Equal Opportunities: Do Shareable Interfaces Promote More Group Participation Than Single User Displays?

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ABSTRACT

Computers designed for single use are often appropriated sub-optimally when used by small co-located groups working together. Asymmetrical interactions can result through one person taking control of the mouse/keyboard. Our research investigates whether shareable interfaces—that are designed for more than one user to interact with—can facilitate more equitable participation in co-located group settings compared with single user displays. Our focus is on tasks where collaboration is desirable, and where interacting with and creating digital content is a fundamental part. We begin by providing an overview of research on shareable interfaces and technologies developed for co-located group work. This is followed by a description of our conceptual framework, Shared Information Spaces (SISs), which characterizes and differentiates between shareable interfaces in terms of how they constrain and invite participation through the design of various ‘entry points’. An experiment was designed that compared three different SISs varying in how they constrained the entry points: a physical-digital set up (least constrained), a multi-touch tabletop (medium) and a laptop display (most constrained). Statistical analyses showed there to be little difference in participation levels between the three conditions other than a predictable lack of equity of control over the interface in the laptop condition. However, detailed qualitative analyses revealed more equitable participation took place in the physical-digital condition in terms of verbal utterances over time. It was also shown that those who spoke the least contributed most to the physical design task for this condition. In contrast, the person who spoke the most in the laptop condition dominated the physical design task. We discuss reasons for the various findings in relation to the conceptual framework and show how it can be used more generally to select, design and combine different display technologies to support different kinds of collaborative activities.
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1. INTRODUCTION

Most of us have experienced a degree of frustration when trying to collaborate with others in a co-located setting while using a single user PC. While it is possible for all to view the information being displayed on the screen it is much more difficult for all to interact with it. Typically, one person is in control of the computer, via a single mouse and keyboard, while the others look on. That person can find it difficult to hand over control to the others while the others find it awkward to ask or take control. Several studies have shown that physical input devices, such as a mouse, a pen, or a keyboard tend to stay with one person throughout a group activity (Jordan and Henderson, 1995; Rogers and Lindley, 2004; Trimble et al., 2003). The effect can be sub-optimal communication of ideas and activity progression. For example, it can be difficult for the person controlling the mouse to both express to the other group members what she is doing at the PC while at the same time act upon the ideas suggested by the others. Likewise, it can be hard for the others to follow what the person at the computer is doing and know when and how to express their ideas and suggestions that will enable the person in control to act upon them in the way they intended (Scaife et al., 2002).

How might more equitable participation and less awkward ways of taking over control be facilitated in small groups where there is a need to interact with and create digital information? One approach is to provide shareable interfaces that are designed specifically for more than one person to use at a time (Sharp et al., 2007). The three core technologies developed for this purpose are large wall displays, (e.g., Smartboards) where users interact with gestures or pens; multi-touch tabletops where small groups interact using their fingers or puck devices; and tangibles where users interact with physically-embedded artifacts and tokens on tables, walls and other surfaces. Similar to some of the early groupware technologies (e.g., collaborative writing and drawing tools), shareable interfaces are intended to support people simultaneously working together on and around the same digital content (e.g., documents). However, a main difference is that whereas groupware was primarily targeted at people working together who were geographically separated, shareable interfaces are being designed for people who are physically co-located and where it is considered necessary for them to be co-present.

Shareable interfaces are assumed to be better for group work than single user interfaces because they can provide more opportunities for equal and flexible forms of collaboration (Sharp et al., 2007). In particular, multiple input devices to the same display and multi-touch surfaces can support simultaneous interaction of digital content by all group members while tangible objects are easy to select, pass around, spatially arrange and manipulate by all group members (Fernaeus and Tholander, 2006). Such actions are highly visible and hence observable by others which is not the case for keyboard and mouse entry.

To date, however, there has been a paucity of empirically-based studies that have systematically investigated whether and how shareable interfaces facilitate or hinder group participation (Marshall et al., 2007). The aim of our research is to investigate how
different kinds of shareable interfaces are used by co-located groups when collaborating on a task. To begin, we describe shareable technologies in terms of a conceptual framework called Shared Information Spaces (SIS). The purpose of the framework is to provide a way of operationalizing a shared information space in terms of how it constrains and invites participation through the design of entry points at the display interface. We describe how we designed an experiment that compared how groups collaborated using three different SISs that varied in how their entry points were constrained from least to most. The least constrained condition was a physical-digital combination of tabletop and tangibles, that provided various entry points at different interfaces; the medium constrained was a multi-touch tabletop that enabled all to participate at the same display and the most constrained was a laptop display controlled by a single mouse input device. We hypothesized that the physical-digital combination would encourage the most equitable participation because of the high accessibility and tangibility of the entry points.

