
<td>1:03</td>
<td>0:22</td>
</tr>
</tbody>
</table>

Statistically significant: T-T \((t(3)=6.79, \text{p}=0.007, \text{Cohen’s } d=3.39)\)

\(N\) refers to the number of brainstorm

---

**Figure 6.30:** Planning Stage – Idea Generation – Time spent for the different conditions.

**Figure 6.31:** Planning Stage – Idea Categorisation – Time spent for the different conditions.
### Phase 1 – Idea Generation

<table>
<thead>
<tr>
<th>Cond. Group</th>
<th>Order</th>
<th>Script</th>
<th>Topic</th>
<th>Time (mins)</th>
<th>Ideas</th>
<th>Time (mins)</th>
<th>Categories</th>
<th>Link Actions</th>
<th>Touches</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-T</td>
<td>1</td>
<td>Team A</td>
<td>5:00</td>
<td>5:00</td>
<td>51</td>
<td>5:00</td>
<td>7:34</td>
<td>8</td>
<td>63</td>
</tr>
<tr>
<td>T-P</td>
<td>2</td>
<td>Team B</td>
<td>5:00</td>
<td>5:00</td>
<td>79</td>
<td>5:00</td>
<td>6:31</td>
<td>8</td>
<td>79</td>
</tr>
<tr>
<td>P-T</td>
<td>3</td>
<td>Preset B</td>
<td>5:00</td>
<td>5:00</td>
<td>45</td>
<td>5:00</td>
<td>5:00</td>
<td>4</td>
<td>23</td>
</tr>
<tr>
<td>T-P</td>
<td>4</td>
<td>Team A</td>
<td>5:00</td>
<td>5:00</td>
<td>23</td>
<td>5:00</td>
<td>5:00</td>
<td>4</td>
<td>13</td>
</tr>
<tr>
<td>P-T</td>
<td>5</td>
<td>Team A</td>
<td>5:00</td>
<td>5:00</td>
<td>26</td>
<td>5:00</td>
<td>4:07</td>
<td>8</td>
<td>27</td>
</tr>
<tr>
<td>P-T</td>
<td>6</td>
<td>Preset B</td>
<td>5:00</td>
<td>5:00</td>
<td>52</td>
<td>5:00</td>
<td>7:00</td>
<td>9</td>
<td>58</td>
</tr>
<tr>
<td>T-T</td>
<td>7</td>
<td>Team A</td>
<td>5:00</td>
<td>5:00</td>
<td>52</td>
<td>5:00</td>
<td>6:09</td>
<td>6</td>
<td>58</td>
</tr>
<tr>
<td>P-T</td>
<td>8</td>
<td>Team A</td>
<td>5:00</td>
<td>5:00</td>
<td>48</td>
<td>5:00</td>
<td>5:50</td>
<td>6</td>
<td>53</td>
</tr>
<tr>
<td>P-T</td>
<td>9</td>
<td>Preset B</td>
<td>5:00</td>
<td>5:00</td>
<td>64</td>
<td>5:00</td>
<td>7:11</td>
<td>8</td>
<td>73</td>
</tr>
<tr>
<td>T-P</td>
<td>10</td>
<td>Team A</td>
<td>5:00</td>
<td>5:00</td>
<td>34</td>
<td>5:00</td>
<td>5:00</td>
<td>7</td>
<td>37</td>
</tr>
<tr>
<td>P-T</td>
<td>11</td>
<td>Team B</td>
<td>5:00</td>
<td>5:00</td>
<td>34</td>
<td>5:00</td>
<td>3:41</td>
<td>6</td>
<td>42</td>
</tr>
<tr>
<td>P-T</td>
<td>12</td>
<td>Preset B</td>
<td>5:00</td>
<td>5:00</td>
<td>50</td>
<td>5:00</td>
<td>7:00</td>
<td>7</td>
<td>72</td>
</tr>
</tbody>
</table>

**Legend:**
- Yellow represents undertime in the phase
- Grey represents overtime in the phase

Table 6.4: Quantitative Brainstorm Outputs in terms of the ideas produced in the ideation phase, and categories, link actions and touches for the categorisation phase. The expected time and actual spent are shown (a grey shade represents the group went over the allotted/agreed upon time, a yellow shade represents the group were undertime).

### Idea Generation – Descriptive Statistics

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Brainstorms</th>
<th>Ideas</th>
<th>Paired samples t-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Order (1st Brainstorm)</td>
<td>12</td>
<td>49.67</td>
<td>26.94</td>
</tr>
<tr>
<td>Order (2nd Brainstorm)</td>
<td>12</td>
<td>51.50</td>
<td>21.93</td>
</tr>
<tr>
<td>Topic A – Promoting Tourism</td>
<td>12</td>
<td>54.08</td>
<td>25.11</td>
</tr>
<tr>
<td>Topic B – University Recruitment</td>
<td>12</td>
<td>47.08</td>
<td>23.48</td>
</tr>
<tr>
<td>Condition: T-T (2nd Brainstorm)</td>
<td>4</td>
<td>46.50</td>
<td>31.16</td>
</tr>
<tr>
<td>Condition: T-P (2nd Brainstorm)</td>
<td>4</td>
<td>63.75</td>
<td>32.99</td>
</tr>
<tr>
<td>Condition: P-T (1st Brainstorm)</td>
<td>4</td>
<td>40.50</td>
<td>12.56</td>
</tr>
<tr>
<td>Condition: P-T (2nd Brainstorm)</td>
<td>4</td>
<td>38.00</td>
<td>19.66</td>
</tr>
</tbody>
</table>

* The results were also run with an assumption to account for unequal time (i.e. were the time spent ideating was not equal). This returned the same statistical observation, for all the conditions. For brevity, these results are omitted.

Table 6.5: Descriptive statistics with regard to the number of ideas generated over different aggregations: the order of the brainstorm; the different topics; and the experimental conditions (T-T, T-P, P-T). Only the T-T condition had a statistically significant effect in terms of ideas generated (p=0.03). The statistical tests were also conducted accounting for different time lengths in the brainstorm – but this did not change the overall outcome.

The group had chosen in the second brainstorm to alter the default layout of the ideas, to instead have the ideas placed alongside the author. This may have also potentially affected the outcome.

The idea categorisation phase was analysed for all groups and all the categories were found to be reasonable for the tasks. In 4 of the 16 tasks with a team-defined script, groups chose the option of grouping ideas first then making categories. Most groups created more links than ideas (19 out of 24 brainstorm), indicating ideas being re-linked (moved from one category to another). Group 7 (T-T) was particularly striking with 27 unlinked ideas in the first brainstorm and 22 unlinked ideas in the second brainstorm.
brainstorm. They spent 7:38 mins categorising ideas in the first brainstorm, and 6:22 mins categorising ideas in the second brainstorm. From review of the video recordings of the group, it was found that the large number of ideas initially created (88 ideas and 100 ideas) made the categorisation process partly labour intensive for this team. Last, it is notable that in 14 instances, groups extended time (after the finish dialog appeared), to allow them to complete outstanding categorisations and to wrap up discussion.

ScriptStorm and Firestorm

To study the impact of the user interface design of ScriptStorm, the outputs from the first phase (idea generation) were compared with the outputs from Firestorm (the earlier tabletop brainstorming interface, presented in Chapter 3). Both interfaces had a similar setup for the idea generation phase, using wireless keyboards for input. The main difference between the two was that Firestorm involved groups of 4, where ScriptStorm was evaluated with groups of 3. To enable comparison, this was accounted for with linear averaging. In addition, only the first 5 minutes were compared, as each study had different time setups (notably each of Firestorm’s idea generation phases were 10 minutes). Table 6.6 summaries the comparisons. For both forms of scripting (the team and preset script), ScriptStorm resulted in a higher output of ideas (statistically significant with the preset-script at \( p = 0.011 \) and the team-defined script at \( p = 0.007 \)). While this needs to be interpreted cautiously, this difference is likely due to the scripting (for example, people becoming more aware of the processes for engaging in effective brainstorms).

<table>
<thead>
<tr>
<th></th>
<th>Brainstorms</th>
<th>Users</th>
<th>Ideas</th>
<th>Welch’s unpaired t-test**</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
<td>Max</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Firestorm</td>
<td>6</td>
<td>4</td>
<td>14</td>
<td>52</td>
</tr>
<tr>
<td>Firestorm (Adjusted)*</td>
<td>6</td>
<td>3</td>
<td>11</td>
<td>39</td>
</tr>
<tr>
<td>Scriptstorm (All)</td>
<td>24</td>
<td>3</td>
<td>16</td>
<td>94</td>
</tr>
<tr>
<td>Scriptstorm (Team script)</td>
<td>16</td>
<td>3</td>
<td>16</td>
<td>94</td>
</tr>
<tr>
<td>Scriptstorm (Preset script)</td>
<td>8</td>
<td>3</td>
<td>26</td>
<td>77</td>
</tr>
</tbody>
</table>

Table 6.6: The first five minutes of ideation from the Firestorm and ScriptStorm studies. The results likely suggest that the scaffolds within ScriptStorm helped groups appreciate the task structure and key activity processes.

Leadership in the Idea Categorisation Phase

Table 6.7 provides a summary of the leaders in the idea categorisation phase. There were ten cases where a leader was active, motivating the group and pushing the task forward (Brainstorm 1 – Groups 1, 3, 7, 9, 12 and Brainstorm 2 – Groups 1, 4, 7, 9, 12). Of these, 7 were from the team-script condition, and 3 from the preset-script condition. There were 9 cases of ineffective leaders (Brainstorm 1 – Groups 4, 6, 8, 11 and Brainstorm 2 – Groups 2, 3, 5, 8, 11). Of these, 5 were from the preset-script condition. Notably, poor leadership was observed for both tasks in Groups 8 and 11, both of which conducted the team-script first. There were 2 cases (Brainstorm 1 – Group 4 and Brainstorm 2 – Group 3) where the team elected themselves all as leaders – because they wanted the extra controls available, rather than wanting to actually lead. There were two cases where a leader emerged who had not been selected in the planning stage (for both instances, Person B in Group 7). There were five cases (Brainstorm 1 – Groups 2, 5, 10 and Brainstorm 2 – Groups 6 and 10) where no leader was selected, nor did one emerge. Of the 16 team-script brainstorms, 7 had effective leadership, 4 ineffective and 5 none. Since the team-script did not force groups to select a leader, these results are not too surprising. For the 8 preset-script brainstorms, 3 had effective leadership and 5 ineffective. In this case, with forced leadership (being Person A), the script did not result in effective leadership. This points to leadership involving a complex of set skills needed in order to guide a group.
Table 6.7: Leaders in the Idea Categorisation Phase.

Interactions in the Reflection Phase

Table 6.8 presents an overview of each team’s interactions with the reflection phase. The reflection phase consisted of a number of widgets (see Figure 6.27, pp. 103) to help individuals answer the post-task questionnaire. Of the widgets presented, 11 groups (from 12) interacted with the ‘statistics’ widget – which was shown in front of each participant. Nine groups (from 12) interacted with the ‘stage choices’ widget. Eleven groups (from 12) interacted with the ‘ideas and categories’ widget, which showed a list-view of the ideas created (and how they were grouped). Only 5 groups (from 12) interacted with the ‘time-summary’
CHAPTER 6. ENHANCING BRAINSTORMING WITH SCRIPTS AND REFLECTION

element. This is likely due to it being hidden within the ‘ideas and categories’ widget, thus many groups did not realise it existed. All groups interacted with the replay timeline – which was set to autoplay like a video by default, which likely drew attention to it.

Triangulating with the post-task questionnaire, on average, participants were mostly neutral with regard to having a reflection stage (3.42/6 for ‘Q11 – I found the information in the reflection stage useful’). Groups spent on average 3mins (SD= 84s) in the reflection phase. Time spent reflecting was statistically higher after the first brainstorm, with 4mins (SD=76s) compared to 2mins (SD=34s) for the second brainstorm (t(11) = 6.63, p < 0.00001, Cohen’s d = 1.91). Overall, the interactions, feedback and time spent, indicate some group members likely found aspects of the reflection phase useful.

**Questionnaire responses**

To gain information about the participants perceptions of ScriptStorm, a pre-task questionnaire (Table 6.9) was asked, as well as a post-task questionnaire (Table 6.10). Both of these were conducted using the tabletop. The Likert scale ranged from 1 to 5 (where 5 represented ‘strongest agreement’). An end of experiment questionnaire asked for general feedback on the brainstorms, reflections and scripts.

The pre-task questionnaire asked a set of general questions. The participants ratings indicate many of them knew each other (Q1–3.97/5). Next, participants were asked about their experience with brainstorming (Question 2). This was initially moderate for the first brainstorm (3.14/5) rising to (3.50/5) for the second brainstorm. The other questions (Q’s 3–5) asked about preferences. Question 3 (‘brainstorming usefulness’) highlighted participants did somewhat find the activity as useful (3.78/5 and 3.89/5). Question 4 (‘preference for a group leader’) showed a slight preference for wanting a leader (3.58/5 and 3.44/5), and Question 5 (‘comfort in leading a group’) showed participants were mildly positive (3.31/5 and 3.28/5), if needing to lead a group.

For the post-task questionnaire, 11 closed questions were asked. Q’s 1–3 addressed key aspects of the interface: stage length, idea categorisation, script option settings. Participants agreed with these for both tasks (with a lower bound of 3.69/5). They more strongly agreed with the four statements regarding authorship (Q’s 4–7) (with a lower bound of 4.06/5). Participants responded positively to being able to see how much they contributed to the brainstorm activity (Q8) (average after the second task, 4.31/5). Importantly with Q9 and Q10, there was agreement that the activity helped participants learn about the key brainstorming phases – idea generation and idea categorisation (with a lower bound of 3.64/5). For

### Pre-task Questionnaire

<table>
<thead>
<tr>
<th>Cond.</th>
<th>Question</th>
<th>Brainstorm 1</th>
<th>Brainstorm 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>All</td>
<td>1. How well do you know these people? (1 = strangers, 5 = good friends)</td>
<td>36 3.97 0.80</td>
<td>3.97 0.80</td>
</tr>
<tr>
<td></td>
<td>2. Rate your experience in the task of brainstorming.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. Rate how useful you consider brainstorming is for finding many creative ways to achieve a goal.</td>
<td>36 3.78 0.67</td>
<td>3.89 0.66</td>
</tr>
<tr>
<td></td>
<td>4. Rate how much you would prefer a group to have a leader (the leader does not necessarily have to be you.)</td>
<td>36 3.31 0.91</td>
<td>3.26 1.17</td>
</tr>
<tr>
<td></td>
<td>5. How comfortable are you in leading a group?</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Conditions: All: T-T (Team Team then Team script); T-P (Team script then preset script); P-T (preset script then Team script).
Condition: All – Question 2 (experience with brainstorming) there was a statistically significant increase between the two brainstorming (W=14, Z=2.86, p=0.006, r=0.17).
No statistically significant effects were observed for the T-T, T-P, P-T conditions.
N refers to the number of respondents (e.g. N = 12, means 12 responses, etc.).

**Table 6.9:** Pre-Task Questionnaire. The Likert scale is from 1 to 5 (where 5 represents ‘strongest agreement’).
Table 6.10: Post-Task Questionnaire Responses (answered during the reflection phase). The Likert scale is from 1 to 5 (where 5 represents ‘strongest agreement’).

the statement (Q11) ‘I found the information in the reflection stage useful’, the average after the second task was 3.42/5. Broadly, participant ratings about the core brainstorm phases were mildly positive.

Free comments were invited in the final post-experiment questionnaire. Table 6.11 lists which aspects of the interface participants liked, disliked and if there were any aspects they would change. Comments pointed to liking the control that was afforded in the team-based script, with at least one member from each group commenting on the ease of use of the interface, and more than half of the participants commenting that the system helped them engage in an effective brainstorm (e.g. quick idea creation, good use of colour, good use of visual interface cues, simple but effective organisation tools, etc.). In terms of dislikes and changes, participants suggested the dwell time (the long press action) be shortened, and a small handful asked if the interface could (in the future) support a mind-map or concept-map mode. Overall, all the questionnaires pointed to a largely positive experience from the participants, and showed that participants considered that the system promoted learning how to brainstorm.

6.1.5 Discussion

The discussion returns to the original hypotheses, drawing on the observations, log data, video analysis and questionnaire responses.

Hypothesis 1: The additional interface complexity of the scripting is acceptable in terms of learnability and usability. All participants were able to use the system with minimal training. On average the scripting component (the planning stages) added a minute and a half, an overhead of 14%. Participant comments were broadly positive about ScriptStorm with many commenting positively on the scripting and none expressing frustration or irritation with it. The evaluation indicates that ScriptStorm was learnable and usable with both forms of scripting.
Effective Brainstorming

4C The system promotes idea generation and helps brainstorming.
7B It facilitated my team mates, enabling them to understand my intentions better.
8A The system is intuitive and easy to use, and it helped in the overall process of brainstorming.
10B I can see other user's idea on the tabletop, so it's helpful to make new ideas.
11B At idea generation, no ideas were evaluated/rejected, and this made it easier to come up with ideas.
12A I felt the system was very effective at enabling a productive brainstorming session. It makes brainstorming fun! Also the guided steps gave clear indication as to when to focus on idea generation and when to focus on categorisation. I feel this enabled us to create more ideas that we would have been able to otherwise. I wish we had this system when I was in school, or even at work.

Planning Stages

1C Timed stages are a good idea as it makes things more efficient.
2C Choices were self-explanatory. There were help functions as well but I did not use it at all.
8C Everyone listened, discussed and if disagreed they would explain why.
12A I liked the voting system, as it gave everyone a fair opportunity to express their preferences without judgement or peer pressure from others. So even though I was out voted on one option, I was still satisfied with the outcome due to the fairness of the system.

Ease of Use

2A Easy to manipulate the ideas placed on the screen.
8C It's quite an enjoyable way of brainstorming! The colour brightened up the display, the sharing of ideas was conducted in an interesting and cool manner. I wouldn't mind having one of these when I have a group project! Also the fact that ideas could be separated into categories made it easier and neater to compile and categorise the information.
9A The interface overall was really simple and clear. Great brainstorming tool.
9B The interface was easy to work with once I understood it; however it was a little confusing to start off with.
9C It's fun and easy to use. It's also a very attractive interface.

Design

2C I was free to express my ideas. The system was easy to use such that I could group my ideas together and represent them in a more complete way.
3A I liked how interactive it was and that you had complete control.
5A Ideas generated were clear for all to view in the interface.
8A The UI [user interface] was customisable and allowed us to work within a framework we had agreed on. This allowed us to brainstorm better.
9C Colour coding was helpful and visually appealing.
12A The system clearly gave visual cues to represent the actions performed. Subtle animations were used to very good effect.
12B The system and its interface were very interesting. I think it will be useful and have a significant impact in collaborative learning.

Reflection

1C Easy to use, statistics were informative.
2B [Liked] the graph (at the very end) which analysed our moves [touches] earlier on.
9A Stage 3 [Reflection] presented easy to read summaries.
12C The reflection stage put our input into different form[s], I can see how I responded.

Table 6.11: Selected quotes from the end-of-experiment questionnaire.

Hypothesis 2: Both forms of scripting are effective in supporting brainstorming. The main measure of success of a brainstorming system is in terms of the number of ideas created and the speed of creating them. On these measures, ScriptStorm was successful, with both forms of scripting, compared with Firestorm, which itself was effective compared with a more conventional brainstorm at a whiteboard (Clayphan et al., 2011a). This appears to be due to the ways that the scripts helped groups follow recommended approaches in the idea generation stage, with the interface minimising production blocking, where ideas were not manipulated and judgement of ideas was deferred. The risk of free-riding was reduced by the use of colour for making authorship clear. The full set of log data confirms the productivity of the groups and the user comments strongly support this hypothesis.

Hypothesis 3: People consider that both forms of scripting help them learn about how to brainstorm. The main evidence for this hypothesis comes from the questionnaire. After using ScriptStorm, participants agreed that using the tool helped them learn about the main phases of the activity (after the second brainstorm, a mean score of 3.78/5 for idea generation and a mean score of 3.81/5 for idea categorisation). Participant comments used the language introduced in the descriptions of the scripting options, another indicator of their learning. This hypothesis interacts with Hypothesis 1, since the planning stages need to be lightweight enough that users consider them, but at the same time are not irritated by
their existence. Of course, in a laboratory study, participants are likely to be more open to such learning than people who come to the interface to complete a brainstorming task; so this needs to be interpreted with a degree of caution.

In particular, the planning stages invoked rich discussion, when group members explored the options and became familiar with what was available. It was also observed that participants internalised knowledge of brainstorm processes and of the items exposed in each of the scripts. For example, in one brainstorm, Group 1, participant C tried to touch the table (when table interaction had been disabled), and participant B told participant C why touch was disabled. A similar event occurred with participants from Group 2.

**Hypothesis 4: People will prefer the team-based script for the control it gives them.** The main evidence for this hypothesis comes from participants’ free comments. Other evidence comes from the active engagement in exploring and setting the scripting options. For 11 team-script tasks, groups actively discussed options, compared with 5 cases (involving 4 groups) with no discussion. All groups engaged with the scripts and none made negative comments about it. The analyses of the three conditions indicate that for the T-T condition, the second brainstorm had much shorter planning stages (indicating teams had internalised their choices). Overall, control options were explored and positive comments were reported, which supports this hypothesis.