2. BACKGROUND

One of the earliest attempts at facilitating wider participation in co-located group meetings by augmenting them with computer technology was the Electronic Meeting System (EMS) approach. The goal was to encourage equal opportunities for participation and democratic decision-making through enabling all in a meeting room to generate ideas that could be readily heard, copied and shared. Most notable, was the Arizona project (Nunamaker et al., 1991), where special-purpose meeting rooms were built. Each room had a series of networked computers embedded in a U-shaped tiered set of desks, facing a large video display (sometimes two or three) at the front of the room, with whiteboards and overhead projectors also being provided (See Figure 1).

Figure 1. The Electronic Meeting Room set up as part of the Arizona Project (Nunamaker et al., 1991, p 42)

The rationale behind configuring the displays and supporting technology in the room in this way was to allow everyone to work on their own computer while also being able to make contributions to the large communal display. Groupware was installed on the networked machines that allowed users to type comments on their personal workstations and then copy them over onto the shared display. The comments were subsequently organized by a leader/facilitator, who sat at the front of the room with a master workstation. A problem with this technology set-up, however, was the rigid, unequal and formal structure it imposed on meetings. The facilitator was given an enormous responsibility of integrating and ordering the ideas that the others sent to the communal board. To make matters worse, the users were situated far away from each other and even further from the facilitator, being required to sit in front of the workstations throughout the meeting. Although there have been experimental studies demonstrating positive experiences of using such systems, they have failed to be taken up by companies. The need for superhuman facilitators has been noted as one of the main reasons:

“to facilitate meetings is heavy, it is mentally tiresome, you often sit in a six or seven hour meeting a whole day and are mentally burnt out afterwards. And then the post session work starts. And then it
requires that you are good at handling relations and processes, and are able to take things ad hoc in the meetings as they occur, you need to be interested in getting a meeting to function. It definitely is not left hand work” (Munkvold and Ansen, 2001, p285)

Since the early research on EMSs, there has been a growing interest in how other kinds of less formal, but still technology-rich, meeting rooms can be designed to facilitate co-located group collaboration. A number of smaller scale and more intimate meeting rooms have been developed using an assortment of pervasive technologies; interconnected displays have been embedded in walls, tables and other pieces of furniture that are interacted with via wireless handheld devices, fingers, pens and gestures. Notable projects include the pioneering Colab (Stefik et al., 1987), the iRoom (Johanson et al., 2002), i-Land (Streitz et al., 1999) and the Interactive Design Collaboratorium (Bødker and Burr, 2002).

Much of this line of research has focused on developing specific kinds of novel functionality for shared displays, such as gesturing techniques (Guimbretiere et al., 2001) and knowledge capturing tools (Ju et al., 2004). Other researchers have explored how to exploit familiar interaction methods in shared settings, enabling users to transfer data between their personal devices, e.g., pen drives, and shared displays (Izadi, 2003; Shen et al., 2003). The extent to which the newer generation of technology-rich meeting rooms can facilitate collaboration, however, is unclear. While an objective is to encourage all group members to join in more it may still be difficult for them to be able to interact with multiple displays and devices. For example, an informal evaluation of the Interactive Design Collaboratorium showed that while participants were able to interact with documents at the wall and table displays they experienced difficulties when trying to move a document from one display to the other (Bødker and Burr, 2002).

How comfortable people feel knowing that their actions and their effects on a shared display are highly visible to others in a group setting may also affect their willingness to participate. Such self-consciousness can deter people from taking part in a group activity (Brignull and Rogers, 2003). Churchill et al (2003) found that people needed constant encouragement and demonstration to interact with a shared whiteboard system called Plasma Poster. Agamanolis (2003) also noted how “half the battle in designing an interactive situated or public display is designing how the display will invite that interaction” (p.329). In contrast, people seem more willing to interact with multi-touch tabletops, such as SenseTable (Patten et al., 2001), SmartSkin (Rekimoto, 2002) and DiamondTouch (Deitz and Leigh, 2001), in the presence of others. This may be because these kinds of shared horizontal surfaces lure people to touch them without feeling intimidated or embarrassed of the consequences of their actions. For example, our earlier research has shown how small groups were more comfortable working together around a tabletop compared with sitting in front of a PC or standing in a line in front of a vertical display (Rogers and Lindley, 2004). The familiar and lightweight action of touching a surface may also make it easier for people to take part in a social/public setting. User studies have shown how groups of people, new to tabletops, find it easy and enjoyable when sharing and assembling of sets of digital images for a variety of collaborative tasks (Huang, 2003; Ryall et al., 2004; Scott et al., 2003; Shen et al., 2002).
Ideally, shared technologies should be designed to allow groups comfortably and easily to access, create, interact with and move digital content in an equitable and free-flowing manner. However, the extent to which these goals can be met depends on a number of factors, including how obvious it is to the participants to know what to do in such settings and how to take turns to progress with a collaborative task. We argue, that of primary importance is whether the technological set-up has been designed to invite people to select, add, manipulate or remove digital content from the displays and devices. This will depend to a large extent on the loci of control and the tangibility of the modes of interaction provided. By the former is meant the availability and placement of points of access to the digital content in the set-up and how easy it is for the group members to move between them. By the latter is meant the property of being palpable or graspable which in turn enables collaborative actions, such as showing and passing around. For example, multi-touch surfaces are considered tangible in the sense of inviting participants standing around them to all ‘dive in’ and manipulate the digital objects represented on them (Rogers et al., 2006). Physical artifacts are also considered to be highly tangible. Group members may use them as external thinking props to explain a principle, idea or plan to the others that is more effective than using equivalent digital representations at a display (Brereton and McGarry, 2000; Fitzmaurice et al., 1995; Fjeld et al., 2002; Hornecker and Buur, 2006). In particular, the act of waving or holding up a physical object in front of others is very effective at commanding attention. The persistence and ability to manipulate physical artifacts may also result in more options being explored in a group setting (Fernaeus and Tholander, 2006), and increase peripheral awareness of others’ activities, which can help collaborators gain a better overview of the group activity (e.g., Scott et al., 2003).

Our research is concerned with how salient properties of shareable interfaces can affect participation levels for group activities. In particular, we are interested in whether technological set-ups that are designed to be highly tangible can invite group members to participate more equitably. We are also interested in whether widening the loci of control form a central hub to being dispersed throughout a room encourages more equitable participation. There has been limited systematic exploration of how the physical positioning of interface and display technologies in space might influence performance and participation. Wignor et al. (2006) describe some of the trade-offs between performance and comfort in environments with non-traditional arrangements of displays and control devices. They suggest the use of multiple control spaces and changes in the arrangement of participants as the number of users increases beyond two. Scupelli et al. (2007) have borrowed from ideas in architecture to explore how measurement of the visibility of space from different positions can be used as a resource to position displays to increase coordination between different work groups.

However, to date there has been a lack of suitable experimental paradigms for comparing how shareable surfaces affect group working (Tan et al., 2007). The few user studies carried out so far have tended to be piecemeal, investigating one particular technological feature or dimension, such as display size, display orientation or type of input device. Can we move beyond the single factor approach to conceptualizing and comparing different shareable technologies?
A problem with comparing different technological set-ups that have their own distinct features and interaction styles is the difficulty of controlling both the independent and dependent variables. For example, the physical actions involved in touching a tabletop (using fingertips) are quite different from the physical actions involved in manipulating tangibles (handling of objects) or using a PC (using a mouse and keyboard). The make-up of small groups of people can also vary along numerous dimensions that can be very difficult to control for. Hence, instead of trying to investigate the effects of one variable while trying to control all others we propose a less formalized, experimental approach that aims to explore the effects of salient variables that affect collaboration; in this case interface accessibility and tangibility. To this end, we propose using a higher-level conceptual framework to characterize how different technological set-ups can invite groups to participate in more or less ways that, in turn, will affect how they collaborate. Using the framework to characterize shareable interfaces in this way provides a means of comparing three different types of ‘shared information spaces’ that vary in how they invite participation.

3. THE CONCEPTUAL FRAMEWORK: SHARED INFORMATION SPACES

The conceptual framework of Shared Information Spaces (SISs) is based on the concept of entry points that comes from the distributed cognition approach (Kirsh, 2001). By an entry point is meant a structure or cue that represents an invitation to enter an environment, such as a website or a physical office. It has been used mainly to characterize the context of work in terms of a user’s perception of the state of various digital and physical resources. For example, in terms of information spaces, the layout of newspapers and websites offer a range of entry points that invite users to read, scan and follow them, including headers, pictures, columns and bold words. As part of an office, users create a collection of entry points on their desks, walls, floors, computers, and so forth, which invite the users to revisit work threads and to scan what is on call and what needs attending to. Dynamic entry points can also be used at certain times to draw a person’s attention, such as a series of blue circles appearing on his computer email window inviting him to scan and review his email and a flashing phone inviting him to listen to his voicemail.