### 6.1.6 Conclusion

This study indicates that the design goals and hypothesis were met. This work makes a new contribution, as the first to incorporate collaborative learning scripts with brainstorming at the tabletop. The study explored both team-defined and preset scripts. One of the ways that a tabletop can facilitate a collaborative activity, such as brainstorming, is to scaffold the interaction and collaboration and to help group members become aware of the recommended approaches for each phase of the activity. ScriptStorm was designed to explore how to harness this potential. The evaluation study indicates that ScriptStorm largely provided appropriate defaults for script settings, and helped participants follow recommended approaches for the brainstorming activity.

### 6.2 Supporting Reflection on the Brainstorming Activity with Open Learner Models

Motivated by the use of the reflection phase in the ScriptStorm study (Section 6.1), this section describes a study exploring designs for a number of open learner models (OLMs) in the form of visualisations, and the study of their potential to help people reflect on a brainstorm session. This draws on the less explored potential of interactive tabletops – harnessing collected data to reveal interactions, collaborative processes and the products built. The goal of this work was to determine if people could easily interpret different open learner model representations in support of reflecting on key aspects of the brainstorming process. This work aimed to help people answer the following questions:

- **Core Question 1 (C1)** – How much did I contribute?
- **Core Question 2 (C2)** – At what times was the group or an individual stuck?
- **Core Question 3 (C3)** – Where did group members appear to ‘spark’ off each other?

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2Section 6.2 is based on the following peer-reviewed publications:


Open learner models are representations of peoples’ knowledge, developed skills, performance, and understanding. Open learner models have been shown to successfully facilitate group interaction (Bull and Vatrapu, 2011) as well as provide effective support for reflection (Bull and Kay, 2008). In addition, literature highlights the merit of utilising multiple OLM representations, to account for the different ways people perceive and interpret information (Mabbott and Bull, 2004). For this study, open learner models have the potential to: help groups understand if they followed recommended collaborative approaches; in particular with helping review processes that actually occurred; highlighting periods of activity and inactivity; as well as communicating to the group when they were likely collaborating.

6.2.1 Design of the Open Learner Models

The design covers the foundation for the open learner models, and the visualisations built to help support reflection over a tabletop brainstorm. The data from the ScriptStorm study (24 brainstorms in total) was used as the basis for designing the open learner models. The design included definition of metrics that represented group productivity, individual productivity and a way to classify periods of group collaboration. To do this a number of key measures were first identified. These were:

1. The average number of ideas created by a group. This was 48 ideas (SD=24) with a range of 16–104.
2. The average time between ideas appearing during a group brainstorm (with a group size of 3 people). This was 7.32 seconds (SD=4.2), with a range of 2.88–17.93.
3. A frequency distribution of the average time between ideas appearing within the group. This was a normal distribution with a slight left shift at a peak of 7 seconds.
4. The mean time between ideas appearing at the individual level. This was 26.16 seconds (SD=21.64), with a range of 5.75–110.5.
5. Sustained idea output. This was determined by analysing idea outputs in clusters of 15 second intervals. After removing outliers, this revealed a range distribution of 0–13 ideas.

These measures were chosen as potential features to help profile the nature of a brainstorm quantitatively. The measures drew on brainstorming literature (Osborn, 1953) on the importance of coming up with as many ideas as possible. These measures attempt to quantify the characteristics of a typical group brainstorm. Using these aspects, a number of predictive features were proposed as inputs to the open learner model representations. These were:

- **Group potentially stuck time.** This is the length of time between two ideas where the group takes three times the overall mean time for a set of ideas to appear (22 seconds). This should indicate the small proportion of times a group is likely stuck, seeking to minimise false negatives. That is, if we haven’t seen an idea come from the group after 22 seconds, they are likely stuck.
- **Individual potentially stuck time.** This is the corresponding measure for individuals. This was defined to be 49 seconds (to account for the effect that other group members ideas likely stimulate the production of other members individual ideas).
- **Sparking time lookahead.** Sparking is defined as the phenomenon that one person’s idea helps another person create an idea. A look ahead time of 22 seconds was used.
- **Traffic light signals.** These were a set of three values to help visually inform how well a group was doing when examining the brainstorm in 15 second intervals. For this it was decided that 0–1 ideas (within a 15 second block) would be classed as slow (red), 2–4 ideas would be classed as medium (orange), and 5+ ideas would be classed as high (green).
The Visualisations

To help people find answers to the questions (contributions, times when stuck, and times likely sparked off each other), a number of different visualisations were designed. Figure 6.32 shows these and their presentation to individuals. Each visualisation is now described.

- **Item 1 – Ideas contributions pie chart (C1).** This showed the idea count per person.
- **Item 2 – Graph of group process (C2,3).** This showed when each idea was created with a dot, the colour of which indicated authorship. The vertical axis indicated the category from the second phase of the brainstorm. Stuck periods were shown as thick coloured bars for the group (2a) and thin coloured bars for individuals (2b). For example, in Figure 6.32, the group got stuck twice between 183–209 and 222–244 seconds, the green user was stuck between 148–209 and 211–266 seconds, the purple user was stuck between 146–245 seconds and the blue user was not stuck at all. To model where people sparked off each other, cases where one person’s idea was closely followed by another was done through the category classification of the ideas. This is shown with the yellow horizontal bars (2c) (near the top left of the diagram). There are seven of these in the diagram, for example for category reference 6 (Australian Society) this is between 65-81 seconds (ideas 65s–C, 77s–B and 81s–B, in the area marked by 2d). This measure is an approximation. However, it may be indicative of sparking as it shows ideas that were generated close together and were later grouped together, and showing this, may help people consider this aspect.
- **Item 3 – Graph of the output frequency of ideas from group members (C1,2).** This shows the performance of each individual in the group, aggregated over 30 second periods, with data drawn from the idea generation phase.
- **Item 4 – Graph of ideas produced by the group over time (C2).** This is a timeline that shows the cumulative progress with segments colour coded according to the rate of contribution.
- **Item 5 – Group audio spectrogram (C2,3).** This indicates when a group was talking. As part of the brainstorm method, participants are instructed to call out ideas. Also, when a group is stuck, this may be useful as a reflection of their efforts to overcome it.
- **Item 6 – Table containing the ideas and how they were categorised (C1).** The table labelled each idea to show who created it. It is also the lookup for the category reference for Item 2 (the graph of group process).

6.2.2 Evaluation

A combined think-aloud and interview study was conducted with 15 people who had participated in the earlier ScriptStorm study (10 male, 5 female, age range 21-30, mean age 24). Each person was interviewed separately. In the study, each participant was asked to study three anonymised brainstorming sessions in succession (Figures 6.32, 6.33 and 6.34). The visualisations were presented on laminated A3 sheets of paper to aid visibility. The participants were asked a set of interview questions (Table 6.12), each linked back to the three investigated questions (as shown in the right-most column of the table). This paper-based prototyping design approach (Tohidi et al., 2006) allowed the quick exploration of initial user experiences with different OLM representations over different group brainstorms.

The interview questions investigated whether participants, could obtain information, about individual/group contributions (Q’s 1–4), if they could identify periods when the group or its members got ‘stuck’ (Q’s 5-6) and if they could define whether the group members sparked off of one another (Q’s 7–9). Questions 10 and 11 served as self-assessment of the group and individual performance respectively, to see how people evaluated a brainstorm within the context of other brainstormstorms. There was also a set of four
Figure 6.32: Open Learner Model Visualisations (Example 1 of 3). A group with 34 ideas in total.

The study had the following experimental procedure:

- **Part 1** – The interviewee was shown a group brainstorm with 34 ideas (Figure 6.32). The interviewee was asked to pretend to be individual who created 13 ideas (the purple user). They then answered the interview questions.

- **Part 2** – The interviewee was then shown a group brainstorm from a group who produced 80 ideas (Figure 6.33). The interviewee was asked if they would change their answers to *Question 10 and 11,*
in light of this groups brainstorm. This was done to see the effect of this new OLM and on what people now considered was a ‘good job’.

- Part 3 – The interviewee was then shown a group brainstorm from a group who produced 98 ideas (Figure 6.34). The interviewee was asked to pretend to be the individual who created 52 ideas (the green user). They then answered the interview questions.

- Part 4 – The interviewee was then asked four final questions:
  1. I think this dashboard should be shown at the end of a brainstorm session?
  2. I think this dashboard would make groups more effective in brainstorming?
  3. If I were a person with a low number of ideas, the visualisations would make me more aware for the next time I brainstorm?
  4. I would have preferred this dashboard to the original reflection phase from the ScriptStorm study?

Table 6.12: Think-aloud interview questions investigating the usefulness of the group-based open learner models.
Responses for each interview question were asked on a 6-point Likert scale (where a 6 represented ‘strongest agreement’). Interviewees were instructed to physically point to any of the visualisations (e.g. the charts, graphs and/or table) that influenced their response. Interviewees were also asked to provide an explanation for items they chose.

6.2.3 Results

Table 6.13 summarises the results from the think-aloud/interview. Most of the participants agreed that the OLM forms provided key information about a group brainstorm (a score of 4.20/6 or higher across all the questions). While participants thought aloud, more than half mentioned ease of understandability, especially by the time they saw the third brainstorm. Some had initial difficulties understanding some visualisations. For example, 4 people (from 15) initially found the ‘graph of group process’ (item 2) overwhelming, though by the end of the activity, only 2 people still found the visualisation confusing.

<table>
<thead>
<tr>
<th>Part 1</th>
<th>Part 2</th>
<th>Part 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>A person who produced 13 out of 34 ideas in the group.</td>
<td>Changes to Q10/11 after seeing a group with 80 ideas.</td>
<td>A person who produced 52 out of 98 ideas in the group.</td>
</tr>
<tr>
<td>Mean (SD)</td>
<td>OLMs used*</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>Q1 I could see how much was my contribution?</td>
<td>5.07 (1.06)</td>
<td>1.3</td>
</tr>
<tr>
<td>Q2 I could figure out when the group made the most ideas in the session?</td>
<td>5.53 (0.62)</td>
<td>3.4</td>
</tr>
<tr>
<td>Q3 I could see how created each idea?</td>
<td>4.87 (0.47)</td>
<td>2.6</td>
</tr>
<tr>
<td>Q4 I could see when the group was talking?</td>
<td>5.40 (0.71)</td>
<td>2.5</td>
</tr>
<tr>
<td>Q5 I could figure out when the group got stuck?</td>
<td>5.67 (0.47)</td>
<td>2.4</td>
</tr>
<tr>
<td>Q6 I could figure out when I got stuck in the brainstorm?</td>
<td>5.87 (0.34)</td>
<td>2.3</td>
</tr>
<tr>
<td>Q7 I could figure out the times when the group created a burst of ideas from the same category?</td>
<td>4.20 (1.22)</td>
<td>2.6</td>
</tr>
<tr>
<td>Q8 I could figure out periods when the group was on a roll (producing many ideas quickly)?</td>
<td>5.00 (1.26)</td>
<td>2.4</td>
</tr>
<tr>
<td>Q9 I could see how the ideas were categorised?</td>
<td>5.20 (1.11)</td>
<td>2.6</td>
</tr>
<tr>
<td>Q10 I thought the group did a good job in the brainstorm.</td>
<td>4.40 (1.02)</td>
<td>1.2</td>
</tr>
<tr>
<td>Q11 I thought I did a good job in the brainstorm.</td>
<td>4.73 (0.44)</td>
<td>2.3</td>
</tr>
</tbody>
</table>

*The top two OLM forms used are reported. Items in bold were statistically significant when compared to Part 1.

OLM representations:
- Item 1 – Ideas created pie chart.
- Item 2 – Graph of group process.
- Item 3 – Graph of frequency of ideas.
- Item 4 – Cumulative number of ideas over time.
- Item 5 – Group audio spectrum graph.
- Item 6 – Table of ideas and categorisations.

Statistically significant differences:
- Part 1 to 2 – Question 10 – decrease from 4.40 to 3.40 (W = 36, Z = 2.79, p = 0.000, r = 0.51)
- Part 1 to 3 – Question 7 – increase from 4.20 to 5.20 (W = 4, Z = -2.74, p = 0.007, r = 0.50)
- Part 1 to 3 – Question 10 – increase from 4.40 to 5.20 (W = 10, Z = -2.40, p = 0.002, r = 0.44)
- Part 1 to 3 – Question 11 – increase from 4.73 to 5.60 (W = 10, Z = -3.24, p = 0.00001, r = 0.58)

Part 4 – Suitable for use for reflection.
- a) I think this dashboard should be shown at the end of a brainstorm session
- b) I think this dashboard would make groups more effective in a group?
- c) If there were a person with a low number of ideas, the visualisations would make me more aware for the next time I brainstorm?
- d) I would have preferred this dashboard to the original reflection phase from the Scriptstorm study?

<table>
<thead>
<tr>
<th>Part 4</th>
<th>Suitable for use for reflection.</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.00 (0.97)</td>
<td>a) I think this dashboard should be shown at the end of a brainstorm session</td>
</tr>
<tr>
<td>4.13 (1.36)</td>
<td>b) I think this dashboard would make groups more effective in a group?</td>
</tr>
<tr>
<td>5.13 (0.72)</td>
<td>c) If there were a person with a low number of ideas, the visualisations would make me more aware for the next time I brainstorm?</td>
</tr>
<tr>
<td>4.18 (1.4)</td>
<td>d) I would have preferred this dashboard to the original reflection phase from the Scriptstorm study?</td>
</tr>
</tbody>
</table>

Table 6.13: Results from the think-aloud interviews (from the 15 participants). The Likert scores are from 1 to 6 (where 6 represents ‘strongest agreement’).

6.2.4 Discussion

Group member contributions to the brainstorm

In the absence of a benchmark to compare the number of ideas generated from one brainstorm to another, participants determined if a group did a good job, by judging levels of equality between the group members, referring specifically to item 1 (the pie graph) and item 3 (a graph of the frequency of ideas from team members every 30 seconds). When additional group OLMs were introduced, participants focused rather on the total number of ideas produced. For individual contribution (Q1), participants drew from items 1 and 3 and also item 6 (the table of ideas and categories). Item 1 was considered to present contributions in a simple to understand form: P4–“easy to understand”; P5–“very clear”; and P3–“I have the biggest cut of
the pie". Item 3 revealed contributions over time: P6—"I generated the most ideas in the first 90 seconds"; and P2—"I compared the number of ideas generated and saw that I created just as many as the others". For determination of active periods (Q2), 10 people (P1–4,8–10,12–13,15) consulted item 4 (cumulative number of ideas over time), specifically citing use of the traffic light colour scheme. A small proportion of participants referred to item 3, looking at times when frequency of ideas generated was high across all members. For the question about who created each idea (Q3), item 2 (graph of group process) and item 6 (the table) were primarily referenced. For item 2— the coloured dots showed the authorship of ideas and their location indicated when the idea was made (P1,5,7-11), and for item 6—the author was written to the left of the idea (P2,3,6,12,14). Overall, the following items were referred to the most: item 1—for assessing individual contributions; item 2—for quickly seeing whom created each idea; and item 4—for examining periods containing a large number of ideas.

**Periods where the group or individuals got stuck**

For Question 5 (identify when the group was stuck) and Question 6 (identify when individuals were stuck), the average Likert score was equal to or greater than 5.27/6 across the two questions (Q5: 5.70 & 5.27, Q6: 5.87 & 5.40). Participants utilised items 2, 3 and 4. For item 2—the shaded regions and horizontal bars were used extensively (P1,7–12,15): P9—"I looked at the interval between ideas"; P3—"I looked for the shades to see if they were stuck, when I couldn’t see any, so I checked this one [item 4] to see if there were any red lines"; and P10—"easy to see when I was stuck, because of the highlights". For item 3—participants looked for when groups tapered off, shown as dips (P1–4,9,14): P2—"The graph plateaued at the end, showing me they got stuck", similarly in item 4—the gradient of the line combined with the colour coded segments (P4–5,9,11,13): P5—"because of the red". Overall, item 2 proved to be most useful for identifying stuck periods. These observations reinforce the usefulness of the measures created from analysing prior brainstorms, in providing potentially useful visual indicators. These indicators (the shading, bars and coloured segments) can be the basis for discussion, reflecting on actions that led to identified periods of inactivity.

**Evidence that group members ‘sparked’ off of each other**

Question 7 asked whether a burst of ideas ended up in the same category. For this question, item 2 was referenced, but with mixed responses: 8 participants said the yellow highlight in item 2 was obvious: P13—"I looked at the yellow lines, as it easily caught my attention", but 4 participants did not find the yellow highlights obvious and instead horizontally scanned the grey lines present for each category reference. Three participants mentioned the table, and said that if they spent more time they could of likely figured out which ideas where sparked, but they were put off by the presentation, being heavy in text, compared with the other highly visual items. Determining when a large number of ideas was created, without the constraint of the ideas being in the same category, participants shifted their focus to item 4 (cumulative number of ideas over time). Overall, item 2 was the most useful for showing when members sparked off of each other. This can be used as a starting point for discussion in a reflection stage to talk about sparking, and what led to it, and how often it occurred.

**The impact of showing people comparison Open Learner Models**

Participants were shown an example of a particularly productive group after the first brainstorm and asked to reflect on Q10 and Q11, questions which related to performance. For group performance (Q10), upon seeing another group, with a higher number of ideas, 7 people (P2–3,7,9–10,13–14) downgraded their answer by an average of 2 Likert points, resulting in a statistically significant decrease overall from 4.4/6 to 3.4/6 (p=0.001). The primary reason cited was the difference in the number of ideas created (P2–3,7,9–10), and the lack of identified stuck periods in the new group (P13–14). Three participants (P11–12,15) kept
their original answer stating whether a group performed well was very complex and numbers did not present the entire story, raising concerns about group dynamics, questions about idea quality, and requested if more group OLMs were available (hinting at the want for a 'typical' or 'average' brainstorm to compare against). For example: P12—“I only have 2 groups to go off, not a complete average, also I don’t know if their quality was the same” and P7—“The first group generated longer multiple word ideas, while this group created single word ideas, I think that’s why the first group had less ideas”. For Q11, 5 participants changed their response, with the bulk of participants pointing out that the user with 13 ideas (the purple user) made the most ideas within their group, so their performance was actually quite good (P1,4,8–9,11,13,15), for example: P9—“purple did a good job in his group, and his performance is also dependent on his team members, so I decide to keep my original answer the same”. Two participants (P6,11) mentioned they wanted to have an average value, to put the number of created ideas into perspective.

These comparisons point to the fact that participants are not only influenced only by their own contributions within a group, but also by the performance of related group brainstorms. An apparently strong feeling of success can be changed when exposed to other group OLMs. This is helpful in promoting reflection, in order to promote a deeper understanding of performance, and also possibly to inspire people to develop skills to improve themselves.

Overall, the impact of showing different group OLMs was helpful with participants commenting on the use of items 1 and 3 for individual performance and items 2, 4 and 5 for group performance. Comments backed up these findings: P12—“It gives good ideas of how their process was, and this is good for feedback which is important and it also gives a summary of what we did, and the graphs are cool to look at”; P13—“Users might be interested to see how they perform and if they worked together, self-reflection is really useful”; and P14—“It can tell users a lot of information and may help them next time, and [identifying] who is least active might encourage [them] to try to do better”.

6.2.5 Conclusion

A series of OLM visualisations was designed for the purpose of analysing whether individuals could understand group and individual processes in order to support reflection for tabletop brainstorming. Results showed people found the OLMs mostly straightforward to use to answer the core questions asked, especially with experience. In the process of the study, it was discovered which visualisations were most commonly referred to and why, leading to a greater understanding of the importance of the value of the different representations. Of the six representations, the graph of group process (item 2) and the graph of the frequency of ideas generated every 30 seconds (item 3) were referred to equally, followed by the line graph of the number of ideas over time (item 4). These were then followed equally by the contributions pie graph (item 1) and the table listing the ideas and categories (item 6). The audio spectrogram (item 5) was rarely used. From this work, a next logical step, is determining how to integrate these OLMs back into the tabletop brainstorming environment.

6.3 Scaffolding Reflection for Tabletop Brainstorming

Building upon the results just reported, this section presents ScriptStorm-Reflect, a system that provides a heavily scaffolded reflection activity after a tabletop brainstorm. The aim is to help groups carefully consider produced outputs and group processes. The system is guided by two core research questions:

- **Question 1 (RQ1) – Do people gain insights from studying egalitarian contribution visualisations?**

  The aim is to find out whether people change their self-assessments on how equal their contributions

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3Section 6.3 is based on the following peer-reviewed publication:

are; and their understanding of this, after viewing different visual representations of traces of their contributions to the group output.

- **Question 2 (RQ2) – Do people gain insights from studying idea sparking visualisations?** This aims to assess if a scaffolding process can trigger reflection compared with inspecting just the final brainstorm outputs. Part of exploring this is to get participants to consider the effects of working in a group.

This work is motivated by the importance of effective reflection for enhancing future collaborative activities. Reflection involves actively monitoring, evaluating and modifying ones’ understanding of processes. It demands thinking back on what has been done in order to discover how various actions have contributed to actual outcomes (Schön, 1983). This work puts at the forefront the importance of understanding what a group has produced, the how and when of its production, and the processes undertaken. This enables all team members opportunities to understand their contributions, and provides the hooks for continuous improvement and development of collaborative skills. The goal is that this can enhance people’s appreciation of the recommended approaches to group work, how their actual actions compared with the recommended approach, and how lessons learnt can be applied in the future.