Entry points have also been operationalized as a generative design principle, describing features that, on the one hand, lure people into them and, on the other, do not deter them from entering (Lidwell et al., 2005). These include providing (i) minimum barriers, (ii) points of prospect and (iii) progressive lures. Examples of physical barriers that prevent people entering are sales people standing at the doorways of stores and busy information displays with too many elements. A point of prospect allow people to become oriented and survey available options in their surroundings before making a choice, and which provide sufficient time and space to do this in. Progressive lures attract people through an entry point, by encouraging them to approach, enter and move through. These include compelling headlines and highlighting of text.
In the context of our research, we describe a shared information space (SIS) as the layout of the physical room, the display and device interfaces provided and the kind and way information is presented (physical or digital). An SIS is characterized in terms of how its entry points invite or constrain participation. Our assumption is that the design of entry points can provide different ways for participants to collaborate in both verbal and physical modes that lend themselves to more or less equitable participation. The least constrained SIS is assumed to provide the most accessible and tangible entry points that will encourage the most equitable participation. It is assumed it can do this through making it easier for participants to move freely around the space – simultaneously or sequentially – selecting, creating or interacting with digital and physical information. The most constrained SIS provides the least accessible and tangible entry points, by restricting access to the locus of control, and allowing only one person to select, create and interact with only digital information.

SISs are further operationalized in terms of the layout the room, which displays and input devices to use and how to present information on them. The physical layout of the room can be varied in terms of the placement of furniture and the use of walls, shelves and tables. A table in the room provides a central hub and a shared horizontal display, like a multi-touch surface that can be placed on it. Chairs placed around the table fix the way group members are positioned relative to one another. Conversely, not having chairs available to sit on can invite participants to move around the room. Having physical objects to select options from that are placed on walls and shelves means participants have to move back and forth from the table to collect them. This can encourage them to share them around, while making it easy to explore alternative solutions without committing to the ongoing activity, through picking them up, holding and examining them and then putting them back down again.

The size, position, and direction of displays can be configured to reduce barriers and to create lures. Likewise, the kind, number and placement of input devices in the physical space will affect how inviting they are and in turn how the group members select and use them when interacting with the information displayed. A multi-touch tabletop display is likely to invite different collaborative interactions compared with a single user display, such as a laptop. GUIs can be designed on the displays to offer digital entry points that guide group members to know what to do next and which part of the display ‘belongs’ to whom. Again, these will vary depending on the type of display used.

The SIS framework was used to design three display interfaces that varied in how they invited participation. These were essentially a laptop condition, a tabletop condition and a physical-digital condition. Details of the design of each SIS are presented in Table 1. Our hypothesis was that the least constrained SIS (the physical-digital condition) would support the most equitable participation and the most constrained SIS (the laptop condition) would have the most inequitable participation. The reason for this is based on the theory that providing multiple entry points in both the physical and digital parts of a shared information space can readily invite group members to know what to do and to make a contribution; showing them where and what they can browse, select and interact with.
4. EXPERIMENTAL DESIGN

4.1. The Design Task

A collaborative design task was devised that involved idea generation, planning, decision-making, weighing of criteria, suggesting of alternative ideas and revising of ideas. Groups of three were asked to browse a large number of options, choose which to include in their design and then determine how best to place them in relation to one another. To enable a level of ecological validity, we chose a task that was topical, engaging and contextually relevant to the participants. At the time of the study, opinions were being sought regarding the design of public spaces for a proposed new building for the university. With this in mind, the particular task set for the participants (who were faculty, students and staff at the university) was to design a layout plan for a public garden intended to be part of the new school building. In this real-world context, equitable participation is considered by the university to be a desirable goal, where everyone is entitled to have a say. It is also more likely that the participants will have a personal interest in the task since the final design could have ultimately affected their working environment.

The task was designed at a level that anyone with some knowledge of gardens and experience of using public spaces could solve. The choices of objects that could be included were a mix of common garden plants (e.g., flowers, trees, shrubs) for different seasons, garden furniture (e.g., benches, chairs) and ornaments (e.g., statues, bird bath). Each item was individually priced, ranging from $10 to $500. A budget of $3500 was set for the task so that the participants had a realistic constraint to guide them in making their design decisions.

The same schematic garden layout plan was used for each condition, presented via different displays and varying in how the participants could select, add, interact with and change the designs being created.