The study aims to provide a new form of tabletop support for a rich reflection activity that leverages the data collected from the group to support self-awareness and build meta-cognitive skills (Mabbott and Bull, 2004). For both reflection aspects, the system presents multiple open learner models, generated in real-time from the data from the underlying collaborative group brainstorm. The system encourages team members to learn about the processes that took place that shaped the final group outputs, as well as the types of collaborative interactions engaged in. In addition, it provides a view of data to appreciate and understand the effects of being part of a team (Dugosh et al., 2000).

### 6.3.1 User View and Experimental Setup

This section presents the interface and activity procedure as it was used in the study. **ScriptStorm-Reflect** consisted of: a 42-inch interactive tabletop (a Samsung SUR40); a 27-inch non-interactive vertical display; and individual wireless Bluetooth keyboards for input (see Figure 6.35). Teams of three first completed a regular brainstorm. Only one brainstorm was conducted per team. Teams were asked to promote their local university to high-school students (all participants were university student volunteers). The idea generation phase lasted 5 minutes, ideas were oriented in the center and colour coded for authorship. Idea categorisation then followed, where students organized, filtered and assessed their outputs. No time constraint was applied to this phase. Next, a **scaffolded reflection exercise** was conducted. This consisted of two parts: reflection on individual contributions and reflection on group effects.

**Reflection on Egalitarian Contributions**

- **Part 1** – Shown the **final output from the brainstorm activity**. This was presented on the vertical display. This was provided to establish a baseline for the reflection on egalitarian contribution aspects (Figure 6.36–‘top-left’).
- **Part 2** – Shown a **pie chart of individual contributions**. This was adapted from the previous study, due to its reported usefulness (Figure 6.37).
- **Part 3** – Shown a **line graph of the frequency of ideas produced** (in 30 second intervals). This was adapted from the previous study, due to its reported usefulness (Figure 6.38).

While viewing each visualisation, the group could discuss their thoughts. Participants were then asked to individually answer – *‘Did I contribute an equal amount to the brainstorm?’*. Participants used a tablet to answer the question. A Likert scale from 1 to 6 was used (with a 6 indicating *‘strongest agreement’*). There was space provided for participants to justify their ratings.
CHAPTER 6. ENHANCING BRAINSTORMING WITH SCRIPTS AND REFLECTION

Figure 6.35: ScriptStorm-Reflect setup – (a) an interactive tabletop; (b) a non-interactive vertical display; (c) individual wireless keyboards; and (d) instruction, topic and activity sheets.

Figure 6.36: Part 1 & 4: a group reflecting on the outputs from their brainstorm (ideas and categorisations). Note: the tablets delivered the evaluation questionnaires, and do not form part of the system.

Figure 6.37: Part 2: a group contributions pie chart, showing individual contribution slices.

Figure 6.38: Part 3: a line graph of the frequency of ideas generated by each person (every 30 seconds).

Reflection on Group Effects

For the second part of the guided reflection exercise, teams were first explained what ‘sparking’ was. This was defined as ‘an idea created due to the inspiration of someone else’s idea’ (either because you heard their idea or you read it, and it helped you come up with your idea). They then engaged with the following:

- Part 4 – Shown the output of the brainstorm activity. This was shown again to establish a baseline for reflection on group effects, looking at the output as seen as the end of the brainstorm.
- Part 5 – Shown a replay of the entire brainstorm (at 4x the speed of the original activity). This was adapted from the timeline widget of the previous study. The rationale was to make the group consider the process, by seeing it unfold over time (Figure 6.39).
- Part 6 – Students were asked to do a classification exercise, where each person classified whether each of their ideas was inspired by another group members’ idea. Classifications were completed using the tabletop. To aid with the exercise, on the vertical display, an accompanying top-down, left to right ideas list ordered by time was shown (Figure 6.40–‘top-right’). After this was complete, a summary of the ideas sparked from others based on the classifications was shown (Figure 6.41). This exercise and summary visualisation replaced the previous graph of group process (from Section 6.2). This was done because the previous visualisation was an approximation and also participants noted it was quite complex. This classification exercise was built to be more straightforward, and had the merit of reporting on the actual beliefs from the participants with regard to the sparking phenomena.

After being shown each visualisation (within each part), individuals separately answered the question ‘Did you spark ideas off other people?’ Again a Likert scale of 1 to 6 was used, and there was room
Figure 6.39: Part 5: a brainstorm replay (the process played like a video at 4x the speed of the original activity).

Figure 6.40: Part 6: a classification exercise where people marked which of their ideas were inspired by others. The vertical display showed all the ideas (ordered by time) to help with the classification exercise.

Figure 6.41: Part 6 (continued): the visualisation shown after the participants had finished classifying which of their ideas they believed were inspired (spark ed) by others.

to justify any responses. At the conclusion of the reflection phase, participants answered a post experiment questionnaire about usability with opportunities to comment on which parts of the scaffolded reflection activity they found most and least useful.

Participants

Participants consisted of 30 student volunteers (23 male, 7 female) recruited from a local university, aged 20–27 (mean=22, SD=2). They had varied majors: social studies, computer science, engineering and medicine. All reported familiarity with personal device touch interfaces. They were predominately from English speaking backgrounds (with the exception of one group who were Korean exchange students). Ten teams of three were randomly organized. Students sat comfortably around the hardware setup with equal viewing access to both devices – the tabletop and vertical display.

6.3.2 Results and Discussion

The analyses report on the perceptions of each of the visualisations for the two aspects of the reflection activity (reflection on egalitarian contributions and reflection on group effects). Data is drawn from the
post-experiment questionnaire, the time spent on the brainstorming and reflection activities, and the changes in the self-reported Likert scores between visualisations.

Post-Experiment Questionnaire

Table 6.14 shows the responses to the post-experiment questionnaire. There was a high level in understanding all aspects of the brainstorm and reflection, with a score of more than 5.13/6 for Questions 1 through 4. Furthermore, on asking if students like being guided (scaffolded), they reported high satisfaction with this (Question 5 – 5.03/6). Table 6.15 shows free form responses on the questions that asked which aspects of the interface students liked/disliked. The responses indicated different OLM preferences among the students (Questions 8 and 9 in the table). Overall, the feedback collected points towards the participants liking the elements within the reflective exercise and the scaffolding provided.

<table>
<thead>
<tr>
<th>Question</th>
<th>Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1. I was able to represent my ideas about the topic?</td>
<td>5.17 (0.73)</td>
</tr>
<tr>
<td>Q2. I was able to easily understand the core operations presented to me?</td>
<td>5.57 (0.50)</td>
</tr>
<tr>
<td>Q3. I found the system made it easy to co-ordinate with other members of my group to do each of the tasks?</td>
<td>5.13 (0.79)</td>
</tr>
<tr>
<td>Q4. Overall, I was able to understand how the system responded to my input?</td>
<td>5.37 (0.60)</td>
</tr>
<tr>
<td>Q5. Did you find being guided through a reflection phase useful?</td>
<td>5.03 (0.91)</td>
</tr>
</tbody>
</table>

The Likert scale was from 1 to 6 (where 6 represents strongest agreement).

Table 6.14: Post-Experiment Questionnaire – Likert Questions and Responses.

<table>
<thead>
<tr>
<th>Q6 – Which aspects of the interface did you like best?</th>
</tr>
</thead>
<tbody>
<tr>
<td>26 explicitly commented on the ease of use with the interface. For example:</td>
</tr>
<tr>
<td>4A – The interaction of typing and touching. Good integration.</td>
</tr>
<tr>
<td>4C – The fact that you could trace back the source of the idea (colour) and also the vertical display was useful.</td>
</tr>
<tr>
<td>8A – I like the fact that it was very simple to use, and the icons were very graphic (I mean that the crosses for erasing, or broken chains for removing connections between categories, etc...).</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Q7 – Which aspects of the interface did you dislike?</th>
</tr>
</thead>
<tbody>
<tr>
<td>17 mentioned the interface was not as responsive as a smartphone / tablet touchscreen.</td>
</tr>
<tr>
<td>7 stated no explicit issues.</td>
</tr>
<tr>
<td>3 mentioned orientation issues (text readability).</td>
</tr>
<tr>
<td>2 wanted a concept map / mindmap mode.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Q8 – Is there any particular part of the reflection exercise (e.g. pie chart, frequency chart, replay, classification activity) that you particularly liked?</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 liked the pie chart.</td>
</tr>
<tr>
<td>8 liked the classification exercise.</td>
</tr>
<tr>
<td>5 liked all the visualisations.</td>
</tr>
<tr>
<td>3 liked the frequency graph.</td>
</tr>
<tr>
<td>2 liked the replay.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Q9 – Is there any particular part of the reflection exercise (e.g. pie chart, frequency chart, replay, classification activity) that you particularly disliked?</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 found the classification exercise redundant after seeing the other visuals.</td>
</tr>
<tr>
<td>3 found the frequency graph confusing.</td>
</tr>
<tr>
<td>3 found the replay took too long.</td>
</tr>
</tbody>
</table>

Table 6.15: Post-Experiment Questionnaire – Open-Ended Questions and Responses.
Time Spent in the Brainstorm Activity and on Reflection

Table 6.16 lists the timing for the brainstorm activity and the reflective activity. The average time to complete both the brainstorming and reflection exercise was approximately 27 minutes (with a range of 17–36 mins). The brainstorm activity took on average 11 minutes, with 5 minutes for idea generation (fixed for the activity) and 6 minutes for idea categorisation (with a range of 3–9 mins). Groups were not time bound for categorisation, and could take as long as they wished. The average time taken to complete the reflection exercise (consisting of six parts) took 16 minutes (with a range of 8 of 24 mins). Overall, parts 1–4 took approximately 2 minutes each, and parts 5 and 6 took 4 minutes each. Overall, 9 out of 10 teams spent more time on reflection than they did on the actual brainstorming activity. This likely points to some form of engagement.

![Brainstorm and Reflection Activities – Timing Information](image)

Table 6.16: Brainstorm and Reflection Activities – Timing Information.

Did participants gain greater insights from studying the egalitarian contribution OLMs?

Table 6.17 reports the results of both the students’ idea generation and the ratings for the different parts of this reflection aspect. Table 6.18 reports on selected qualitative feedback for each part. From the ideas generated, certain group themes emerged: near equal (Groups 2, 3, 5, 7 and 8), a leader (Groups 6 and 9) and a straggler (Groups 1, 4 and 10). For reflection on egalitarian contribution, participants were first primed with the output of their brainstorm, which showed the state of the brainstorm at the end of the idea categorisation phase (for example, see Figure 6.36, pp. 124). This is the baseline, available in the core brainstorming activity. People were asked to assess their contributions at this stage, so it could then be assessed what they gained from the later OLM visuals. On this, 22 out of 30 people left a comment in the post-experiment questionnaire that this visual helped them in some way to understand their contribution to the group (Table 6.17–‘Part 1 (Insight column)’, pp. 128). Participants commented primarily on colour distribution and equality of different members ideas within categories (Table 6.18–‘Part 1’), with comments revealing ‘gut intuition’ and ‘memory’ as the primary bases for self-assessment.

Next, participants were shown a contributions pie chart (e.g. Figure 6.37, pp. 124), with segments to indicate each person’s contribution. For this item, 23 out of 30 people (76.67%) found insight, measured by either a change in their self-assessment score or from written feedback. This included 6 new people for whom the prior visualisation (brainstorm output) had not provided insight. For the pie chart, written responses revealed knowledge discovery and back-talk (Schön, 1983). For example “it was less than I thought...”, “I just found out...”; “I just realised...”. This illustrates knowledge discovery. The contribution pie chart led to an appreciation and awareness from many of the participants. Even though 16 students
Table 6.17: Reflection on egalitarian contributions. Question asked after each visual: ‘Did I contribute an equal amount to the brainstorm?’ The Likert scale is from 1–6 (where 6 represented ‘strongest agreement’).

did not change their self-assessment scores, 9 still made a comment about the usefulness of the visual. For these people it served to confirm their understanding. Table 6.18–‘Part 2’ lists participant remarks.

Last, participants were shown an idea frequency timeline (e.g. Figure 6.38, pp. 124). Seventeen people noted an effect, again judged by a self-assessment Likert score change or from the written feedback. Ten participants altered their self-assessment score (relative to the score from Part 2). Comments indicate that this visualisation allowed participants to see their developing proficiency in the group brainstorm and better understand the approaches they took when creating ideas (Table 6.18–‘Part 3’). Moreover, analysis of the recoded video of the sessions revealed this OLM prompted discussion.

In summary, people were able to gain insights on their performance from the brainstorm which was not possible from just viewing the final state of the brainstorm output. This points to the value of multiple visualisations as a way to keep attention on the reflection process. The contributions pie chart helped people reflect about their real contribution to the brainstorm, with many updating their self-assessments as a result. The idea frequency timeline helped people reflect on the process, and triggered rich discussion.
CHAPTER 6. ENHANCING BRAINSTORMING WITH SCRIPTS AND REFLECTION

Selected Quotes – Reflection on Egalitarian Contributions

Part 1 – Brainstorm Output (after categorising the ideas)

4A Based on the colour-coding, appears to be a fairly even contribution spread at first glance.
8C I looked at the colours of the words and I think I came up with a little more than a third of them.
9A There isn’t a lot of blue but there is a lot of the other colours.

Part 2 – Pie Chart (of individual contributions)

1A Did worse than I thought.
5A The results showed that I contributed the same amount compared to the other participants. The average number of ideas were around 26-27 ideas and I was in that average.
7A Being able to see the number of contributions I made relative to everyone else made me appreciate my own contributions more.
8B Of the 35 ideas, 12 were mine therefore I was right to think that I contributed equally

Part 3 – Line Graph (Frequency of ideas over time)

4A This chart, showed the peaks and troughs on my contribution over time - it made it clear to me, that I wasn’t consistent (I thought I was).
5B I was very consistent throughout the brainstorming process. I feel like my contributions were appreciated.
7A This graph made me feel like I contributed more than the information presented in part 1 [the brainstorm output], but it made me also feel like I did less than what I saw in part 2 [the pie chart]. Sometimes, my contribution frequency was close to zero, but other times, it was really high. This graph made me realise my contributions were done in bursts.

Table 6.18: Reflection on Egalitarian Contributions – Selected Participant Comments.

Did people gain insights from studying the sparking OLMs?

Table 6.19 reports the number of ideas sparked (Columns: ‘Sparked Ideas’, ‘% sparked (individual)’ and ‘Total group sparked %’) as self-reported from the students’ classification. Table 6.20 reports comments from this aspect of the reflection. Sparked ideas from individuals ranged from 0%-69% (Mean=38%, SD=15), while the total amount of ideas sparked per group ranged from 22%-47% (Mean=35%, SD=8). It is interesting, that so many students appeared to have been aware of sparking.

For reflection on group effects, participants were shown the output of their brainstorm. Here 23 from 30 students indicated that they felt they had sparked ideas (Table 6.19–‘Part 4’). This was confirmed on review of the justifications that accompanied the scores, for example “[I] felt like I sparked a lot of ideas off others” and “listening to /an/ idea someone spoke I was able to be more creative and complement it with others”. Following, this visualisation, a replay of the brainstorm was provided. Twenty people (66.67%) stated that the replay provided insight. For example, “it remind[ed] me of [my] mental processes [and] reinforced that a number of [my] ideas were sparked”; and “it helped me remember ideas that were actually sparked, that I thought were original”. Notably the replay was the only visual where 3 people explicitly commented that the replay took too long (an average of 4 mins, see Table 6.16, pp. 127).

The last part consisted of a classification exercise where people went through their ideas, indicating if these were inspired by others’ ideas. The classification exercise allowed people to more deeply engage with understanding the process of sparking. For example, when people viewed the final brainstorm output, one commented that ‘sparking likely only occurred at or towards the end of a brainstorm’. Upon studying the sparking visualisations, it became apparent that they considered that sparking contributions were distributed throughout the entire brainstorm. The only problem reported for this item, much like the replay, was the time required to do the classification exercise and then review the visual generated. At an average of around 4 mins for the classification exercise, people made comments such as “long and laborious”, but did acknowledge it had benefit, for example “[while it] was quite long, it was useful to think
**Table 6.19:** Reflection on Group Effects (Idea Sparking). Question asked after each visual: ‘Did you spark ideas off others?’ The Likert scale is from 1–6 (where 6 represented ‘strongest agreement’).

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<th>% sparked (individual)</th>
<th>Total group sparked %</th>
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<th>Part 5 - Replay</th>
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* Insights are based on:
(1) either a score change, or
(2) whether a specific comment was left by the participant indicating some form of insight (e.g. ‘it made me realise...’)

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**Selected Quotes – Reflection on Group Effects (Idea Sparking)**

**Part 4 – Brainstorm Output (after categorising the ideas)**

3A Some of my ideas are expanding on others.
4A From memory and observation of the display, I think about half my ideas were sparked.
7A Felt like I sparked a lot of ideas off others and judging from the way we categorised the different ideas as shown, I would say that's the case.
8B Overall collaboration during the brainstorming exercise increased my frequency of ideas. Listening to an idea/word someone spoke I was able to be more creative and complement it [their idea] with others.

**Part 5 – Brainstorm Replay (4x speed of the original)**

2A Helps my memory.
2B Lets me see how we did the brainstorming.
4A This helped remind me of the mental processes I went through in the brainstorm and reinforced that a number of ideas were sparked.
5B I found that I did take some ideas from others.
7A [The replay] made me feel like I sparked more ideas off others than Part 1 [the display of the final brainstorm], mainly because it helped me remember some ideas were actually sparked off others, when I originally thought I had come up with them on my own.

**Part 6 – Sparking Classification and Visual**

2A Interesting to see I sparked a quarter of my ideas.
7B This exercise confirmed my feeling about my sparked ideas, especially after just seeing the replay.
9C There were actually even more ideas been sparked off [others], when I looked at the ideas in detail.

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**Table 6.20:** Reflection on Group Effects (Idea Sparking) – Selected Participant Comments.
about the sparked ideas”. This is a clear tradeoff, with certain aspects of reflection needing more time than others. If a facilitator (or teacher), wants a group to reflect on this aspect, this time may be justified.

From the qualitative feedback from the students, both the replay and classification exercise were used in different ways. The brainstorm replay (e.g. Figure 6.39, pp. 125) allowed people to revisit processes undertaken throughout the entire brainstorm. The classification exercise (e.g. Figure 6.40, pp. 125) helped people deeply consider which of their ideas were due to the effect of working in a group. This helped uncover misconceptions – such as the extent to which the group sparked ideas from one another. The results of the both representations confirm the difficulty in attempting to measure sparking automatically, and indicates the benefits of such an exercise as part of a dedicated reflection period.

6.3.3 Conclusion

The aim was to offer people the benefit of reflection on what they did, how they did it, and what they learnt. This work guided people with a set of scripted activities exploring different reflection aspects. Multiple representations for both egalitarian participation and idea sparking led to insights for 28 of the 30 people (when either aspect was considered – ‘Overall insight’ column from Table 6.17 and Table 6.19). The reflection phase provided the opportunity to enhance peoples understanding of key brainstorming processes. It appears from the results captured, both from the self-reported Likert scores and the feedback, that many participants found the different OLM forms useful, with the frequency line graph allowing performance tracking; the replay activating memory; and the hands-on classification exercise highlighting the extent of sparking (i.e. the effect of being in a group).

This study demonstrates that OLMs forms are effective for gaining insights beyond those of just the final products arising from a collaborative activity. Furthermore, this work is the only study to date, that has measured the group brainstorming effect of sparking, by calling on people’s actual classifications.
Chapter 7

Brainstorming in a Multi-Session Tabletop Classroom

This chapter reports the in-the-wild use of ScriptStorm (a tabletop brainstorming tool) within a multi-surface classroom environment (Figure 7.1). ScriptStorm was used to support two university level courses, an undergraduate level HCI course with 108 students and a postgraduate level Pervasive Computing course with 42 students. Both courses came with their own associated pedagogical requirements and learning objectives as set by the teachers. The use of ScriptStorm in this setting provides an authentic test-bed to analyse not only usability and user experience, but to test assumptions of the brainstorm interfaces developed through Chapters 3, 4 and 6. Notably, the study ran over 9 weeks of classes, so reducing novelty effects in later classes. This is one of the largest works to date on this scale.

This chapter starts with the design of the classroom environment. This work was a collaboration, as reflected in the resulting publications in the footnote. The work builds on the infrastructure of MTClassroom (Martinez-Maldonado et al., 2013c). This was jointly extended to allow: multiple learning applications to be orchestrated (where ScriptStorm was one of them); detailed lesson plans to be defined and deployed to the technology-enhanced classroom; and the use of a portable teachers dashboard to control the technology as well as provide group based radars of participation.

This chapter links to the thesis statement, leveraging the affordances of interactive tabletops to support small-group collaboration, with the tabletops complimented by other tools in the classroom – vertical displays, and a portable teacher’s dashboard. This chapter recounts the use of ScriptStorm with 33 distinct project groups under the direction of 4 class teachers, supporting a diverse set of learning aspects.