4.2. The Conditions

Table 1 presents the three conditions were designed for the experiment. The laptop condition was the most constrained, providing a single display placed on a table with three fixed seats in front of it (see Figure 2). This was chosen to be the equivalent of a control condition, where access to the locus of control and interface tangibility is minimal. A wired mouse was positioned centrally in front of the laptop enabling all three seated participants to interact with the garden plan using default GUI operations, i.e., dragging and clicking. Having only one input device available creates a barrier restricting access to the display to only one person at a time. The display size was a standard 15” with 1024 by 768 resolution.
Piles of icons representing the available options were presented in the four corners outside of the garden plan (see Figure 5a). To aid recognition, a simple classification of options was used: spring flowers were placed in one corner, summer flowers in another; garden furniture in the third and shrubs and trees in the fourth. Moving an icon in the laptop condition involved a simple drag and drop action using the mouse. Additional information about each object, i.e. its price, its common and Latin name, handy growing tips (e.g., perennial, likes shade) and a photographic image of it could also be obtained by double clicking. This information appeared as a pop-up image (see Figure 5b). To avoid cluttering the display the pop-ups could be made to disappear again by clicking on the image. An object was removed from the garden plan by dragging its corresponding icon back to the corner from which it came.

The tabletop condition used the same software application running on the laptop but presented via a multi-touch tabletop display. There were no physical barriers in this condition as all group members could touch the tabletop display simultaneously with their fingertips and interact with the digital information from different sides of the table. No chairs were provided so participants were free to move around the table. The MERL DiamondTouch tabletop was used (see Figure 3) that provides good points of prospect where all participants can see, select and move the object icons from the different sides of the display. The display size that was usable measured 65cm by 50cm and had the same resolution as the laptop display. The same piles of icons and operations were used as in the laptop but involving fingertip dragging and tapping instead of mouse movements.

The physical-digital condition was designed to provide equivalent information to the other two conditions but with the options being represented as a set of RFID tagged physical artifacts instead of icon piles. These were located around the room on three walls and two sets of shelves (see Figure 4). The distance between the tabletop and each wall was just under a meter, requiring a couple of paces to reach from each side of the table. The table measured 152cm by 86cm. The tagged objects could be transformed into the same digital icons as used in the tabletop condition by placing them on the table surface adjacent to the tabletop display. An RFID reader and aerial were placed underneath the table and a yellow square was drawn on the table to show where the objects could be read. The physical objects were made up of a combination of cards and 3D models (see Figure 6). The reason for choosing both objects is that images are good at depicting complex and sophisticated shapes—for example, showing the overall effect of a border of flowers—but are not as good for showing textures and the 3-dimensional proportions of objects. Conversely, 3D models are good at showing the relational proportions of objects but not as good at showing the overall impression. The additional information about each option appeared on the cards or model bases. The cards were
adhered, using magnets, to the walls and divided into two categories (spring plants and summer plants). The miniature models were also divided into two categories (garden furniture and trees) and placed on adjacent shelves.

The physical-digital set up offers the most flexible points of prospect; all group members can explore options without having to commit to adding them to the design and hence changing the layout plan.

Figure 5. (a) Bird’s eye view of the garden plan with icons of spring and summer plants in two corners and garden furniture and trees and shrubs in the other two corners, and (b) a pop-up detail for a scarlet lily flower, showing color photo, price and flowering details

Figure 6. Examples of a (a) physical card and (b) objects used in the physical-digital condition

4.3. Participants

A between-subjects design\(^1\) was used where six groups of 3 participants took part in each of the 3 conditions (54 participants in total)\(^2\). The groups were mixed according to age, gender, gardening experience, and familiarity with each other as friends or work colleagues. There were two all female groups, one 2 male/1 female group and three 1 male/2 female groups in both the tabletop and physical-digital conditions. In the laptop there was two all male groups, two 2 male/1 female group and two 1 male/2 female groups. The ages of the participants varied between 22 and 60. All were experienced with using PC computers although none had used a multi-touch tabletop or tangibles before. All groups knew each other at the university as work colleagues (e.g., secretaries, faculty, administrative staff) or as friends (e.g., students). Gardening experience ranged across groups, with some participants having a lot, medium and a little.

4.4. Procedure

The groups were introduced to the design task and were told that the aim of the study was to investigate how new technology could be used to support group work. In the laptop condition they were shown how to move, open and delete icons using the mouse. In the tabletop and physical-digital conditions they were shown how to move, open and delete icons using their fingertips. In the physical-digital condition they were also shown how to transform the physical artifacts into digital representations on the tabletop.

After a familiarization session with the technology and an introduction to the task the groups were given 30 minutes to complete the task, allowing sufficient time for patterns to emerge and change over time (c.f. Arrow et al., 2000; McGrath and Hollingshead, 1993). Following the completion of the task, a 10-15 minutes open-ended group interview was conducted with the participants to discuss their experiences. The following day they were each sent an online survey to reflect upon, individually, their experiences of working as a group.
The sessions were video taped and the interactions at the tabletop and laptop recorded using the screen capture software, Camastasia. The streams of video and captured screen data were combined. Two researchers reviewed them, independently, transcribing the utterances and physical interactions that took place. The transcriptions were subsequently coded in terms of types of utterances and physical actions (see below).