Broadly, the contributions of this chapter are: i) the description of the design process that was needed

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Sections 7.1 through 7.4 and parts of Section 7.5 are based on the following peer-reviewed publications:

i) Martinez-Maldonado, R., Clayphan, A., Ackad, C., & Kay, J. (2014). “Multi-touch technology in a higher-education classroom: lessons in-the-wild”. In Proc: Australian Computer-Human Interaction Conference (pp. 220-229). ACM. This paper explains the design process undertaken to deploy multi-touch technology to a classroom setting. This was part of a research team effort from all the authors from the Computer Human Adapted Interaction Research Lab at The University of Sydney, Australia. The paper explained the design rationale as well as the different learning applications deployed to the multi-touch interactive tabletop classroom (brainstorming, concept mapping and meeting support). I made significant contributions to all aspects of that work, defining the problem, design of the software infrastructure and its implementation for the classroom, design and conduct of the studies and writing the paper. I led aspects related to the brainstorming sessions and collaborated with the others in their sessions.

ii) Martinez-Maldonado, R., Clayphan, A., & Kay, J. (2015). “Deploying and Visualising Teacher’s Scripts of Small Group Activities in a Multi-surface Classroom Ecology: a Study in-the-wild”. In: Journal of Computer Supported Cooperative Work (JCSCW), 24(2-3), 177-221. This paper describes the design and use of configurable lesson scripts, for use in orchestrating activities in a multi-touch interactive tabletop classroom. The configurable lesson plan architecture was built on top of two classroom frameworks: MTClassroom and MTDashboard. Two learning applications are explored in the paper: Brainstorming (led by myself) and Concept Mapping (led by Dr. Roberto Martinez-Maldonado). My role was joint input to the design of the lesson plan protocol; the implementation of the lesson plan functionality for the brainstorm tool; and effort toward the experimental design, analyses conducted, the evaluation, and interpretation of results for both learning applications, as well as writing the paper.
to successfully deploy ScriptStorm to the interconnected multi-touch tabletops; and ii) the real use of ScriptStorm in a longer-term setting, as a flexible learning application, and the experience of using it.

7.1 Background on Classroom Support

The value of collaboration for small-group work and creative problem solving is supported by a large body of research (Osborn, 1953; Stahl, 2006; Dillenbourg et al., 2009). Interactive tabletops offer potentially valuable affordances to facilitate collaborative classroom activities (Kharrufa et al., 2013a). Key among these are: ‘support for group collaboration’, because they allow direct face-to-face interaction (Benko et al., 2009; Müller-Tomfelde and Fjeld, 2010) at a large, horizontal display that creates a shared interaction space (Benko et al., 2009); and ‘the potential to exploit the learner’s digital footprints usefully’ which can provide valuable evidence-based insights to learning (Müller-Tomfelde and Fjeld, 2010). However, an identified serious limitation is a lack of strategies to make multi-touch technology effective in a classroom.

There is also a substantial body of work on many aspects of tabletop interaction (see, for example, reviews in Scott et al. (2003), Benko et al. (2009), and Müller-Tomfelde and Fjeld (2010)). A growing slice of this work tackles the particular demands of learning contexts (Dillenbourg and Evans, 2011; Higgins et al., 2011; Evans and Rick, 2014). Yet, there has been little work involving actual authentic classroom deployments (for an overview, see Section 4.2.2, pp. 45). As Kharrufa et al. (2013b) highlights, there is a real need for ‘studies in realistic environments’ to enable important progress in this area.

A comprehensive rethinking on ways in which teachers can link their pedagogical intentions with the technical features of digital surface technologies (tabletops, whiteboards, tablets, etc.) is still needed (Higgins et al., 2011). Exploring this may provide a better understanding of the possible, more effective uses of technologies and a basis for their integration in a digital classroom ecology. In particular, little has been done to help teachers design the lesson of planned small-group activities and deploy them in a classroom enhanced with these kinds of devices.

7.1.1 Teacher’s Support in the Classroom

Teachers routinely conduct small group activities in the classroom because when such activities are designed effectively, they may positively reduce social loafing and also facilitate the management of the class so teachers can provide feedback more effectively (Michaelsen et al., 1997). However, conducting small group activities, especially in newer environments, such as the one presented in this chapter, requires teachers to become comfortable with managing an increasingly complex set of educational resources whilst
ensuring learning objectives are still met. This raises issues of: the type of support needed by teachers in the classroom, specifically the type of support in these technology-enhanced rooms; and which aspects of collaborative scripting and classroom orchestration theory that can be drawn on to help manage and utilise all the available resources. These aspects are required to inform an understanding of how the collection of resources (multiple tables, walls, dashboards, and the surrounding environment) can be used to enact the intended learning design(s), and importantly how to not overload the teacher in the process.

Teachers play a crucial role in the classroom as coordinators of all the resources involved in the collocated environment (Dillenbourg et al., 2011). But they also have an important role in the design and execution of the planned learning activities even if they are not physically present or delivering the activities in the classroom (Prieto et al., 2011) (for example, this occurs in blended learning environments, where face-to-face classroom sessions are combined with computer-mediated activities, or when tutors deliver the class on behalf of the main teacher). This is very common in tertiary education, where lectures are delivered to more than a hundred students concurrently, who are then divided into smaller groups, for tutorial or lab sessions (Kottasz, 2005).

In the latter case, the main teacher has to perform a series of design tasks before the class. These include for example: designing the activities; planning the workflow of the class; choosing relevant learning materials and tools; writing the instructions for the students; and defining an ideal lesson plan for the enactment of the class. Then, during the class, although the teacher may intend to adhere to the planned lesson, many times they may need to improvise according to the conditions and unexpected events that may occur in the classroom (Dillenbourg et al., 2011). Examples include: students arriving late; students not understanding instructions; ensuring students are not left behind; and the need to tune the duration of the activities, which may have been under or over estimated in the initial design of the lesson script.

As stated earlier, while research on interactive tabletops has targeted educational contexts, little has been done to provide direct support to teachers. The approach described in this chapter goes beyond previous work by designing the infrastructure for translating teacher’s designs into a format that can be understood by a technology-enhanced classroom, allowing the teacher to control and be aware of the progress of a designed lesson plan, during class-time and for later analysis.

7.1.2 Classroom Orchestration

This work is grounded on the metaphor of classroom orchestration (Dillenbourg et al., 2011). This provides links between design, deployment and review of the lesson plan. Orchestration describes the role of the teacher in terms of the design of the learning activities and the runtime management of the classroom resources, learning processes and teaching actions (Dillenbourg and Jermann, 2010). These teaching actions may include tasks of monitoring, provision of feedback, improvisation and assessment (Prieto et al., 2011). Orchestration can be described as a loop of awareness and regulation: the teacher monitors the state of the classroom, compares its state to some intended scenario, and performs actions to reach the optimal state in the classroom (Dillenbourg et al., 2011).

Prieto et al. (2011) performed a comprehensive analysis of literature on orchestration, identifying that a key component of orchestration is designing and planning the learning activities that will be monitored and coordinated in the classroom. The approach described in this chapter takes into account the information that can be captured by the tabletops to inform teachers with key indicators that they can use to re-configure the class script on-the-fly or to adapt the activity for future sessions. Another aspect identified by Prieto et al. (2011) includes the management and regulation of the resources available in the classroom (technological, physical and human) to achieve the objectives of the learning activity. For the approach taken, this is addressed by providing the means for the teacher to control the digital technology and activities deployed in the classroom through an interactive teacher’s dashboard. Another
aspect of the definition of orchestration is that both the learning activity and technology have to allow change and adaptation of the lesson script, to accommodate unplanned events during the enactment of the learning activities. This can be done by teaching mechanisms or through the technology itself. The approach in this chapter aims to provide teachers with mechanisms to improve their awareness of the state of the classroom and the activity workflows.

The orchestration approach defines two key required processes: state awareness and workflow manipulation (Dillenbourg et al., 2011). According to this, the technology itself does not need to perform complex analysis or automated actions, but instead it should provide key information about the classroom state leaving the diagnosis of such data to the teacher. Dillenbourg and Jermann (2010) define fifteen factors that provide a teacher-centred and integrated view of technologies for classroom orchestration. Of these, ten are described as they directly apply to the learning context employed here:

1. Teacher-centred. Teachers should design the learning scenario, the activities and lead the collective management of resources in the classroom.
2. Flexibility. Teachers also should be able to change the learning scenario or the lesson script if needed, and the technology should provide the flexibility to allow this.
3. Control. The technology should provide teachers with the means to keep control over the class resources and students.
4. Integration. The technological resources should be accessible and consistent in all individual, small-group or class-level activities. The products from the activity should also be accessible after class.
5. Linearity. The method is a simple sequence of activities that almost all students will perform at almost the same time. In this way it is easy to be explained to the students.
6. Relevance. The activities should be designed according to their impact as specified in the regular curriculum.
7. Physicality. In contrast with other models that mostly address networked learning spaces, classroom orchestration refers to the concrete physical space in the classroom.
8. Awareness. The technology should help teachers to be aware of the state of the student’s activities and any trend or pattern of behaviour that may be relevant.
9. Minimalism. The functions offered by the technology should be simple but effective, providing services that are not already provided by other tools in the classroom or that do not empower classroom activities compared with not having such technology.
10. Sustainability. The approach can be easily repeated and adopted by the teacher and be implemented in the classroom.

7.2 Context of the Study

The studies in this chapter were conducted as part of two courses taught at the School of Information Technologies, at the University of Sydney in Semester 2, 2013. Each course had weekly lectures that all students were expected to attend. Students were divided into 1-hour tutorials consisting of 20–25 students, with one session per week, where they worked on either: small group activities; or their design projects, with support from the main teacher or class teachers (tutors). Each course had 6 and 2 tutorial classes respectively. Tutorial activities were designed to support students’ learning and to provide opportunities for applying material covered in lectures. These activities required students to work in groups and typically included a reflection task involving the entire group at the end of the tutorial. Table 7.1 lists the weekly schedule, including the learning activities, and the application that supported each week.

For both courses, from Week 5, all tutorial classes were held in the technology-enhanced classroom, where students were organised into smaller groups of 3, 4 or 5, with whom they worked with for the rest
Table 7.1: Overview of the learning activities for the two tertiary courses supported during the semester in the technology-enhanced classroom. Tabletop applications: B–Brainstorming; C–Concept Mapping; and M–Meeting Support (bold indicates the Brainstorming activities).

<table>
<thead>
<tr>
<th>Week</th>
<th>HCI</th>
<th>Pervasive Computing</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td><strong>User tasks and goals (B)</strong></td>
<td><strong>System Goals (B)</strong></td>
</tr>
<tr>
<td>6</td>
<td>Prototype sharing (M)</td>
<td><strong>Think-aloud (B)</strong> and Evaluation Planning (M)</td>
</tr>
<tr>
<td>7</td>
<td><strong>Think-aloud (B)</strong> and Mid-term revision (C)</td>
<td>Demo prototypes (N/A)</td>
</tr>
<tr>
<td>8</td>
<td>Demo prototypes (N/A)</td>
<td>Planning (M)</td>
</tr>
<tr>
<td>9</td>
<td>Cognitive Walkthrough (M)</td>
<td>Mid-term revision (C) and Planning (M)</td>
</tr>
<tr>
<td>10</td>
<td>GOMS (M)</td>
<td><strong>Tasks for final demo (B)</strong> and Planning (M)</td>
</tr>
<tr>
<td>11</td>
<td>Refine presentations (M)</td>
<td>Group Meeting (M)</td>
</tr>
<tr>
<td>12</td>
<td>Project presentations (N/A)</td>
<td>Project presentations (N/A)</td>
</tr>
<tr>
<td>13</td>
<td>Course revision (C)</td>
<td>Course revision (C)</td>
</tr>
</tbody>
</table>

of the semester. Each group was assigned a specific tabletop that they remained at, for each tutorial session and each student was given a designated seat that was the same for all the learning activities and tutorials in the classroom. During the semester, three different tabletop applications were used: brainstorming, concept mapping, and meeting support. The study in this chapter concerns only the brainstorming activities organised during Weeks 5, 6, 7 and 10.

The same weekly lesson plan ran in each of the 6 tutorials for the HCI course; and a different lesson plan was designed for the 2 tutorials of the Pervasive course. Lesson plans were different each week, as designed by the main teacher. A total of four teachers ran the tutorials across the two courses. For the tutorials of the HCI course, the main teacher was in charge of conducting one class and 2 other class teachers (tutors) had 2 and 3 classes respectively. For the Pervasive course, the main teacher conducted one tutorial and another class teacher the other tutorial.

7.2.1 Multi-surface Classroom

The multi-surface classroom presented in this chapter made use of the MTClassroom framework (Martinez-Maldonado et al., 2013c). This framework was enhanced as part of a team effort to integrate the use of multiple learning applications, with the associated MTDashboard framework also enhanced. Each tabletop was 46 inches, 1080p in resolution, and supported 32 concurrent touches, making it suitable for use with up to groups of 5 students. Each tabletop used CollAid (Martinez-Maldonado et al., 2011), which provided information to identify who was touching each part of the interactive surface (the evaluation of the accuracy of CollAid (Clayphan et al., 2013a) indicated it as highly accurate for small-group use).

The five tabletops were interconnected and synchronised such that all the logs of the captured activity were recorded to the same repository, and also all the tabletops could be controlled by a central orchestration service. The classroom integrated three public vertical displays, connected to the same orchestrator service. In this way, these displays could be used as regular projectors (for example, to show the teacher’s slides with instructions) or to run applications to show the content of specific tables for whole-class discussion on-demand. In addition, the class ecosystem provided a student project server digital store (web-accessible group sites). This was a place where the materials produced on the tabletops were uploaded, so students could access the materials outside of the classroom. Importantly, this provided persistence of the artefacts that students created in each class activity across sessions during the whole semester. This key function has not been reported in previous tabletop classroom literature.

Figure 7.2 illustrates the components of the classroom, where a teacher is taking one of the tutorials. The teacher controls the technology though a handheld tablet: tables can be blocked – to influence students to pay attention to the teacher; activities can be started; the classroom lesson plan can be controlled;
and the student’s artefacts from tables can be sent to the vertical displays. Additionally, the handheld dashboard shows live visual indicators of each groups’ task progress and levels of participation.

### 7.2.2 Classroom Applications

The classroom featured three learning applications to support the diverse activities in each of the tutorials for the two courses. These were brainstorming, concept mapping and support for meetings. Each application implemented the interface required by the MTClassroom orchestration service. This allowed each tool to be controlled by the teacher during class time. As this thesis deals only with the brainstorming application, details of the other two applications are omitted.

For brainstorming, a classroom version of ScriptStorm was used (Figure 7.3). This provided the core brainstorming tasks – idea generation, and idea categorisation, as well as the macro-scripting negotiation facilities (similar to the interface described in Chapter 6.1). However the classroom version provided flexible utilities for instructional prompts, student-teacher reflection widgets and hooks to allow the application to be orchestrated. This classroom version also supported the teacher in defining tasks that could be easily added, reordered or omitted. The provision of this form of scaffolding is important for classroom activities that have strict time limitations. This tool allowed students to perform the following tasks (in an order prescribed and controlled by the teacher):

- **Idea Generation:** this is the first *core* activity of the brainstorm where students use the keyboards to add ideas in parallel, ideally sparking from each other’s ideas to generate even more ideas.

- **Idea Categorisation:** this is the second *core* activity that allows students to group ideas according to criteria they agree on. Students can create categories and associate ideas with them.

- **Negotiation:** this is optionally available before *Idea Generation* or *Idea Categorisation*. It provides students with an interface to explicitly agree on recommended configurations of the interface. For example, colour coding ideas to indicate contributions *(see Appendix A, pp. 195 for more detail).*

- **Instructions:** the teacher can transition the interface to show information about the next activity on-screen, whilst additional information is given either verbally or via worksheet handouts.

- **Reflection:** this optional task is provided after the core tasks have been completed. For example, a teacher can define a set of ideas for the groups to consider. This calls upon the students to judge
their own ideas, in relation to the teachers’ provided set. The aim is to encourage students to think more about the posed learning problem.

- Feedback Questionnaire: this optional task displays an interactive questionnaire in front of each student. The teacher can design a questionnaire before class to be displayed during class (commonly the last step of the learning activity). The questionnaire supports Likert style responses. This provides flexibility for the teacher to capture a range of feedback from the different classes, so to better understand how students perceive the activities, the instruction, the support and the technology. This is useful for refining both the content of future lessons as well as the activity workflows.

- Whole Class Sharing: this optional task establishes an active link between the teacher’s dashboard, the ScriptStorm instances at the tabletops and the vertical displays so the teacher can send the brainstorm output from a specific tabletop to the public displays to facilitate whole-class discussion. Mechanisms were built to automatically re-orient text for the vertical displays to enhance readability. This design decision was made to allow all ideas to be easily read by any student seated around the classroom, minimising problems associated with angled or possibly upside down text.

Outside of the classroom features added to the ScriptStorm interface, one change to the core interface was how individuals selected the settings during group negotiation. This was updated from having the selection and help screens separated (Figure 7.4–‘left’) to both aspects combined in one panel (Figure 7.4–‘right’). This change was made in light of observations in the earlier ScriptStorm study where some participants failed to refer to the available setting descriptions. This change ensured the detailed information was available when students were discussing and making their selections.

7.3 Lesson Plan Classroom Infrastructure

This section describes the approach for designing, deploying and visualising the teacher’s lesson plan of small-group idea generation and problem solving activities in the classroom. A requirement for the digital classroom being able to deploy the teacher’s designed activities was that the tools should be orchestrable, that is, configurable and adaptable to an extent. As defined by Tchounikine (2013), orchestration technology can support teachers in orchestrating (managing and monitoring) the learning activities or perform automated actions to reduce the teacher’s orchestration load. By contrast, an orchestrable technology allows teachers to configure or adapt the use of the technology for different purposes, before the class and/or while the class is being conducted. This can help teachers target the technology to a range of pedagogical objectives rather than restricting the teacher to a specific method or style of instruction.
7.3.1 Conceptual Approach

In general, the search for improved learning and productivity in the classroom by introducing new technologies has delivered very modest benefits to teaching practice, effectiveness of instruction or improved quality of student’s learning (Cuban, 1986; Fabos, 2001; Muir-Herzig, 2004). There has been a recurring over-expectation of the effects of introducing new technologies, such as radio, films, television and different kinds of computing tools, in educational environments (Cuban et al., 2001). This is a problem, since effort has been devoted to design and deploy educational technologies that have often failed to provide intended learning benefits. At this very early stage of harnessing tabletops to support classroom small-group work, available literature was drawn on to help inform the design of the classroom experience, both for the teachers and students. This study builds on the following:

1. **Use tabletops for small-group activities**
   Tabletops have been shown to support collaborative activities effectively (Scott et al., 2003; Rogers and Lindley, 2004; Kharrufa and Olivier, 2010; Clayphan et al., 2016).

2. **Divide the process into stages: lesson plan scripts.**
   Kharrufa et al. (2013a) recommended that larger activities be broken down into sub-activities, so as to allow effective provision of manageable instructions and scaffolds. Some forms of collaborative scripting have been implemented for single-tabletop environments (Kharrufa et al., 2010; Shaer et al., 2011; Martinez-Maldonado et al., 2013a), however support for multi tabletop classrooms is still emerging (Kharrufa et al., 2013b).

3. **Provide a private teacher space: a teacher’s dashboard.**
   Kharrufa et al. (2013a) proposed that the factors that have the largest impact on the outcome of a classroom session are the teacher’s awareness and control over the learning activities. The teacher’s private space should not only include information about the activity that is happening in each tabletop (AlAgha et al., 2010) but also simple key indicators of the progress of the task at a class level. It has been suggested that the lesson script of the class should be explicitly defined.
and displayed in the teacher’s private space, to help teachers assess the overall progress of the class (Kharrufa et al., 2013a). This work is the first study in-the-wild to implement and assess this.

4. Support sharing of resources across spaces

Interactive whiteboards have predominantly been used for whole-class learning where they can serve as a source of joint attention that the teacher can use to deliver instructions or clarifications (Kharrufa et al., 2013a). Tabletops are most compelling for small group work, while handheld devices can serve as private interfaces as required (Evans and Rick, 2014). This ecology of devices is more or less orchestrable, depending on the degree of interconnection and capabilities of resource sharing between devices, but this facility also depends on the degree to which the teacher can modify, adapt or design their learning activities for deployment on such devices (Tchounikine, 2013). The approach in this chapter aims to formalise the interactions among the ecology of devices through the definition of a lesson plan script at design time. This allows the teacher the option of defining the particular small-group tasks at the tabletops (linked with specific materials for the classes) and also to use the vertical displays for guiding tasks at a class level.

5. The need for an infrastructure for device ecologies.

Bellucci et al. (2014), in their recent review of literature about the use of interactive tabletops, highlighted the need to develop infrastructures and consider interaction design for creating device ecologies. For this, the technical definition of a lesson plan may help a facilitator or instructor orchestrate the technology to meet user requirements. This chapter presents the infrastructure and then validates its impact by providing teachers with additional services such as the opportunity to control and monitor the progress of the designed classroom lesson.