5. FINDINGS

Quantitative analyses were initially performed to determine if there were any significant differences in the level of participation among the groups in the three conditions, and, in particular, to test the hypothesis that the least constrained condition would elicit the most equitable participation. More extensive qualitative analyses were then carried out to examine in detail the patterns of collaboration and interaction over time that took place across the different conditions.

5.1. Quantitative Analyses

In the quantitative analyses described below, Pearson’s r is used as a measure of effect size for all t-tests and planned comparisons. ω is used as a measure of the overall effect size where we report the results of an ANOVA.

A preliminary analysis investigated how long it took the groups to complete the task across the three conditions. A significant effect of interface condition was found, F(2, 45) = 4.72, p < .05, ω = 0.37. Gabriel post hoc tests indicated that the mean time taken by participants in the tabletop condition (M = 22:24, SE = 02:00) was less than those in both the physical-digital (M = 30:00, SE = 02:16), p < .05, and laptop (M = 29:20, SE = 02:00), p < .05, conditions. No difference was found between participants in the laptop and physical-digital conditions, p > .10. This result suggests that the tabletop encouraged faster completion of the task. It also means that statistical analyses of the level of participation across conditions needed to be normalised over time.

To investigate the types of collaborative discourse produced by participants using the different interface configurations and to test the hypothesis that the least constrained SIS would result in most equitable participation, we carried out an analysis of:

(i) The quantity and type of discourse produced while carrying out the garden planning task

(ii) the inequality of participation for both verbal contributions and interface activity

The total number of utterances made by each group member were first normalized by dividing by the time taken to complete the study. The mean number of utterances per minute are shown by condition in Figure 7, which suggests that participants in the laptop
condition tended to produce dialogue at a faster rate than those in the less constrained tabletop and physical-digital conditions.

Figure 7. Mean number of utterances produced by a participant in each interface condition

The rate of dialogue production was compared across the three conditions to get an overall measure of verbal participation. Interface condition was found to have a significant effect on the number of utterances made per minute, F(2, 45) = 3.25, p < .05, $\omega = 0.29$. Planned contrasts tested the initial hypothesis that the less constrained an interface condition, the more dialogue would be produced. Contrary to our expectations, the rate of dialogue production was found to be significantly higher in the laptop condition ($M = 2.88$ utterances per minute, $SE = 0.21$) than in either the tabletop condition ($M = 1.89$, $SE = 0.28$; t(45) = -2.06, p < .05 (2-tailed), r = 0.29) or the physical-digital condition ($M = 1.79$, $SE = 0.27$; t(45) = -2.27, p < .05 (2-tailed), r = 0.32). No difference was found between the rate of dialogue production for participants in the tabletop and physical-digital conditions, t(45) = -0.20, p > .10, r = 0.03.

These findings suggest that considerably more conversation took place in the laptop condition than in the other two conditions. However, they do not show what kinds of dialogue were produced. To investigate further, we analyzed each participant’s utterances related to the ongoing design task across conditions. A classification scheme was developed for this purpose. Six different kinds of communicative acts were identified that were used during the task. These were suggestions (S), confirmations (C), probing questions (PQ), queries (Q), answers (A), and other (O). A suggestion was defined as an utterance that offers a possible course of action, e.g., “Let’s have a private area for people who want to be alone.” An utterance that supported a suggestion was classified as a confirmation, e.g., “Sure, why not”. A probing question was distinguished from a suggestion if it was an explicit request for a suggestion from the others, e.g., “Where should we put those?” A query was further distinguished from a probing question when a participant asked something specific about the software or an object that was not intended to elicit suggestions about the design from the others, e.g., “What was the name of that red flower?” Answers were defined as replies to queries, e.g., “It’s called a Scots pine”. The category of ‘other’ was used to describe miscellaneous utterances, e.g., comments about the weather and making jokes.

These categories of utterances were initially derived through iterative classification of a sample of the transcripts by all members of the project team, rather than by adopting an a priori set. Two independent raters then went through all of the transcripts coding the utterances using the scheme. One transcript was randomly selected to be coded by both raters to assess the inter-rater reliability. Table 2 lists Cohen’s $\kappa$ scores calculated for each utterance category. These are in the range described by Fleiss (1981) as good ($\kappa > 0.60$) or excellent ($\kappa > 0.75$).

Table 2. The inter-rater reliability scores using Kappa for utterance categories
Normalised values were calculated for each of the utterance categories for each participant by dividing the number of utterances by the time spent carrying out the task. These are shown per condition in Figure 8, which shows that by far the most common utterance for all three conditions was a suggestion.

Figure 8. The mean number of utterance types per minute for each condition

A MANOVA showed that the pattern of utterances produced was related to participants’ interface condition, Pillai’s trace F(10, 84) = 2.70, p < .01. A univariate ANOVA uncovered a significant effect of interface condition on the number of answers produced by participants per unit time F(2, 45) = 6.55, p < .01, ω = 0.43. Gabriel’s post hoc tests indicated that individuals in the laptop group produced significantly more answers per minute (M = 0.43, SE = 0.07) than those in the tabletop (M = 0.25, SE = 0.04), p < .05 or physical-digital (M = 0.18, SE = 0.03), p < .01, groups. No difference was detected between the tabletop and the physical-digital groups (p > .10).

For the probing question scores per minute, the assumption of homogeneity of variance was violated and therefore the Welch F-ratio is reported. There was a significant effect of interface condition on the number of probing questions produced per minute, F(2, 26.8) = 4.37, p < .05, ω = 0.29. Games-Howell post hoc tests indicated that participants in the laptop condition (M = 0.27, SE = 0.06) asked significantly more probing questions per minute than participants in the tabletop condition (M = 0.12, SE = 0.02), p < .05. No differences were detected between participants in the physical-digital condition (M = 0.20, SE = 0.04) and either of the other two conditions, p > .10.

The greater amount of conversation that took place in the laptop condition can be attributed to more probing questions and answers given than in the other conditions. In some ways, this is to be expected since there is only one point of access, it requires more verbalizing by the mouse holder to let the others know what he is doing and conversely, the other participants to respond by agreeing or disagreeing. No effects of interface condition were found for any of the other utterance categories suggesting that the level of suggestions did not differ significantly across conditions.

Based on these findings it is not possible to accept the hypothesis that there is more equitable verbal participation in the least constrained condition. Further statistical analyses were conducted to assess the level of equality across conditions. These are described in the section below.

(ii) Inequality of participation for both verbal contributions and interface activity

The level of participation across the conditions was further tested using the Gini coefficient of inequality. This measure is most frequently used to measure inequality of income distribution (e.g. Firebaugh, 1999), but has also been used to measure discourse participation, for example in the classroom (Kelly, 2007) and in electronic
communication (Fitze, 2006). It is a ratio measure that can be used to compare inequality across cases with different overall measures. It ranges between 0 (no inequality) and 1 (total inequality). Hence, a low score indicates more equitable participation while a score closer to 1 indicates inequitable participation (N.B. For small group sizes where the distribution does not tend to that of a Lorenz curve, the maximum inequality will be less than 1). Details of how to calculate Gini coefficients are provided in Fitze (2006, Appendix A).

Inequality of participation was compared initially between the physical-digital, tabletop and laptop groups for verbal participation in terms of utterances over time. A further comparison was made between the three groups for physical participation. Physical participation refers to the number of interface actions (e.g., moving icon, deleting icon) performed by each participant at the tabletop.

Verbal participation

Gini coefficients were calculated for groups in the physical-digital (M = 0.12, SE = 0.04), tabletop (M = 0.19, SE = 0.10) and laptop conditions (M=0.19, SE = 0.08). As can be seen in Figure 9, the lower Gini coefficient for the physical-digital condition indicates the most equitable participation in terms of verbal contributions. This difference was not found to be statistically significant, F(2, 13) = 1.02, p > .10, ω = 0.33. However, because the comparison of verbal participation is necessarily at the group level, the sample size is very small and therefore this finding should be treated with caution.

Figure 9. Mean Gini coefficients for utterances and physical contributions

Physical participation

In contrast to the verbal utterances, the Gini coefficients calculated for groups in the laptop condition (M = 0.48, SE = 0.09) were considerably larger than those in the tabletop condition (M = 0.15, SE = 0.06) or the physical-digital condition (M = 0.21, SE = 0.03) (see Figure 9).

The assumption of homogeneity of variance was violated for the physical participation Gini coefficients and therefore the Welch F-ratio is reported. There was a significant effect of interface condition on the inequality of physical participation, F(2, 7.72) = 4.69, p < .05, ω = 0.65. Planned contrasts indicated that inequality was greater in the laptop condition (M = 0.48, SE = 0.09) than in either the physical-digital condition (M = 0.21, SE = 0.03), t(6.46) = -2.91, p < .05, r = 0.75, or the tabletop condition (M = 0.15, SE = 0.06), t(8.75) = -3.04, p <.05, r = 0.72. There was no difference detected in the inequality of physical participation between the tabletop and physical-digital groups, t(6.02) = 0.81, p > .10, r = 0.31. However, given the small number of groups and the medium sized effect (Cohen, 1988), this finding should be treated with caution.