7.3.2 Technical Approach

Two existing frameworks, MTClassroom and MTDashboard (Martinez-Maldonado et al., 2013c) were extended as part of a team effort to build the final classroom infrastructure described. A machine understandable lesson plan specification was mutually agreed on and developed by the different learning application designers. Additionally, any other learning application that implemented the specification could be used. MTDashboard was updated with controls to interact with the lesson plan, as well as visualisations added in the form of a lesson plan timeline and a time on task/overtime alarm. The approach for extending both frameworks was based on three main teacher processes:

1. Defining the pedagogical objectives
2. Designing the lesson plan of the learning activities
3. Conducting the lesson in the learning environment (and possibly modifying or adapting the plan)

Figure 7.5 shows the approach in terms of the three processes. The first action consists of the teacher defining the learning and pedagogical objectives of a lesson or group of lessons (Figure 7.5–’Item 1’). This includes making decisions about what kind of activity or activities need to be conducted, how they will be conducted in the target setting, and the resources available or those that are required. For example, the topic for the weekly tutorial; the learning applications to be used; the particular activity or task workflows; how long each task will be; and so on.

The teacher needs to translate these pedagogical intentions into a form that can be understood by the orchestrable digital ecology. The MTClassroom Orchestration service is the element of the infrastructure that is in charge of the execution of the script by linking all the software elements running on the tabletops, walls and the teacher’s dashboard. The MTClassroom database contains information about the students in each tutorial, the group’s formation and is also the repository of the log events captured by all the devices in the digital classroom ecology.
In order to design the script of the lesson plan to be run in the classroom, the teacher needs to define the structure of the learning activities and tasks. This is the second activity of the teacher, illustrated in Figure 7.5—‘Item 2’. This approach uses an XML-based specification to represent the teacher’s design. The output is a lesson plan script that MTClassroom can execute. This lesson plan script allows the definition of: the learning activities; the applications that will be used to support students in these activities; the sub-tasks within these activities; the scheduling; associated resources needed for the activities; and what will be shown on the teacher’s dashboard.

Figure 7.6 shows an example lesson plan. For this classroom setup, the XML-based lesson plan scripts were manually generated based on the main teacher’s requirements, which were based on a high level verbal description of the workflow of the lesson. In this figure, the teacher aims to conduct a 1-hour tutorial with two main learning activities: first students brainstorm about goals for their semester project; and second they build a concept map based on a case study.

The properties ‘show_in_orchestrator’ and ‘visualisation’ (Lines 4–5) in the node <script> allows a teacher to see visualisations on the dashboard to get information about the enactment of the lesson plan and information about group participation at each tabletop. The property ‘tutorial’ (Line 7) in the node <script> indicates to the MTClassroom Orchestration service the specific tutorial session that will be running. In this way the service can obtain from the MTClassroom database, information about the students who should be at each seat (e.g. group membership, full names, and student identifiers).

For the first activity the teacher uses the brainstorming tool (ScriptStorm) (Line 10: <application name="ScriptStorm">); and for the second activity, the concept mapping tool (CMate) is used (Line 60: <application name="CMate">). The brainstorm activity in the example is divided into 5 sub-tasks: ‘Instructions’ (Line 13); ‘Choose options for the Idea Generation Stage’ (Line 23); ‘Idea Generation’ (Line 33); ‘Idea Categorisation’ (Line 42); and ‘Reflection’ (Line 51).

For each task the teacher can define the planned duration (‘planned_duration’, in minutes), whether the task will be shown on the teacher’s dashboard (‘show_in_orchestrator’) and, if so, the text to be displayed.
uses_wall'). The parameter of the node <task> 'description', creates a link between the tasks of the script (nodes <task>) with functions of the learning application (ScriptStorm and CMate in this case). In other words, this allows the ability to plug into other orchestrable tabletop tools. The property 'uses_wall' associated with a <task> triggers an application that will be ready to receive commands from the teacher’s dashboard to show a specific tabletop’s content on the public displays.

Finally, the teacher can add any resources that may be associated with specific tasks. For example, brainstorming items which a teacher wishes students to reflect upon (Line 56).
Conducting the Lesson

Much like a conventional classroom, the teacher explains the activities that will take place in the tutorial. Once the activities are underway, the teacher may wish to tune or adapt parts of the original lesson plan according to the way the class actually runs (Tchounikine, 2013). The MTClassroom orchestration service uses the script specification to allow the teacher to deploy the activities to the target technologies. Figure 7.7 illustrates the technological infrastructure that deploys the script of the lesson plan and how the different keywords provide information to trigger relevant classroom actions.

First, each interactive tabletop has controlling processes, called dispatchers, which are controlled by the orchestration service to: select and launch applications; restart the system; or automatically shift from one application to another. If a lesson script contains learning activities using more than one tabletop application, these services can automatically stop the current application and start the next one on all the tabletops simultaneously. For example, transitioning one task belonging to one application and another task belonging to another application. This means that the teacher does not have to deal with stopping and re-launching the applications during class time. For example, in Figure 7.6, when the sequence of the enacted script finishes the last task of the first activity (Line 51: task description="reflection"), the system looks for the next <application> node, then dispatchers automatically handle the transition at the tabletops, that is, they will close ‘ScriptStorm’ and then open ‘CMate’ for all the tables simultaneously. A similar dispatcher controls applications to be launched on the wall displays when a task has the property ‘uses_wall’. In the same way, the properties in the script, control what is shown on the dashboard (e.g. Lines 4–5: show_in_orchestrator=1 and visualisation="participation"). The dashboard affords the teacher the ability to advance the lesson sequence, and control the duration of each task.

Monitoring the Lesson

This section describes the teacher’s dashboard, with a focus on the elements designed to help the teacher track their progress through the lesson plan. Figure 7.8 shows the dashboard. The left side of the dashboard provides the facility to start and progress tasks within the sequence of the lesson (Item A),
which may include multiple learning applications during a tutorial. The top right shows the progress of the lesson plan (Item B). It also shows (on the lower left) the time elapsed for the current task as well as an overtime visualisation (Item D). In the center of the dashboard are indicators of small group participation (Item C). Finally there are controls to send content from specific tables to the wall displays (Item E).

Now described are two new additions to the MTDashboard framework (Martinez-Maldonado et al., 2013c): the lesson plan visualisation and the time in the current task/overtime visualisation. Figure 7.9 shows examples of the lesson plan visualisation. The lesson plan visualisation offers a simplified view of all tasks that are in the lesson plan as a linear sequence of events. The blue progress bar represents tasks that have been completed and also the current task – for example in HCI Week 7, the current task is ‘Categorisation’, while for Pervasive Week 5, it is ‘Reflection’. The progress bar advances each time the teacher selects the option ‘Next Phase’ (at the upper left of Figure 7.8). The red section(s) in the progress bar indicates phases where more time was spent than initially planned. For example, in Figure 7.9, for

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**Figure 7.8:** Example dashboard screen for the teacher to monitor the enactment of the lesson to control the classroom, and see visualisations of each group’s progress.

**Figure 7.9:** Examples of lesson plan visualisations from different tutorials. Top: HCI–Week 7 Lesson Plan with Brainstorming and Concept Mapping activities. Bottom: Pervasive–Week 5 Lesson Plan with just Brainstorming.
HCI Week 7, ‘Instructions’ ran overtime, and in Pervasive Week 5, both the items: ‘Instructions’ and ‘Idea Gen.’ were overtime. The sections without colour are parts of the lesson plan that have yet to occur. In this way, the entire lesson plan is shown, with the state of each sub-step visible.

Figure 7.10 shows an example of the ‘time spent on the task/overtime alarm visualisation’. This was designed to help the teacher maintain awareness of the planned duration for the current task. This is particularly important for cases where the teacher enacting the script did not design the lesson plan. The visualisation turns red if the time allowed for the current task is exceeded. When this happens, even when the teacher advances the class to the next task, this task remains highlighted red in the lesson plan visualisation (see Figure 7.8—‘top-right’). This design was to help the teacher to revise the rest of the plan to account for the slippage.

Figure 7.10: Example of the Overtime Alarm Visualisation. Left: Time still remains. Right: The visual turns red once the current task goes overtime, as in this case which is 1:25 minutes beyond the planned 5:00 minutes.

7.4 Study Design

This section begins the key contributions of this thesis from the classroom studies of ScriptStorm. The study design is split between two areas. The first is the work that concerns the classroom-level use of the teacher’s portable dashboard to support the enactment of each class and enable the teacher to be aware of the lesson’s progress and of small-group work occurring at each of the tables. This is an important aspect for considering support for small groups of people working together. The second is the work that involves ScriptStorm taken to the classroom. This involves utilising different collaborative scripts (a preset script – driven by the teacher; and a team script – negotiated by the group), evaluation on assumptions built into the tool, examining idea placement and the use of colour for authorship, and the exploration of a role-based script. These aspects link back to the thesis statement and seek to validate the work of ScriptStorm in an authentic setting. Both aspects, the work supporting the teacher, and the explorations of ScriptStorm are guided by research questions and hypotheses, which are introduced below. Table 7.2 shows the tutorial classes and study conditions, providing the intersection of all the different variables that were considered in this classroom endeavour.

7.4.1 Teacher’s Dashboard Studies

The focus was to explore the impact of making the lesson plans visible to the teachers and warning them about overtime tasks in the classroom. Two research questions drove this work:

- Research Question 1 (RQ1) – Do lesson progress visualisations help teachers follow the lesson plan?
- Research Question 2 (RQ2) – Do teachers value the lesson plan and group indicator visualizations?

These research questions were linked to a series of conditions defined for the weekly tutorials that used the dashboard (Table 7.2 – columns: ‘Lesson vis.’ and ‘Small-group vis.’). The ‘Lesson vis.’ conditions (V/NV) consisted of showing or hiding both the lesson plan timeline and the overtime alarm visualisations. In parallel, the ‘Small-group vis.’ conditions presented one of three different small group indicators to

\footnote{Acknowledgement: The dashboard was created by Dr. Roberto Martinez-Maldonado. This chapter describes the collaborative use of it for the brainstorming classes listed in Table 7.2.}
**Table 7.2:** Study conditions for the weekly tutorial sessions for the two courses, taught by four different teachers. Columns: ‘Teacher’ – A (main teacher), B,C,D (class teachers, tutors); ‘Lesson vis.’ – this shows whether the lesson plan visualisations (see Figure 7.8, pp. 145, items B and D) are shown to the teacher; ‘Small-group vis.’ – this varies the form of small group visualisation shown to the teacher (see Figure 7.11, pp. 148); and ‘ScriptStorm settings’ – these are the different brainstorm conditions for each of the tutorial weeks.

- The items in grey were analysed in experimental setups.

Data Collected

To gain insights to the impact of the lesson plan scripts, semi-structured interviews with the class teachers (B, C and D) were conducted at the end of Week 6. This was done to understand the preferences regarding the information made available (both the lesson plan visualisations and the type of small group indicator) and how this influenced the enactment of the tutorials. The focus of the interviews was with the class teachers who were not involved in the design of the plan. Additionally quantitative information was inspected about the enactment of the tasks of the lesson plan (automatically captured by the dashboard interface) to triangulate the qualitative evidence from the interviews. Feedback collected also informed later visuals provided in the semester.

### 7.4.2 Brainstorm Studies

The focus was to explore the impact of taking ScriptStorm evaluated previously in a laboratory environment to a longer-term authentic setting, to evaluate the impact of the tool with regard to supporting small-group
work and collaboration. This work was driven by the following hypotheses:

- **Hypothesis 1 (H1)** – The preset-script (as led by the teacher) and the team-script (as negotiated by the groups) will be understood and liked.

- **Hypothesis 2 (H2)** – All groups will engage with the negotiation process of the team scripts.

- **Hypothesis 3 (H3)** – ScriptStorm will be found as usable and quick to learn.

- **Hypothesis 4 (H4)** – Students will find that ScriptStorm helps them feel part of a group.

- **Hypothesis 5 (H5)** – Placing ideas in a circle around the center of the tabletop during ideation will lead to more egalitarian categorisations.

- **Hypothesis 6 (H6)** – Students will appreciate the reflective exercises built into ScriptStorm.

- **Hypothesis 7 (H7)** – Groups with specified roles will appreciate the extra scaffolding.

The study design split the focus between the two courses (HCI and Pervasive). The HCI course deployed ScriptStorm in a similar fashion to that of the lab study in Chapter 6.1, comparing team and teacher-set scripts (Hypothesis 1). This was done to bring ScriptStorm out of the lab, to see its function in an authentic multi-session learning setting (Hypothesis 2), with associated constraints. This aim was to gain insight into the real use of the tool and see how it supported collaboration (Hypotheses 3, 4 and 6). Table 7.3 presents the HCI course brainstorm lesson plans for Weeks 5 and 7.

The Pervasive course took an experimental focus. First, testing idea layouts in the ideation stage (Hypothesis 5). This was an assumption taken in the earlier brainstorm studies in Chapters 3, 4 and 6.


**Table 7.3:** HCI Course – Lesson Plans for the Brainstorming Activities.

Second, was to explore the effects of the team script, passing control to groups (Hypothesis 2). Lastly, the exploration of a role-based collaboration script, based on the Jigsaw pattern (Aronson, 1997) which provided a deeper level of scaffolding (Hypothesis 7). Table 7.4 presents the Pervasive course brainstorm lesson plans for Weeks 5, 6 and 10.

**Data Collected**

To gain insights to the use of ScriptStorm for both courses, each tutorial asked a standardised set of questions at the end of the learning activity in each class. This collected feedback on group work, the activity and the usability of ScriptStorm. Table 7.5 lists these standard questions. Each of these questions were asked at the tabletop. For all questions asked, a Likert scale of 1 to 6 was used. This was a decision taken to force the students in the classroom to make a directional choice, to avoid having the midpoint used as a placeholder, in the case of a scale with an odd number of items (Chomeya, 2010; Tsang, 2012).

Importantly as the questions are asked over time, this allows for time based comparisons, where the novelty effect can likely be discounted. Outside of the core set of questions, a set of optional questions were added each week as required. This served to ask specifics related to the conditions that week, not covered by the core generic set. For example in Pervasive Week 10 which explored a role-based collaborative script, two questions were added: ‘R1) Having a role was useful?’ and ‘R2) Having a role forced me to coordinate with others?’. The total number of questions (core and optional) did not exceed more than 10 items. This was a design decision influenced by the time constraints of the class, as filling in the questionnaire was the last item for the students, either before they departed the classroom, or before they moved to a different (non-brainstorming) activity in class.
Table 7.4: Pervasive Course – Lesson Plans for the Brainstorming Activities.

<table>
<thead>
<tr>
<th>Duration</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 mins</td>
<td>Wait for students to come into the room</td>
</tr>
<tr>
<td>2 mins</td>
<td>Explanation of Idea Generation Settings</td>
</tr>
<tr>
<td>5 mins</td>
<td>Idea Generation</td>
</tr>
<tr>
<td>2 mins</td>
<td>Explanation of Idea Categorisation Settings</td>
</tr>
<tr>
<td>5 mins</td>
<td>Idea Categorisation</td>
</tr>
<tr>
<td>5 mins</td>
<td>Feedback Questionnaire</td>
</tr>
</tbody>
</table>

Total planned time: 24 mins

Table 7.5: Standard Feedback Questions asked in all the brainstorms (at the tabletop interface). The Likert scale is from 1 to 6 (where 6 represented ‘strongest agreement’).

<table>
<thead>
<tr>
<th>Topic/Purpose</th>
<th>Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group work</td>
<td>Rate your level of contribution (low-1 to high-6)</td>
</tr>
<tr>
<td>Activity</td>
<td>Today’s activity was easy to understand?</td>
</tr>
<tr>
<td>Activity</td>
<td>I found the reflection stage useful?</td>
</tr>
<tr>
<td>Technology</td>
<td>The system was easy to use?</td>
</tr>
</tbody>
</table>

* The question on reflection is only shown for weeks that had a reflection exercise/stage. The Likert Scale is from 1 to 6 (where 6 represented ‘strongest agreement’).

In addition to the use of Likert questionnaires, detailed information about the brainstorming sessions were captured by the tabletops, and observational notes were taken by a researcher each week. The tabletop produced a record of the group’s outputs, which was uploaded to each group’s project store after class (for examples, see Appendix A, pp. 196). The outputs from the activity were also used by the main teacher (teacher A) at the end of the semester, to conduct a post-hoc analysis on the group work outputs.
7.5 Results and Analysis

This section reports the results and analyses of the two aspects of the classroom studies. This first section presents the Dashboard studies and the second has the Brainstorm studies.

7.5.1 Teacher’s Dashboard Studies

Analysing the impact of the lesson plan visualisations on the classroom lessons

This analysis measures the extent to which the actual runtime of the classes matched the design of the lesson plans. It seeks to gain insights to the first research question (‘Do lesson progress visualisations help teachers follow the lesson plan?’). Table 7.6 overviews the lesson visualisation conditions (an excerpt drawn from the larger study conditions table). Figure 7.12 depicts the duration of the different tasks (horizontal axis) of the planned brainstorm activities and the actual runtime from the six tutorial sessions from Weeks 5 and 7 of the HCI course (vertical axis).

<table>
<thead>
<tr>
<th>Time</th>
<th>HCI Week 5</th>
<th>HCI Week 7</th>
<th>Pervasive Week 5</th>
<th>Pervasive Week 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>9am</td>
<td>NV(A)</td>
<td>V(B)</td>
<td>V(D)</td>
<td>NV(D)</td>
</tr>
<tr>
<td>10am</td>
<td>V(B)</td>
<td>NV(B)</td>
<td>NV(A)</td>
<td>V(A)</td>
</tr>
<tr>
<td>11am</td>
<td>NV(C)</td>
<td>V(C)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12pm</td>
<td>V(C)</td>
<td>NV(C)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1pm</td>
<td>NV(B)</td>
<td>V(B)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2pm</td>
<td>V(B)</td>
<td>NV(B)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3pm</td>
<td></td>
<td></td>
<td>NV(A)</td>
<td></td>
</tr>
<tr>
<td>4pm</td>
<td></td>
<td></td>
<td>V(A)</td>
<td></td>
</tr>
</tbody>
</table>

**Legend:**

- **V/NV** – Lesson plan visualisations shown / not shown
- **Teachers** – A, B, C, D

Table 7.6: Lesson plan visualisations (timeline and overtime alarm) experimental conditions.

For Week 5, the main tasks in the lesson plan included: 5 mins for idea generation (Figure 7.12–‘top-left’, first line, green horizontal bar); 5 mins for idea categorisation (the red bar); and 14 mins for the two reflection activities (the dark blue bar). Overall, the lesson plan was designed such that the teacher would spend a total of 33–37 minutes of the tutorial for the brainstorm learning activity (including instructions, negotiation (if applicable), and filling out the feedback questionnaire). The remainder of the class time was for students to work on their group projects. For the condition where the lesson plan visualisations were shown on the dashboard (Condition V), it shows that the class teachers adapted the designed script giving more time to students for the idea generation process (the green bars in tutorials at 10AM, 12PM and 2PM, almost exactly 10 minutes each). Similarly, idea categorisation was longer than planned (from
5 to 8.5 mins on average for Condition V). However, these main two stages were also somewhat similarly enacted for the tutorials where the script visualisations were not provided (Condition NV), with key differences in the other tasks such as the provision of instructions, the reflection and the questionnaire. While the tutorial at 11AM was not different from the ones in Condition V, there were bigger differences in the other two tutorials. For the tutorial at 9AM, the duration of the learning activity extended beyond 40 minutes, and for the tutorial at 1PM, the class teacher skipped the last of the tasks. These differences are not necessarily associated with a lack of access to the visual representation of the lesson plan. In the teacher’s interviews, Teacher C expressed: “if it was needed I adjusted the lesson plan depending on what happened in the classroom”. So for example the first tutorial (at 9AM) may have been extended because of students arriving late and that the teacher made a decision to reduce the duration of the reflection tasks in the activity. The median of the difference between the duration of each planned task and its enactment for Condition NV was 15% over. By contrast, for the tutorials in Condition V the median was -6.9%, meaning that, overall, individual tasks were adapted by teachers so the entire class runtime duration was similar to that as planned. A significant effect of the presence of the lesson plan visualisations was found (Mann-Whitney, \( U = 232 \), \( Z = 2.76, p < 0.05 \)). The total mean difference between each task’s planned duration and their enactment was 19.1% (±52) for Condition NV and -13.6% (±30) for Condition V.

For Week 7, Teacher B took A’s class, and thus each teacher was in both the V and NV tutorial conditions. In this case, the tutorials consisted of a brainstorming activity and a concept mapping activity, with the brainstorming activity enacted first, planned for 18-20 minutes. In this case, a visible difference between conditions was observed. For Condition V, even though the three tutorials were over time, the teachers gave similar time to each task, keeping the overall activity below 25 minutes. This meant that:

1. The lesson plan may have not been properly calibrated to give adequate time to the idea generation and categorisation tasks. However the lesson design was not based on prior experience of conducting the activities in such a classroom of this nature before, so this too is likely to have contributed to plan and enactment mismatches. Teacher C remarked: “sometimes the timing for a planned task [as in the main teacher’s design] was not right”.

2. All teachers adapted the runtime lesson plan script giving more time for the core brainstorming tasks and reduced the time for the questionnaire.

3. As indicated by class teachers B and C, the visualisations helped teachers realise the tasks that were over time, with the need to compensate, using time from other less important tasks (as in this case, the feedback questionnaire).

Teachers confirmed (from interviews), that the visualisations enhanced their awareness to make informed choices about how to adapt the lesson plan at runtime. For example, Teacher B explained that: “the script visualisation specially helped me figure out when I had to compensate the duration of certain tasks, for example, if I saw many red sections (over time tasks) I knew I had to consider that for the current stage”.

For Condition NV, more time was allocated to idea generation than in the tutorials in Condition V (13.2 and 8.6 mins respectively). This caused an extension of the activity beyond 28 minutes (as in the case of the tutorials at 10AM and 2PM); and with it a large reduction in the time available for idea categorisation and reflection, which are important tasks in this learning activity (tutorial at 12PM). A significant effect of the presence of the lesson plan visualisations was found (Mann-Whitney, \( U = 36.5, Z = -3.66, p < 0.01 \)). The total mean difference between each task’s planned duration and their enactment was 78% (±85) for Condition NV and 36.2% (±34) for Condition V.

For the Pervasive course, Figure 7.13 shows the match between the planned brainstorm for Weeks 5 and 6. Similar to the HCI course, each week had a different brainstorming topic. The plan was that the activity would last 19 minutes in Week 5 and 23 minutes in Week 6. There were two tutorials conducted for each condition. With the small sample, no relationships could be drawn statistically. However, it is
noted that the teacher who designed the scripts (Teacher A – 4pm) varied the actual runtime of the lesson plan during their classes. For example, in Week 5, the main teacher skipped over the instructions stage (0.1 mins for instructions), and upon realizing this, needed to then explain the activity in the idea generation task (whilst students already had the user interface in front of them). The main teacher also shortened the idea generation task below the planned time. For the class teacher who received the script visualisations in Week 5 (Class Teacher D – 3pm), even though the tutorial went over time, equal amounts of time were prioritised toward the core stages of the learning activity. For Week 6, the main teacher (Teacher A – 4pm) had access to the visualisations of the lesson plan, and they kept the actual runtime closer to the designed plan.

### Teacher’s preferences: to be informed about the lesson plan visualisations (timeline and overtime alarm) versus visualisations of the small group’s progress

This analysis seeks to gain insights to the second research question (‘Do teachers value the lesson plan and group indicator visualisations?’). The three class teachers were asked about their preferences for the different visualisations on the dashboard at the end of Week 6. To do this, they were presented with physical printouts of all the different versions of the dashboard (Figure 7.11, pp. 148). Teachers were asked to rank the three versions that they found most useful. The ranking was from 3 to 1 where 3 represented the version most preferred. They were also asked to justify their responses. The objective was to learn whether they prioritised information that enhanced awareness of the lesson plan, compared to the small-group visualisations (which potentially showed groups that may have needed closer attention or feedback).

Figure 7.14 shows the results of the teacher’s rankings accumulated (in the vertical axis) for each of the conditions shown (in the horizontal axis). This shows teachers preferred the version of the dashboard that included both visualisations forms. In only two out of the nine rankings (3 rankings from each of the three teachers), did two different teachers consider that the visualisation of size of the group’s solution was more important than being aware of the lesson plan. Teacher B justified their choice with the following statement: “it was really important that I could see the lesson plan visualisation in all conditions of the dashboard, along with the information about the size of student’s solutions… those are the things I wouldn’t be able to see by myself” and “[without using the dashboard] I could be relatively aware about what students [are] discussing, but not about the lesson plan or the progress of student’s solutions”.

During the post-tutorial interviews with the class teachers, all gave very positive feedback about the use of both the lesson plan timeline and the overtime alarm visualisations. For the timeline visualisation, Teacher B commented: “the information provided by the lesson [timeline] visualisation was very useful and easy to understand”. Teacher D also commented: “looking at the lesson [timeline] visualisation helped me have a better idea about the tasks I was supposed to conduct.” For the overtime alarm visualisation, Teacher D noted: “[the overtime alarm] conveyed key information, similar to the lesson [timeline] visualisation, with
the difference that I can read the time elapsed” and Teacher B explained that: “it was useful to know what was the expected duration of the current task”.

The teachers also explained that both lesson plan visualisations (the timeline and overtime alarm) complemented each other: the runtime script visualisation informed teachers about the enactment of the whole script without showing details of each task; and the overtime alarm visualisation depicted information about the current task, informing the teacher when the planned time was consumed. Teacher C remarked: “These visualisations made it much easier to know how I was going with the lesson plan rather expending all the time and realising at the end of the class that some tasks would need to be skipped”.

Overall, teachers preferred the condition of the dashboard where both visualisations about the lesson plan were shown, which is perhaps not surprising, but does indicate that these teachers did not feel overloaded with the extra information. The teachers justified this preference and argued for both forms of visualisations as discussed above. Teacher C gave an example of how they used the visualisations to conduct the lesson: “the script visualisation was very useful in general since it tells you where are you up to in the tutorial, it was useful to see if you are going okay with the timing for each task; and the [overtime alarm] visualisation was useful to be aware of the amount of time to do the current task”. Teachers also reported other uses of the visualised lesson plan, such as knowing about the progress of the students when combined with the visual indicators of the group work, and thus helping them decide when to intervene. For example, Teacher C explained this as: “it was also useful to be aware of the partial time in a task and link it to the student’s activity to realise that, for example that, [if] a group generated 50 ideas in the first 5 mins and another group has produced only 10 [ideas], it made me be aware about the different pace of groups related to time.” These results show that the class teachers were open to using both visualisations related with designed lesson plans and that they found both useful in helping keep them aligned to the tasks designed by the main teacher.

**Summary**

Overall, the dashboard provided useful information to teachers in an accessible format during class time. This provided teachers with visual information about the progress of the lesson plan, when tasks were over time, and indicators of small group work. Teachers’ preferences favoured the information about the lesson plan visualisations (timeline and overtime alarm) over the visualisations of small-group participation and progress. The two types were helpful for the teachers in different ways: first, it allowed teachers to regulate and adapt the planned activities according to the time available (RQ1); and second, it allowed...
teachers to identify groups that may have needed attention and/or feedback (RQ2). The data captured also demonstrated that showing the lesson plan timeline and overtime alarm visualisations helped teachers to: 1) better keep to the lesson plan timing; 2) adapt and prioritise the duration of certain tasks during runtime; and 3) expand the duration of the tasks in cases where they disagreed with the plan. In all cases, the approach proved useful for enhancing teacher’s awareness of the class lessons, for the enactment of the brainstorming activities that supported the learning exercises required for both classes.

### 7.5.2 Brainstorm Studies

Both courses focused on aspects of human centered computing and design. The topics of the brainstorm each week were designed to support the semester long group projects. This was intended to help students think about prototypes they would build, formulate goals and learn how to utilise and apply relevant evaluation techniques. The tabletop classroom was first used in Week 5 and continued as the main tutorial space for the remainder of the semester (see Table 7.1, pp. 137). In the first tutorial, about 10 minutes were allocated to let students familiarise themselves with the tabletop brainstorm interface (ScriptStorm), while also getting to know their newly formed group better. During lectures in the prior week, students had been taught about small-group collaboration, including: the Big-5 theory (Salas et al., 2005); collaborative scripting (Fischer et al., 2007); and the brainstorming approach (Osborn, 1953).

This section reports the two courses in turn, due to the large number of intersecting hypotheses, as well as due to the complex nature of the classroom. First, the HCI course explores the use of ScriptStorm in a larger and longer in-the-wild setting; and second the Pervasive course takes an explorative approach to ScriptStorm – evaluating assumptions and testing new methods.

### ScriptStorm in the HCI Course: Negotiated Scripts in-the-wild

The HCI course involved a semester long case study, tackling the problem of physical inactivity. Students needed to define goals for their systems, establish user requirements, apply standard design approaches, evaluate their interfaces with discount and user-based techniques, and explain how human factors influenced the design and construction of their final prototype. This section reports on the brainstorms from Weeks 5 and 7, the experimental script conditions, and considers effects over these 2 weeks.

#### Week 5 Brainstorm

The topic for this week asked the students to come up with user tasks for measuring inactivity. Students were told to think about distinguishing features of groups of people, strategies to reduce levels of inactivity, and information a person might need. This was an exercise to help groups think about their main project. The brainstorm consisted of the usual idea generation phase, followed by a scaffolded categorisation phase. For categorisation, teams were asked to select from their idea set their top 5 ideas and their next top 5 ideas. The categorisation was scaffolded so the teacher could visit and quickly provide feedback on the chosen ideas. The groups then took part in a reflective exercise in which they considered a set of ideas provided by the main teacher and they were asked to identify if the teacher’s ideas matched their own idea set. Figure 7.15 shows the widgets that were used to support this. The second reflective exercise was similar with students classifying whether their top 5 ideas were represented in the teachers set.

Figure 7.16 presents the feedback from the end of activity questionnaire. It shows the responses in terms of the counts, coloured by the Likert response (1 to 6, 6 being ‘strongest agreement’). The figure also shows the weighted percentage for the agree side of the Likert scale (presented on the right vertical axis). The figure shows a view of all the tutorials aggregated (top), as well as the response profiles for each of the six tutorial classes (bottom). At the aggregated subject level, there were 82+ respondents for Q’s 1-6. Students on the whole reported a mostly positive experience. On group work, students
Figure 7.15: Interface widgets used to support group reflection. The blue widget (left) showed the ideas from the group. The brown widget (right) showed the teacher’s ideas and provided the ability for the group to make a selection as to whether they thought their ideas covered each of the teacher’s.

Figure 7.16: HCI Week 5 – Likert Questionnaire Feedback (each count represents a student selection).

reported they were participating (Q1–4.48/6) and felt their peers were also (Q2–5.08/6). There was a weak correlation between the two questions \( (r_s=0.39, \ n=92,\ p<0.001) \). Teams mostly understood the activity (Q3–4.59/6), with the exception of 1 group (5 students) from the 1pm class (who gave a mean score of 2.8/6 \( (SD=1.6) \)). For ease of use, the class was split somewhat in the middle, with a slight slant on the agree side of the scale (Q5–4.23/6). This did not however appear to affect how students viewed the technology as enabling them to be part of their group (Q4–4.95/6). It is noted for the 12PM and 2PM
classes where 11 students voted ‘strongly disagree and disagree’ both these classes used a team script. No statistically significant differences however were found between the two script conditions.

For reflection, there was a near even distribution of responses on the disagree and agree side of the scale (Q6–4.08/6) (Figure 7.17). Table 7.7 shows an analysis of the first reflective exercise, coded by the main teacher at the end of the semester. The reflection task was to classify if the teachers supplied set of ideas were represented in the group’s set of ideas (which were also provided to the group) (see Figure 7.15, pp. 156, for detail regarding the user interface widgets provided to accomplish this). The table shows the group classifications (columns marked ‘G’) and the teacher classifications (columns marked ‘T’). Agreement between the group and teacher are shown in green, student based false positives in red, and false negatives in white. The circles represent actual coverage over the teacher idea set, as assessed by the teacher. Of the 24 groups, 16 groups had at least 1 idea that matched the teachers set (of 7 ideas). Of the 8 groups who did not have overlap, the main teacher noted that 4 groups (11am-tables 3,4 and 1pm-tables 1,3) were either way off, or did not have valid ideas. These results as a whole should not be interpreted as a failure of the reflective exercise or the students’ ideas, given the subjective nature of the task. However, it does shed light on what class teachers noted during class time – that groups were overly optimistic (and inaccurate at times) in classifying their ideas (false positives in red). This represents a knowledge gap, which a teacher needed to rectify at the end of the class. No correlation was found between quantity of ideas and the number of student-teacher-matcher matches.

Table 7.7: HCI Week 5 – Reflection Exercise. Students were asked to classify whether the teacher’s supplied set of ideas were represented within the ideas generated by the group.

<table>
<thead>
<tr>
<th>Time</th>
<th>Table</th>
<th>Number of ideas from the group</th>
<th>log times using a computer</th>
<th>start social walking</th>
<th>get a peer to agree to take a lunch time walk</th>
<th>set a phone alert for every 30 mins</th>
<th>minutes of no known activity</th>
<th>minutes of known inactivity</th>
<th>overview before and after new strategy</th>
<th>Items matched (out of 7)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9am</td>
<td>1</td>
<td>62</td>
<td>N N</td>
<td>Y Y</td>
<td>Y Y Y</td>
<td>Y N N</td>
<td>N N N</td>
<td>N N N</td>
<td>G T G T G T G T G T</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>48</td>
<td>N N</td>
<td>Y Y</td>
<td>Y Y Y</td>
<td>Y N N</td>
<td>N N N</td>
<td>N N N</td>
<td>G T G T G T G T G T</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>23</td>
<td>Y Y Y</td>
<td>Y N</td>
<td>Y N Y</td>
<td>Y Y Y</td>
<td>Y Y Y</td>
<td>Y Y Y</td>
<td>G T G T G T G T G T</td>
<td>1</td>
</tr>
<tr>
<td>10am</td>
<td>1</td>
<td>45</td>
<td>Y N Y</td>
<td>Y N</td>
<td>Y N Y</td>
<td>Y Y Y</td>
<td>Y Y Y</td>
<td>Y Y Y</td>
<td>G T G T G T G T G T</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>33</td>
<td>Y N Y</td>
<td>N N</td>
<td>Y N Y</td>
<td>Y Y Y</td>
<td>Y Y Y</td>
<td>Y Y Y</td>
<td>G T G T G T G T G T</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>32</td>
<td>Y N Y</td>
<td>N N</td>
<td>N N N</td>
<td>N N N</td>
<td>N N N</td>
<td>N N N</td>
<td>G T G T G T G T G T</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>55</td>
<td>N N Y</td>
<td>Y N</td>
<td>Y N N</td>
<td>Y N N</td>
<td>Y N N</td>
<td>Y N N</td>
<td>G T G T G T G T G T</td>
<td>1</td>
</tr>
<tr>
<td>11am</td>
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<td>22</td>
<td>Y N N</td>
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<td>N N Y</td>
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<td>Y N N</td>
<td>Y N N</td>
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<td>0</td>
</tr>
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<td>G T G T G T G T G T</td>
<td>2</td>
</tr>
<tr>
<td></td>
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<td>N N N</td>
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<tr>
<td>12pm</td>
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<td>N N</td>
<td>N N Y</td>
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<td>N N N</td>
<td>N N N</td>
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<td>42</td>
<td>N N Y</td>
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<td>0</td>
</tr>
<tr>
<td></td>
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<td>N N Y</td>
<td>N N</td>
<td>N N N</td>
<td>N N N</td>
<td>N N N</td>
<td>N N N</td>
<td>G T G T G T G T G T</td>
<td>1</td>
</tr>
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<td>81</td>
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<td>N N N</td>
<td>N N N</td>
<td>N N N</td>
<td>G T G T G T G T G T</td>
<td>3</td>
</tr>
<tr>
<td></td>
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<td>N N</td>
<td>N N N</td>
<td>N N N</td>
<td>N N N</td>
<td>N N N</td>
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<td>0</td>
</tr>
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<td>N N</td>
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<td>N N N</td>
<td>N N N</td>
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<td>G T G T G T G T G T</td>
<td>0</td>
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<td></td>
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<td>61</td>
<td>Y N Y</td>
<td>N N</td>
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<td>N N N</td>
<td>N N N</td>
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</tr>
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<td></td>
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<td>N N</td>
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</tr>
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</tr>
<tr>
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<td>N N N</td>
<td>N N N</td>
<td>G T G T G T G T G T</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>46</td>
<td>Y N Y</td>
<td>N N</td>
<td>N N N</td>
<td>N N N</td>
<td>N N N</td>
<td>N N N</td>
<td>G T G T G T G T G T</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>35</td>
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<td>N N N</td>
<td>N N N</td>
<td>G T G T G T G T G T</td>
<td>1</td>
</tr>
</tbody>
</table>

Columns: G (Group Classification); T (Teacher Classification)
Colours: Green – Group and Teacher agreement, Red – Student False Positives, White – False Negatives
The circles represent actual coverage between the teacher idea set and the group’s set of ideas

Figure 7.17: Distribution profile for Q6–‘I found the reflection stages useful’ (based on 82 student responses).
Week 7 Brainstorm

This brainstorm was used to help groups think of tasks they could ask people to do, to gain feedback on the preliminary low-fidelity prototypes they had started to develop. Figure 7.18 presents the feedback from the end of activity questionnaire. At the aggregated subject level, there were 63 + responses for Q’s 1–7, and 43 responses for Q’s S1/S2 (questions involved with the team script condition). It is immediately evident from the view over the entire week, that there was a problem with understanding the class topic (Q3–3.72/6). Furthermore, looking into the tutorial profiles, this was a key issue for all tutorials except the 12PM class. The confusion was particularly pronounced in the 2PM class. For the class at 2PM, the issue with the topic (Q3) appeared to intersect with the way they viewed the reflective activity (Q5), with a very strong positive correlation ($r = 0.95, n = 6, p < 0.001$) for at least a third of the students (i.e. the ones that responded to the question) from that class. Coming back to Q3 (understanding the topic), observation notes and comments from the teachers revealed this as a mismatch between understanding the difference between a ‘concrete task’ and an ‘abstract task’. Despite the confusion, this did not appear to correlate with any of the other items recorded. On the attributes of group work, students reported they felt they were contributing ($Q1–4.58/6$) and also felt their peers were too ($Q2–4.72/6$). A moderate correlation between Question 1 and 2 was observed ($r = 0.57, n = 89, p < 0.001$).

HCI Week 7 – Questionnaire Feedback

Activity: Come up with concrete tasks to gain feedback on your low fidelity prototype(s)

Figure 7.18: HCI Week 7 – Likert Questionnaire Feedback (each count represents a student selection).
test found a significant difference for Question 1 ($U=568.5$, $Z=-3.58$, $p<0.001$, $r=-0.38$), with the tutorials with the team script (group negotiated settings) reporting higher levels of participation. So it appears the team script for this week may have added to a feeling of extra involvement. The system was seen as easy to use ($Q7=4.75/6$), but this did not translate into students feeling that it helped them be part of their group, with a moderate mean response of ‘somewhat agree’ (3.92/6) for Question 4. This may likely be a side-effect of the novelty of the technology starting to wear off, given it was the groups third week in the technology-enhanced classroom. For the reflective exercise ($Q5$), students reported a moderate mean response of 4.01/6. Questions 4 and 5 were moderately correlated ($r_s=0.46$, $n=70$, $p<0.001$).

On $Q6$ ‘I liked the ability to choose the categories to make’, in reference to the difference between the Week 5 brainstorm which had category headings pre-supplied, about two-thirds of the class appreciated the freedom to decide their own groupings ($Q6=4.04/6$). For Questions S1 (about idea layout choice) and S2 (choice to have colour coding), for the team script condition, these seem to have been received well ($S1=4.19/6$ and $S2=4.23/6$). There were no statistically significant differences found between teams in either script condition (outside of Question 1, as reported earlier).

Table 7.8 shows an analysis of the reflective exercise from Week 7, coded by the main teacher at the end of the semester. It followed the same format of the exercise from Week 5, where the task was to classify a set of tasks from the main teacher, rating whether the group’s ideas covered these. This week saw higher coverage and agreement between the student classifications and the teachers. It is possible that despite many students reporting they had difficulty with the topic ($Q3=3.72/6$), the coaching and feedback from the teachers during the ideation and categorisation phases in the classes helped students create some suitable tasks. Indeed only 6 groups did not have any match, and in 2 of those cases (9am-table 1, and 12pm-table 4), from the researcher observations, those two groups deferred the set class activities, instead spending class time discussing their major project in their groups. Overall, it appears groups were more conservative with their classifications this week, with a higher incidence of false negatives (in relation to the coded outputs from Week 5). No correlation was found between quantity of ideas and the number of student-teacher matches.

**Table 7.8: HCI Week 7 – Reflection Exercise. Students were asked to classify whether the teacher’s supplied set of ideas were represented within the ideas generated by the group.**

<table>
<thead>
<tr>
<th>Time</th>
<th>Table</th>
<th>Number of ideas from the group</th>
<th>during the last 7 days</th>
<th>did this user have any periods with more than 60 minutes of inactivity today?</th>
<th>did this user have any physical activity at lunch (12 to 2)?</th>
<th>did this user have any physical activity in the evening, after 7pm?</th>
<th>how many minutes today was this user inactive?</th>
<th>has this user been more active in the last month, than they were in the first month of this year?</th>
<th>has this user average fewer inactive minutes per day in the last month, than in the first month of the year?</th>
<th>Items matched/ total of 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>9am</td>
<td>T</td>
<td>G T</td>
<td>G T</td>
<td>G T</td>
<td>G T</td>
<td>G T</td>
<td>G T</td>
<td>G T</td>
<td>G T</td>
<td>G T</td>
</tr>
<tr>
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<td>N T</td>
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<td>N T</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>25</td>
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<td>Y N</td>
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<td>Y N</td>
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</tr>
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<td>N N</td>
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</tr>
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<td>N N</td>
<td>N N</td>
<td>0</td>
</tr>
</tbody>
</table>

Columns: G (Group Classification), T (Teacher Classification).
Colours: Green – Group and Teacher agreement, Red – Student False Positives, White – False Negatives

The circles represent actual coverage between the teacher idea set and the group's set of ideas.

**Table 7.8: HCI Week 7 – Reflection Exercise. Students were asked to classify whether the teacher’s supplied set of ideas were represented within the ideas generated by the group.**
Brainstorming Script Settings

As noted earlier, the groups in the HCI course for Weeks 5 and 7 were exposed to an element of macro-scripting within the brainstorming activity. This was in the form of negotiation prior to the idea generation or idea categorisation tasks. The script conditions were counterbalanced between the weeks. Table 7.9 shows the conditions. The preset script refers to a fixed script, with settings chosen by the main teacher for the groups to use. The team script condition refers to the affordance of choice being provided to groups to elect some of the interface settings, using a group-based voting mechanism (see Figure 7.4, pp. 140).

<table>
<thead>
<tr>
<th>Time</th>
<th>Week 5</th>
<th>Week 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>9am</td>
<td>Preset script</td>
<td>Team script</td>
</tr>
<tr>
<td>10am</td>
<td>Team script</td>
<td>Preset script</td>
</tr>
<tr>
<td>11am</td>
<td>Preset script</td>
<td>Team script</td>
</tr>
<tr>
<td>12pm</td>
<td>Team script</td>
<td>Preset script</td>
</tr>
<tr>
<td>1pm</td>
<td>Preset script</td>
<td>Team script</td>
</tr>
<tr>
<td>2pm</td>
<td>Preset script</td>
<td>Team script</td>
</tr>
</tbody>
</table>

Table 7.9: Script conditions within the brainstorm activities within the HCI Course.

Table 7.10 shows the script settings selected. It is striking that for Week 5, for the 13 groups in the team script condition, 11 groups decided to enable touch during the idea generation phase. This was in contrast to the advice provided by the interface (see Appendix A, Figure A.2, pp. 195). By comparison, in Week 7, only 6 groups from 11 elected to enable touch screen. Perhaps, as these groups started with touch disabled (that is, teams with the preset script condition in Week 5), this may have influenced this decision in Week 7. Another striking observation was for idea categorisation, where 11 groups from 13 elected to have 1 or more students as a leader. This provided those students with extra controls, to toggle idea/category highlights and enable/disable keyboard input.

A side effect of having the touch screen enabled during idea generation were that some groups started to categorise ideas and move ideas prior to the formal idea categorisation phase. This is similar to what was reported in Chapter 3 with the Firestorm brainstorm study. This may be due to the class level control (by the teachers) over timing for the individual stages. In other words, some groups finished their ideation earlier than others. Table 7.11 shows the extent of this; with 10 from 17 groups electing to categorise ideas early. From interviews with the class teachers at the end of Week 6 (as part of the data collected for the dashboard studies), class teacher C specifically noted: ‘for some items I would have liked to progress the groups at different rates, because sometimes I had groups taking longer and other groups who finished quickly and they had to wait for the slower groups to catch up…. but on saying that, it depends on the type of activity’. From the table, it is interesting to note that the options: ‘colour code ideas?’; and ‘place ideas in the center?’ were for the most part not changed from their default recommendations. Overall, it appears all groups engaged with the negotiation process of script selection, as evidenced by the different voting score tallies and final selections.

Effects over time

Table 7.12 shows the statistical tests for the common questions asked in both Weeks 5 and 7. There was a statistically significant effect (a decline) on ‘understanding the activity’. Even though the topics between weeks were different, each student was taught the aspects required in the lecture prior to the tutorial. As already noted, the task in Week 7, to create well formulated concrete tasks was found difficult. There was also a statistically significant effect (a decline) on ratings for ‘the technology helped the students be part of their group’. This may indicate the reduction in the novelty effect. Last, the question on ‘participation’, was close to significance ($p=0.05$) (also a decline).
### Table 7.10: Script settings made by the groups in the HCI Course.

<table>
<thead>
<tr>
<th>Time</th>
<th>Table</th>
<th>Time given for idea generation</th>
<th>Categorised early?</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>9am</td>
<td>1</td>
<td>10 mins</td>
<td>No</td>
<td>N/A</td>
</tr>
<tr>
<td>10am</td>
<td>2</td>
<td>10 mins</td>
<td>Yes</td>
<td>First 2 mins categorising, then created ideas for 6 mins, then stopped.</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>10 mins</td>
<td>No</td>
<td>N/A</td>
</tr>
<tr>
<td>11am</td>
<td>1</td>
<td>10 mins</td>
<td>Yes</td>
<td>Started categorising at 3 mins</td>
</tr>
<tr>
<td>12pm</td>
<td>2</td>
<td>9 mins</td>
<td>Yes</td>
<td>Started categorising at 4 mins</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>10 mins</td>
<td>Yes</td>
<td>Started categorising at 4 mins</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>10 mins</td>
<td>Yes</td>
<td>Started categorising at 5 mins</td>
</tr>
</tbody>
</table>

### Table 7.11: Team script condition, groups who elected to enable touch during ideation. Of those groups, those that took part in early categorisation are shaded in orange.

<table>
<thead>
<tr>
<th>Time</th>
<th>Table</th>
<th>Time given for idea generation</th>
<th>Categorised early?</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>9am</td>
<td>2</td>
<td>7.5 mins</td>
<td>No</td>
<td>N/A</td>
</tr>
<tr>
<td>11am</td>
<td>1</td>
<td>8.5 mins</td>
<td>Yes</td>
<td>Started categorising at 2.5 mins, playing at 4 mins</td>
</tr>
<tr>
<td>1</td>
<td>5</td>
<td>10.5 mins</td>
<td>Yes</td>
<td>Started categorising at 6.5 mins</td>
</tr>
</tbody>
</table>

Colours: Green - no deviation from the default teacher settings; and Orange - deviation from the defaults.

The preset script was designed by the main teacher and had the following configuration: touch was disabled, ideas were placed in the center, ideas were colour coded and no individuals were given leader controls.
**Table 7.12:** Common Questions in Weeks 5 and 7 of the HCI course with statistical differences over time.

### ScriptStorm in the Pervasive Course: Explorations of the Brainstorming Tool

This course introduced key aspects of human computer interaction and explored these in terms of research towards creating user interfaces that disappear into the environment, for example in homes, workplaces and cars. The semester long case study was to tackle the problem of inactivity (the same domain as the HCI course, but with different interfaces). The Pervasive course had two tutorial classes. In this course, the following aspects of ScriptStorm were explored: the built-in assumption of idea placement during ideation; the use of team scripts; and the use of a role-based collaborative script. These analyses report on the brainstormings from Weeks 5, 6 and 10, the experimental conditions tested, and noted effects over time.

### Week 5 Brainstorm – Effects of Ideation Idea Placement on Idea Categorisation

For this week, students were led to tackle the inactivity problem by thinking about ‘what might you log at a device [like a phone] near your bed?’ The brainstorm fits within the larger context of the semester-long group project being investigated. The brainstorm procedure consisted of an idea generation stage, followed by an idea categorisation phase. The experimental condition tested was that of idea placement during ideation. For the 3pm class, all groups had ideas placed in a concentric circle in the middle of the table (Figure 7.19–‘left’). For the 4pm class, the ideas came up oriented nearest to the author of the idea (Figure 7.20–‘left’). This linked to Hypothesis 3 that ‘placing ideas in a concentric circle layout during ideation would lead to more egalitarian categorisations’.

Figure 7.21 presents the feedback from the end of activity questionnaire. All 5 questions showed high levels of satisfaction, with average Likert scores being 4.74 or above (as scored out of 6). Furthermore, no responses reported a rating of ‘strongly disagree’. It appears students felt they were participating (Q1=4.74/6) and that their peers were as well (Q2=5.00/6). These two questions (Q1/Q2) were moderately correlated ($r_s=0.59, n=39, p<0.0001$). Interestingly, 2 of the 3 respondents who nominated the response of ‘disagree’ for Q2 (perception of group equality) came from the same group (4pm – table 2). The same two students rated themselves as low contributors in their group. All students reported understanding the

![Figure 7.19](image1.png)  ![Figure 7.21](image2.png)

*Figure 7.19:* Left: ideation condition: ‘ideas in the center’. Right: ideas distributed amongst different authored categories – highlighting a shared process of categorisation.
Figure 7.20: Left: ideation condition: ‘ideas near the author’. Right: non-group based categorisations, likely due to territoriality because of the earlier idea layout condition.

Figure 7.21: Pervasive Week 5 – Likert Questionnaire Feedback (each count represents a student selection).

week’s activity ($Q3–5.28/6$). It is noted that all responses for $Q3$ were on the agree side of the Likert scale. For the majority of students, the technology helped them feel part of their group ($Q4–5.05/6$). Question 4 was correlated moderately with the two prior questions on group work: $Q1$ ($r_s=0.47, n=39, p=0.002$); and $Q2$ ($r_s=0.55, n=39, p=0.0003$). Overall, the system was reported as very easy to use ($Q5–5.08/6$).

Table 7.13 presents the number of ideas generated by each group, the idea layout condition during the ideation stage and noted effects of the idea layout on group categorisations. Examining both tutorials, there were no statistically significant differences found on any of the affective measures collected (the questionnaire). In addition, there was no statistical difference in the number of ideas generated between the two conditions. There was, however, a very visual difference in how groups categorised their ideas. For groups with condition: ‘ideas in the center’, all groups had ideas distributed within different categories (e.g. Figure 7.19–‘right’). For groups with condition: ‘ideas near the author’, this led 3 groups (from 4) in the categorisation stage to link only their own ideas to their own categories (e.g. Figure 7.20–‘right’).

In summary, it appears, for these groups of students, the hypothesis ‘placing ideas in a concentric circle layout during ideation will lead to more egalitarian categorisations’ (H3) was confirmed, with equal amounts of different authored ideas distributed amongst categories, compared with ideas being placed near the authors which resulted in personal but non-group shared categorisations.
### Pervasive Week 5

<table>
<thead>
<tr>
<th>Time</th>
<th>Table</th>
<th>Number of ideas generated by the group</th>
<th>Condition: ScriptStorm idea location setting</th>
<th>Effect on the idea categorisation stage?</th>
</tr>
</thead>
<tbody>
<tr>
<td>3pm</td>
<td>1</td>
<td>42</td>
<td>ideas in center</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>39</td>
<td>ideas in center</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>81</td>
<td>ideas in center</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>11</td>
<td>ideas in center</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>18</td>
<td>ideas in center</td>
<td>No</td>
</tr>
<tr>
<td>4pm</td>
<td>1</td>
<td>45</td>
<td>ideas near author</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>39</td>
<td>ideas near author</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>42</td>
<td>ideas near author</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>33</td>
<td>ideas near author</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Table 7.13: Pervasive Week 5 – Ideas generated, layout condition, and observed categorisation effects.

### Week 6 Brainstorm – Exploring Team Scripts

This week required groups to formulate tasks to evaluate their early interface prototypes. The experimental condition tested the use of macro team-negotiated scripts for the brainstorms. This allowed all groups to choose the idea layout and whether ideas were colour coded for the ideation stage (see Table 7.2, pp. 147). The procedure for this week also added a reflection task at the end of the main brainstorm activity.

Figure 7.22 presents the feedback from the end of activity questionnaire. For the core questions (Q’s 1–6) all averages fell within ‘somewhat agree’. It appears personal levels of contribution (Q1) fell slightly more to the agree side of the Likert scale, with 24 responses compared with 14 on the disagree side (Q1–4, 11/6). Drilling down into the student responses, lower participation was reported from individual students in 6 of the 9 groups. There was a concentration of low favour reported by Group 5 in the 3pm

![Figure 7.22: Pervasive Week 6 – Likert Questionnaire Feedback (each count represents a student selection).](image-url)
class, where all 4 students self-reported low group contributions. This corresponds to the low number of ideas produced by that group (4 in total, compared to a tutorial average of 17.8). It appears this group was confused by the task, with 3 of the 4 students reporting disagreement for Q3 (‘I understood the task’). Coming back to the entire class, there was a majority view that levels of participation were equal between group members (Q2 = 4.50/6). Question 1 and 2 were moderately correlated (r = 0.57, n=39, p=0.0002). Overall, more than two-thirds reported understanding what the task required (Q3 = 4.45/6). Similarly two-thirds of the class found the technology helped them be part of their group (Q4 = 4.16/6). Question 4 – ‘technology enabling groupwork’ was strongly correlated with Question 2 – ‘the perception of group work and equality’ (r = -0.71, n=32, p < 0.0001). For the most part, the system was reported as easy to use (Q5 = 4.38/6). This week featured a reflection exercise, that was also well received (Q6 = 4.39/6). Across the core questions there were no statistical differences reported between the two tutorial classes.

Table 7.14 presents the script settings selected, the number of ideas produced by each group, and outcomes from the reflection activity (as coded by the main teacher at the end of the semester). For the idea layout setting, 3 groups decided to not place ideas in the center of the table. Interestingly, 2 of these 3 groups were from the 3pm tutorial which, in the previous week, had ideas placed in the center. It is possible these groups were thus interested in experiencing the other layout due to this. Triangulating the script selections with the student feedback, a majority (>70%) liked being able to choose the idea placement setting (S1 = 4.24/6). Of the 9 students who gave a score on the disagree side of the Likert scale for idea placement, 4 were students whose selection was out-voted by others in the team. This led to the feedback on this question being statistically different between the two classes (U = 106.5, Z = -2.02, p = 0.045, r = 0.33). For colour coding of ideas during ideation, all but 1 group coloured the ideas. Crossed with the student feedback (S2 = 4.53/6), 79% of the students whom responded (30 from 38 students) found this choice useful. The 8 responses on the disagree side of the Likert scale came from 6 groups, with no majority from any one group. Overall, feedback was positive for the use of the team script, confirming Hypotheses 1 and 3 (the team script was understood and that ScriptStorm was easy to use).

Pervasive Week 6

<table>
<thead>
<tr>
<th>Time</th>
<th>Table</th>
<th>place ideas in centre?</th>
<th>colour code ideas?</th>
<th>Number of ideas from the group</th>
<th>Reflection: Looking at your entire idea list, did your ideas cover these?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>You sat for 14 hours today - log that.</td>
</tr>
<tr>
<td>3pm</td>
<td>1</td>
<td>Y (35)</td>
<td>Y (55)</td>
<td>17</td>
<td>G T G T G T G T G T G T G T</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Y (55)</td>
<td>Y (45)</td>
<td>26</td>
<td>Y Y Y N N N Y Y Y Y Y Y Y Y</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>N (35)</td>
<td>N (45)</td>
<td>37</td>
<td>Y Y Y Y Y Y Y Y Y Y Y Y Y Y</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Y (44)</td>
<td>Y (44)</td>
<td>5</td>
<td>Y Y Y Y Y Y Y Y Y Y Y Y Y Y</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>N (34)</td>
<td>Y (34)</td>
<td>4</td>
<td>Y Y Y Y Y Y Y Y Y Y Y Y Y Y</td>
</tr>
<tr>
<td>4pm</td>
<td>1</td>
<td>Y (34)</td>
<td>Y (24)</td>
<td>33</td>
<td>N N N N N N N N N N N N N N</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Y (55)</td>
<td>Y (55)</td>
<td>31</td>
<td>N N N N N N N N N N N N N N</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>N (45)</td>
<td>Y (55)</td>
<td>21</td>
<td>N N N N N N N N N N N N N N</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Y (62)</td>
<td>Y (22)</td>
<td>18</td>
<td>N N N N Y Y Y Y Y Y Y Y Y Y</td>
</tr>
</tbody>
</table>

Table 7.14: Pervasive Week 6 – Script Selections and the Reflection Exercise (students were asked to classify whether the teacher’s supplied set of ideas were represented within the ideas generated by the group).

For the reflection exercise, groups were provided with a set of ideas and asked to reflect if they believed their ideas were similar to the ones provided. From the 9 groups, 5 groups achieved at least 1 or more matches with the teachers set. Of the 4 groups who did not have coverage, one was Group 5 (from 3pm), who only had 4 ideas in total (as mentioned earlier, they had difficulty understanding the task), and two groups (4pm – Groups 4 and 5) created items that were not actually tasks (e.g. ‘sitting hours’/‘timetable’). The reflection exercise helped class teachers see the problem more clearly to provide assistance, to all groups during the class.
**Week 10 Brainstorm – Exploring Role-Based Collaboration**

The condition for this week was to explore the use of a role-based collaborative script. Half of the groups were assigned roles, and the other half had a freer brainstorm without roles. The role-based script was based on the Jigsaw pedagogical technique (Aronson, 1997) and drew on CSCL scripting theory (Dillenbourg and Jermann, 2007). The role-based script distributed the functions of the regular group brainstorm (creating ideas, creating categories, and organising the layout on the table) to individuals or pairs of students in the group. The reasoning was that this tighter scaffold would improve collaboration by directing students to interact and work with one another to construct the required outputs for the tutorial. Roles were enforced using the technology that reported who was touching the tabletop (an algorithm based on where people were sitting). Roles were noted alongside the student’s name (Figure 7.23). The activity for the week was to create a set of tasks for use in the evaluation of the group’s final prototype.

![Figure 7.23: Pervasive Week 10 – Roles (indicated next to the person’s name).](image)

Figure 7.24 presents the feedback from the end of activity questionnaire and Table 7.15 presents the ideas generated, the condition, and observations. Despite what looks like a difference in affective distributions between the 3pm class (roles) and the 4pm class (no roles), on the non-role related questions (Q’s 1–5 and S1/S2), there were no statistically significant differences. Looking at the individual groups, it was found that the majority of the ‘strongly disagree’ and ‘disagree’ responses came from 3pm–Group 5. Once excluded, the affective profiles between the two classes were similar. Outside of the student feedback, there was a near significant effect on the number of final ideas produced ($t(6)=2.45$, $p=0.052$, Cohen’s $d=1.7$), with more ideas produced in the condition that did not have roles enforced.

For this week, students rated their contributions as fair ($Q1–4.40/6$), with the majority (>75%) giving a rating on the agree side of the Likert scale. Perception of group quality was also fair ($Q2–4.19/6$), with 3 of the 4 negative responses coming from the 3pm–table 5 group. Question 1 and 2 were weakly correlated ($r_s=0.44$, $n=27$, $p=0.02$). What was required by the groups was understood by the majority of students ($Q3–4.78/6$). The system was also perceived as moderately helpful in enabling students to feel part of their group ($Q4–4.40/6$). For the groups with roles, this strongly correlated with $R2$ – ‘Having a role forced me to co-ordinate with others’ ($r_s=0.65$, $n=13$, $p=0.017$). Again, with the groups with roles, two-thirds reported having a role as useful ($R1–4.07/6$). The strong dissatisfaction (on R1) came again from the students of 3pm–Group 5 (registering the two ‘strongly disagree’ responses). Role usefulness (R1) strongly correlated with the groupwork questions: $Q1$ – ‘personal level of contribution’ ($r_s=0.67$, $n=15$, $p=0.006$) and $Q2$ – ‘perceived group contribution equity’ ($r_s=0.64$, $n=14$, $p=0.014$). Coming back to the entire course, the system was viewed as moderate for its ease of use ($Q5–4.17/6$). However, despite a lack of statistical significance on Q5 (likely due to the small numbers of responses), for the groups that had assigned roles, just over half (55%) found the system easy to use ($mean=3.85/6$, $SD=1.51$, $n=13$). For groups without assigned roles, 90% reported satisfaction on the agreement side of the Likert scale ($mean=4.60/6$, $SD=0.80$, $n=10$).

These results paint an interesting picture for the role-based script, which appeared to not reach the same level of achievement as the groups without roles. Analysing the individual groups within the role-based script condition (i.e. the 3pm tutorial) uncovers some of the issues encountered. First, of the five groups, Group 5 reported low scores across the board. Drawing on researcher notes, it appeared
there were communication difficulties for Group 5, where students ignored each other, which lead to a stalemate in terms of idea output (2 ideas produced after 25 mins). This was because half of the team (2 of 3 students) spent the majority of the tutorial time doing items not related to the task at hand, as well as 2 members from the group not turning up to class. A second notable observation, was Group 4, where only 1 member of the group came to class (usually a group of 4). This led to confusion for the first few minutes, until the student realised the group members were likely not coming, and decided to take action. To do this, the student physically changed seats every few minutes, in order to create ideas, to create categories, and to arrange the items on the screen (as the technology was used to restrict roles to people’s usual seated location). It is interesting that these groups had problems, as in Week 6, the same two groups had task-related difficulties. Outside of these two groups, the other groups functioned well. It appears that, Hypothesis 7 – ‘students with roles will appreciate the extra scaffold’ was not confirmed.
While already well-functioning groups (e.g. 3pm – Groups 1,2,3) were able to adapt, groups which had prior problems (e.g. 3pm – Groups 4,5), the introduction of a role-based script exacerbated problems. This week featured the use of the public vertical displays for whole class sharing of the produced group brainstorm. A representative from each group gave an overview of the reasons for the items constructed. The majority of students (87%) reported that they found the sharing stage useful (S1–4.50/6), and a smaller proportion (77%) reported they would have liked to have had the whole-class sharing in previous weeks (S2–4.20/6). S1 and S2 were weakly correlated (\(r_s=0.45, n=30, p=0.013\)). Overall the addition of whole-class sharing via the vertical displays was useful.

Effects over time

Table 7.16 shows the statistical tests for the common questions asked in Weeks 5, 6 and 10. Considering the three weeks together, there were no statistically significant effects found. However looking pair-wise across time, did reveal three effects. The first was a significant effect (decline) on ‘understanding the activity’. The Week 6 activity (where the decline was registered) was concerned with coming up with well formulated concrete tasks, the topic that was also difficult for the HCI class. The second effect was a decline in the feeling that ‘the technology helped students be part of their group’ from Week 5 to 6, but then followed by a statistically significant increase from Week 6 to 10 (the third effect).

<table>
<thead>
<tr>
<th>Common Questions</th>
<th>Likert Scores</th>
<th>Statistical Test (Within-subjects)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area</td>
<td>Question</td>
<td>Week 5</td>
</tr>
<tr>
<td>Group work</td>
<td>Rate your level of contribution (low-1 to high-6)</td>
<td>4.74 (1.28)</td>
</tr>
<tr>
<td></td>
<td>The participation in the group was equal?</td>
<td>5.00 (1.30)</td>
</tr>
<tr>
<td>Activity</td>
<td>Today’s activity was easy to understand?</td>
<td>5.28 (0.75)</td>
</tr>
<tr>
<td>Technology</td>
<td>The technology helped me be part of the group?</td>
<td>5.05 (1.18)</td>
</tr>
<tr>
<td></td>
<td>The system was easy to use?</td>
<td>5.08 (0.69)</td>
</tr>
</tbody>
</table>

*Note: when considering Weeks 5, 6, 10 together, there were no statistically significant effects found over any question (when using a Friedmann test). Items in grey/bold were statistically significant across Weeks 5, 6 or Weeks 6, 10 at the p < 0.05 level.

Table 7.16: Common Questions in Weeks 5, 6 and 10 of the Pervasive course with statistical differences over time.

7.6 Reflections and Conclusions

Evaluating scripted brainstorming at the tabletop in-the-wild in an authentic classroom scenario, including teachers, students and learning activities as part of the normal curriculum, offered both limitations and advantages. The main limitation was the difficulty in managing experimental conditions and tightly controlling variables. For example, it was not possible to compare the use of the infrastructure with a control group, since the teacher needed to offer similar learning conditions and opportunities to all students. This also meant restrictions to the degree to which the macro-scripted elements of the brainstorm tool (ScriptStorm) could be used. For example, the negotiation time for teams was at the discretion of the teacher, advancing the step in the lesson plan. But, in contrast to a laboratory setting, deploying the system in-the-wild demonstrated the feasibility and flexibility of the real use of ScriptStorm. The study demonstrated, both qualitatively and quantitatively, that the classroom infrastructure and ScriptStorm could support real teachers in an authentic classroom, with all the constraints of the environment, including time restrictions, students arriving late and students asking questions.

For the orchestration of the classroom, the lesson plan infrastructure focussed on whole-class support. This meant that, within each tutorial, timing was at the discretion of the individual class teacher, advancing all groups together. This was a design trade-off, and meant individual tables could not follow their own
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timing plans. From data collected about the dashboard, class teachers C and D remarked: “it may have been useful if I could advance individual tables to the next task or even let students advance it themselves”. This is an aspect to be investigated in future work.

There is still much research that can be performed to explore how the information on the portable dashboard can be communicated. Class teacher D pointed to a problem in the need to carry the device around the class: “the problem is that you cannot use one of your hands, this makes it not easy at times where you need both hands to revise work or other devices that students may want you to check”. Class teacher D gave a suggestion that it would have been nice if the dashboard could ‘beep or vibrate when overtime, since I might put the tablet down’.

Using a tablet to show key information about the status of the classroom to the teacher in real time has been recommended by Kharrufa et al. (2013a) and Martinez-Maldonado et al. (2013c) as it provides mobility and privacy (though privacy comes at a need to take care that students do not see data on other groups). Overall, teachers liked having access to the live information. As part of the data collected for the dashboard studies, class teacher D said: “it is good having the tablet because you [can] decide when to check visualisations no matter where in the classroom you are”.

The collected lesson plan data, can also have other uses which are prime for research. This includes using information about the enactment of the designed lesson to offer a choice of suggested re-configurations. In addition, a teacher may use the visualisations to see what has happened across classes. For example, if the first class is treated as a test run, the teacher can review the timing and then revise the plan for the later classes that week. Even if this is not possible, as in the case of these classes, scheduled close together, the data can inform revisions to the learning design for future years.

For the two courses that used the ScriptStorm tabletop brainstorming tool, the information collected from the tabletop devices, and the collected student feedback, revealed:

- that both the preset (teacher) script and the team (negotiated) script were understood and liked (Hypothesis 1 confirmed), evidenced by the questionnaire feedback with the majority of responses on the agree (positive) side of the Likert scale, across all the tutorial weeks.
- that all groups engaged with the negotiation process of the team scripts (Hypothesis 2 confirmed), evidenced by the different voting score tallies, final sections and the student feedback responses.
- that the system was found as easy to use which contributed to participation in the brainstorms (Hypothesis 3 confirmed), as evidenced by the responses of the group work and technology questions (for an overview, see Table 7.12, pp. 162). In addition, groups reported liking the whole-class sharing, being able to talk about their produced outputs with other groups in class.
- that in the earlier weeks, the technology had a role in helping students feel part of their group (Hypothesis 4 partially confirmed).
- that ‘placing ideas in the center’ during ideation did led to more egalitarian collaboration as evidenced by the categorisation outputs (Hypothesis 5 confirmed).
- for tutorials that had a reflective exercise at the end of the brainstorm, this was seen as useful and helped clarify questions and ambiguities, which the class teacher could direct their attention towards (Hypothesis 6 confirmed).
- that the role-based collaborative script did not appear to have extra benefit over a free and open brainstorm, instead exacerbating team problems (Hypothesis 7 not confirmed).

In summary, the studies from this chapter presented a framework for designing, deploying and supporting teacher’s lesson plans for small group collaborative activities in a multi-surface classroom, as well as the multi-session use of ScriptStorm, in a variety of contexts, in support of the different learning needs within the classroom. The system demonstrated was effective for both teachers and students.
Part II: Exploring Methods to Scaffold Collaboration at the Tabletop

Summary

The second part of the thesis explored methods for scaffolding collaboration at the tabletop. Key findings are shown below. Chapter 6 introduced ScriptStorm, a tool that used collaborative scripts to help scaffold collaboration at the tabletop for the brainstorm activity within a lab environment. The chapter also explored the potential for reflection in order to raise awareness on group processes. Chapter 7 took ScriptStorm to a real-classroom for longer term use, as a flexible adaptive tool to support the different needs of two university level courses. It did this by working within a classroom orchestration framework, offered negotiated script forms and a role-based collaborative script, was flexible with how activities could be designed, and provided support utilities, e.g. sharing with the class, a persistent store, reflection, etc.

<table>
<thead>
<tr>
<th>Ch.</th>
<th>Setting</th>
<th>Focus</th>
<th>Who</th>
<th>Key findings</th>
</tr>
</thead>
</table>
| 6   | In-the-lab (Within-subjects) | Collaborative scripting Team negotiated vs preset scripts at the tabletop | University students | • The additional complexity of the scripted elements was quick to learn and rated as highly usable.  
• Both script forms were preferred, with a slightly higher preference for team negotiated scripts. |
| 6   | In-the-lab | Open Learner Models to support Reflection Think-aloud on paper | University students | • OLMs were straightforward to understand  
• OLMs helped people reflect on group processes and outputs |
| 6   | In-the-lab | Scaffolded Reflection with a tabletop and non-interactive screen | University students | • The scaffolded tabletop system was highly useful (and liked).  
• The system helped expose the true extent of sparking, which was much higher than many students originally thought. |
| 7   | Authentic Classroom (Within/mixed) | Teachers use of a dashboard to support lesson plans | Teachers | • Teachers were able to use the lesson plan visualisations to help them run the classroom  
• Teachers were able to use the small group visualisations to inform them about the different groups in the class, which allowed for targeted feedback. |
| 7   | Authentic Classroom (Within-class-groups) | Collaborative scripting Team negotiated vs preset scripts at the tabletop | Undergraduates | • Both the team and preset scripts were understood and liked  
• Groups engaged in negotiation processes, evidenced by score tallies, selections and responses  
• Groups found end of activity reflection exercises useful |
| 7   | Authentic Classroom (Between-class-groups) | Testing effect of activity assumption Ideas in center | Postgraduates | • Ideas placed in the center during ideation spurred more egalitarian categorisations (whereas ideas placed near authors, led to personal, but not shared categorisations). |
| 7   | Authentic Classroom (Between-class-groups) | Evaluation of a Role based Script | Postgraduates | • The use of a role-based script was not preferred over a preset collaborative script. |

An overview of the studies from each chapter with key findings.

The nature of the brainstorm tasks ranged considerably, with far more complex forms in the classroom to support required learning objectives. The classroom work also looked at how to support teachers by using digital interaction trails captured from learners. The studies examined group sizes in the range of 3–5 people. The main results stemming from the different studies were that:

- collaborative scripts integrated into the user interface of applications designed for the tabletop are useful for creating engagement, discussion and raising task awareness.
- with the careful design of the interface, script components are quick and easy to learn.
- reflection is important, allowing both individuals and the team to assess and view their work.
- harnessing aspects of group interaction enabled just-in-time support from teachers, as well as allowed for richer small-group based activities (e.g. reflection classification tasks).
- the ScriptStorm tool was flexible in supporting a wide variety of learning needs.
- the tabletops enabled groups to come and work together effectively.
Chapter 8

Conclusions and Future Work

Designing effective user interfaces for interactive tabletops is important but challenging. This thesis explored how to harness interactive tabletops for small groups of collocated people to do richly collaborative activities such as brainstorming. This was accomplished through the exploration of a set of foundational studies, followed with a specific focus on collaborative scripting. This explored how the affordances of tabletops could promote mutual awareness, face-to-face communication, and support for small-group work. Table 8.1 overviews the studies undertaken. The broad contribution areas were:

- Comparison of horizontal versus vertical displays (Chapters 3, 4 and 5). Tabletops were found to be favoured on affective measures and the vertical orientation was seen as promising.
- Scripted collaboration (Chapters 6 and 7). Multiple benefits arising, including promoting group discussion, consensus building, encouraging effective group processes and output awareness.

<table>
<thead>
<tr>
<th>Ch.</th>
<th>Setting</th>
<th>Focus</th>
<th>Who</th>
<th>Task</th>
<th>Posture</th>
<th>Groups</th>
<th>Group size</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>In-the-lab (Within-subjects)</td>
<td>Foundational Study Multi-touch tabletop vs Non-interactive whiteboard</td>
<td>Adults</td>
<td>Brainstorming</td>
<td>Standing</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>In-the-wild Classroom environments (Within-class-groups)</td>
<td>Foundational Study Multi-touch tabletop vs Multi-touch vertical displays vs Index cards and pens</td>
<td>University students</td>
<td>Brainstorming</td>
<td>Seated</td>
<td>14</td>
<td>3-4</td>
</tr>
<tr>
<td>5</td>
<td>In-the-wild Local museum (Between-subjects)</td>
<td>Foundational Study Multi-touch tabletop vs Single-touch whiteboard</td>
<td>Primary school children</td>
<td>Collaborative poster creation</td>
<td>Standing</td>
<td>12</td>
<td>3-7</td>
</tr>
<tr>
<td>6</td>
<td>In-the-lab (Within-subjects)</td>
<td>Collaborative scripting Team negotiated vs preset scripts at the tabletop</td>
<td>University students</td>
<td>Brainstorming</td>
<td>Standing</td>
<td>12</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>In-the-lab</td>
<td>Open Learner Models to support Reflection Think-aloud on paper</td>
<td>University students</td>
<td>Brainstorming</td>
<td>Seated</td>
<td>15 students (interviewed separately, people drawn from earlier study)</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>In-the-lab</td>
<td>Scaffolded Reflection with a tabletop and non-interactive screen</td>
<td>University students</td>
<td>Brainstorming</td>
<td>Seated</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>7</td>
<td>Authentic Classroom (Within/mixed)</td>
<td>Teachers use of a dashboard to support lesson plans</td>
<td>Teachers</td>
<td>Brainstorming</td>
<td>Standing</td>
<td>4 class teachers</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Authentic Classroom (Within-class-groups)</td>
<td>Collaborative scripting Team negotiated vs preset scripts at the tabletop</td>
<td>Undergraduates</td>
<td>Brainstorming</td>
<td>Seated</td>
<td>24</td>
<td>3-5</td>
</tr>
<tr>
<td>7</td>
<td>Authentic Classroom (Between-class-groups)</td>
<td>Testing effect of activity assumption Ideas in center</td>
<td>Postgraduates</td>
<td>Brainstorming</td>
<td>Seated</td>
<td>9</td>
<td>3-5</td>
</tr>
<tr>
<td>7</td>
<td>Authentic Classroom (Between-class-groups)</td>
<td>Evaluation of a Role based Script</td>
<td>Postgraduates</td>
<td>Brainstorming</td>
<td>Seated</td>
<td>9</td>
<td>3-5</td>
</tr>
</tbody>
</table>

Table 8.1: Overview of the studies conducted in the thesis with the key dimensions explored.
In-the-wild studies (Chapters 4, 5 and 7). This added to the small body of work already existing (AlAgha et al., 2010; Mercier et al., 2012; Martinez Maldonado et al., 2012; Kharrufa et al., 2013b).

The contributions of each chapter and how they relate to the thesis statement of harnessing tabletop affordances for small-group work are listed below:

**Chapter 3** presented a user study designed to gain an understanding of how a tabletop could be used to support the brainstorming process. The chapter:

- unveiled *Firestorm*, a novel tabletop brainstorming system;
- found the tabletop allowed for more ideas to be generated, attributable to the keyboards;
- provided a set of design guidelines for creating tabletop interfaces to support brainstorming;
- found that some groups failed to follow task directions, suggesting the potential for benefits from scaffolding interaction at the table.

**Chapter 4** presented a user study comparing tabletops and walls to support brainstorming as part of a real classroom exercise. The chapter:

- contributed to understanding the effectiveness of interactive tables versus walls, so filling gaps in the previous work;
- revealed both SDG forms (horizontal/vertical) helped create more ideas, but on quality, the outcome was not differentiated between the two;
- showed that tabletops were preferred for people’s perception that they provided better mutual awareness support;
- showed particular promise for interactive vertical displays (contrasting prior literature);
- contributed insights into the use of different technologies and materials for brainstorming.

**Chapter 5** presented a user study with children, comparing interactive tabletops and whiteboards when combined with carried portable devices for small groups working in a museum. The chapter:

- found both SDG forms were effective for individuals working in small groups of 3–7;
- found aspects of off-task behaviour registered at both device forms, here, too, indicating potential benefits from collaboration guidance, particularly for students of this age (10–14);
- showed that tabletops were preferred on affective measures, being seen as increasing group awareness and allowing people to work in parallel with each other.

**Chapter 6** presented studies exploring the use of collaborative scripts with tabletops. The first study explored negotiated scripts, and the second and third study looked at the potential for supporting reflective activities at the tabletop, using collected interaction trail data. The chapter:

- unveiled *ScriptStorm*, a novel script-based tabletop brainstorming system
- showed that both script forms: preset-scripts (in the notion of a facilitator/teacher) and team-scripts with negotiation were useful and quick to learn;
- showed that groups discussed the script’s settings and process, that the scripting helped them realise what was required in the activity, and the rationale for different option settings;
- showed open learner models (OLMs) as useful for developing understanding of group processes and outputs within reflection at the table.
Chapter 7 was the last study, conducted in a longer term setting in a multi-tabletop classroom in a university. The chapter took ScriptStorm into the wild, showing its flexibility and how the tabletop could support a diverse range of learning objectives. The chapter:

- showed the power of ScriptStorm in enabling both teacher and student support, ranging from classroom orchestration, to flexible scaffolds with different configurable learning elements;
- showed how data from the tabletop could inform teachers about the class activity and also provide indicators of small-group collaboration;
- validated earlier assumptions about the brainstorm activity conducted at the tabletop (being the choice of available settings: idea layout, colour coding ideas, leader options, and touch interaction);
- documented the experience from the semester-long use of multiple interactive tabletops in two real university courses, with a high level of satisfaction for tabletops for small-group use;
- showed ScriptStorm helped promote group work and the feeling of being part of a group in the early stages of the semester, when groups were first formed.

8.1 Future Work

There are many possibilities for exploring the large space of ways to collaborate at an interactive tabletop. This thesis explored this via a sequence of novel prototypes – Firestorm, ScriptStorm and MuseWork. Part I studies suggested the potential benefits of using the tabletop to provide guidance and to scaffold the collaborative task. This motivated exploration of collaborative scripts as a scaffold to promote discussion, discourse, group awareness and group processes. This work opens up a number of opportunities for further work into harnessing this approach for collaborative support at the tabletop.

There is a need for longer studies across multiple domain areas and multiple user demographics. The majority of the studies in this thesis were constrained to a single session, and primarily with university students (partly as they were the most available volunteers). Further explorations may see tabletops in small business, large corporations, the home, libraries, museums – almost anywhere groups come and work together. Also, with longer term studies comes the benefits of being able to study changing perspectives and attitudes over time, as the device becomes a familiar tool for people working together. Importantly, size of the group is an aspect that deserves more research. Whilst the average group size was 4 people in this thesis (with a handful of teams of 5, 6 and 7 people), there is much to learn about larger group sizes and the ways they can use tabletops to collaborate.

In addition to larger group sizes and longer studies, there is an opportunity for expansion into other related SDG forms. This was made apparent from the studies that compared the tabletops to the vertical displays and whiteboards in Chapters 4 and 5. These found that vertical displays have a largely unrealised potential, and that, with effective design of the interface, to account for interaction space limitations, it is possible for small groups to work at such devices, outside of a presentation/display capacity. Furthermore, it would be interesting to investigate a hybrid of these, with both tabletops and vertical displays (going beyond similar explorations in the very last study of Chapter 6).

Another consideration is scripted collaboration outside of the brainstorming activity. The majority of the work undertaken in this thesis involved brainstorming. This was chosen because it is both established and it is a rich small-group activity encompassing different forms of small-group work. However, Chapter 5 explored work with school children in a museum setting, with a collaborative poster application tool. It was observed that some student groups sometimes had difficulty managing collaboration. This points to the potential need for structure and guidance. A scripted version of the poster tool was built (using
ScriptStorm as the base) and evaluated by a Master’s student (Kovacevic, 2013). This work provided a demonstration that the scripting approach of ScriptStorm could be translated to another application, with somewhat different collaborative aspects. However, the evaluation was based in the lab and with adults. While these participants did not feel the need for scripting, they volunteered comments on its value for children and the studies demonstrated how the scripting approach of this thesis could be translated to another tabletop application. It would be particularly interestingly to take this work to the Museum to see the effect of the scripting for the school students.

The classroom work of Chapters 4 and 7 brought to light many of the real issues of managing a classroom and the use of new technologies within such environments. The tabletop provided the opportunity to tap into a large source of collected data, and with it, comes potential for further analyses. For example, feeding data back into parts of the collaborative activity as a form of real-time feedback, and also the exploration into different ways to reconceptualise the activity, based on mined patterns of collaboration. This was beyond the scope of this thesis. The data collected could serve as the basis for future research, particularly about tabletops in the classroom.

Several of the studies in this thesis were conducted in learning contexts. Within the scope of the thesis, it was necessary to focus on the technical and interface design questions and challenges. A complementary strand of future research should tackle the many educational aspects. Chapter 4 touched on these in its analysis of the quality of the brainstorm outputs across conditions. Chapters 4, 5 and 7 certainly took careful account of educational issues in the foundational design of the interfaces and systems and in the conduct of the studies. There is much more to be done to assess the learning benefits. This will require studies that evaluate the potential learning benefits of interactive tabletops and walls, both for building collaboration skills and in better domain learning, based on collaborative learning activities. These are still needed if interactive tabletops are to achieve the promise for better ways for people to both learn collaboratively and to learn to collaborate.

8.2 Summary

This thesis began by highlighting the potential that tabletops appear to offer for small-group collaborative activities like brainstorming. It then explored key research questions, by designing, implementing and evaluating a series of tabletop interfaces. This work broke ground establishing a deeper understanding of the relative benefits of tables versus walls. Through the foundational studies, it was also found that the tabletops could provide a valuable role in scaffolding collaboration, by providing mechanisms for guiding and encouraging effective collaboration. This was explored through user-controllable collaborative scripts, a learning scaffold from the computer supported collaborative learning domain. This exploration provided valuable insights for the core goals of the thesis, indicating the scripts designed were effective at providing a useful tool for encouraging people within small groups to both work together effectively and become aware of group processes.

The contributions of this thesis, the interfaces and use of them to support small-group collaboration are important. If tabletops are to become a mainstream device, they will need to be easy for people to use, and must provide benefits over current forms of collaboration. This thesis has demonstrated how to harness key aspects of the potential of the tabletop, but there is still much that can be done. This work thus provides an important research foundation to harness the affordances of tabletops for small-group work and collaboration.
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Appendices
Appendix A

Additional User Interface Images

A.1 Chapter 7: ScriptStorm Classroom Setting Dialogs

Figure A.1: Idea Generation Instructions.

Figure A.2: Option: Touch Interaction.

Figure A.3: Option: Colour Code Ideas.

Figure A.4: Option: Idea Layout.

Figure A.5: Idea Categorisation Instructions.

Figure A.6: Option: Leader selection.
A.2 Chapter 7: Example Activity Uploads to Project Websites

Figure A.7: Example brainstorm uploaded to a group project site (Week 5 HCI, 9am class, Table 3).

Figure A.8: Example brainstorm uploaded to a group project site (Week 5 Pervasive, 4pm class, Table 1).