The main finding from these two comparisons of inequality measures is that, as predicted, participants in the very constrained single-input laptop condition showed considerably less equity of physical participation than the other two groups, with one
participant carrying out all of the interface actions in three out of the five groups and high Gini coefficients in the other two. There were no other statistically significant differences. However, given the very small sample sizes (N = 5) this is unsurprising. The descriptive statistics indicated that there might be greater equity of verbal participation in the least constrained physical-digital condition than in the other two groups and conversely that there might be greater equity of physical participation in the tabletop condition where the participants all face one another.

Taken together, these two sets of Gini coefficients indicate that the physical-digital set-up might support more equitable participation among groups in terms of verbal utterances. While the physical-digital and tabletop configurations were predictably associated with far greater equity of physical participation than the laptop, the physical-digital fared less well for physical contributions (i.e. adding options, changing the design over time) when compared with the tabletop condition. These findings suggest that having more accessible and tangible entry points in a shared information space can invite more equitable verbal participation but that having a variety of accessible and tangible entry points does not necessarily result in more equitable physical participation. If anything, such an array dispersed around the room may encourage a division of labor among the participants, where they designate certain areas in the space to certain roles they each adopt. For example, at the beginning the person nearest the RFID tag reader may take on the role of the person who adds the physical options to the tabletop and the person closest to them at the tabletop may adopt the role of the one who collects the digital icons and positions them in the garden layout. In contrast, the tabletop, having a less dispersed set of entry points, may not afford the creation of particular roles. Instead, it has been suggested that tabletop territoriality often emerges where the space in front of each participant becomes their personal responsibility while other parts of the tabletop remain shared (Scott et al., 2004), promoting the switching between individual and collaborative working.

To examine whether this happened and whether further working patterns emerged over time for the different shared information spaces we carried out a number of qualitative analyses. Compared with the quantitative analyses, they are able to reveal the intricate patterns of interactions and conversation that unfold over time and how these can affect participation levels.

5.2. Qualitative Analyses

To examine the forms of collaboration that took place in relation to the ways the entry points were used by the participants to make a contribution, a number of qualitative analyses of the video data and survey responses were subsequently conducted. These were of:

(i) the collaboration and coordination strategies that emerged

(ii) the patterns of contribution made by each participant relative to the others in the group
(iii) the types of verbal and non-verbal communication

(iv) the participant’s views of working in the different set-ups

(i) The collaboration and coordination strategies that emerged

The videos showed how the groups initiated and managed their participation varied across conditions. In the physical-digital condition, the invitation to look at the available options was very strong, drawing all groups to view all the physical objects on the walls and shelves in a systematic way, often reading out aloud the information to each other, before making any suggestions as to what to add to the design. In contrast, in the tabletop condition the groups started the task by discussing various criteria for their design before exploring any of the digital icon options on the display. To begin, they opened up a few of the pop-ups for several of the icons and discarded them if they were not the one they were looking for, for example:

P1: “See what that little round thing is.”
P3: “Oh Sequoia, we don’t want that!”

For the laptop condition, half of the groups formed a plan and then looked for icons to match their suggestions while the other half began the task by searching for icons to inspire their design.

The strategy in the physical-digital condition of looking at the options and matching these to their criteria persisted throughout the task. All groups moved back and forth between the tabletop and the wall/shelves selecting objects and bringing them to the tabletop (M=14, SD=5.24). Figure 10 shows the trajectories of three of the groups moving between the walls, the tabletop and the RFID reader. As can be seen there is considerable variation in how the groups moved, with some groups walking together on mass while others moved as pairs or individually. These different ways of working developed in an implicit manner as the task progressed.

At various points during the task, a division of labor evolved in the groups where one participant took the role of selecting the physical objects, another the role of placing them in the square on the table over the RFID reader, and the other the role of ‘collecting’ the digital representation of the object as it appeared on the display and moving it to a position on the layout plan. As commented by one participant:

“We often traded tasks. Didn’t get in each other’s way although when they were nearer the magic square I would hand them the items. I was closer to where they landed so I got to move them round the table.”

This division of labor can explain, therefore, why physical participation was not as equal in the physical-digital condition as hypothesized. In particular, the participant at the tabletop collecting the options was likely to have more physical participation. However,
when the participants were all at the tabletop the division of labor was less – as each moved the icons around to change the design.

Such a division of labor did not occur in the other two conditions. It was extremely rare for someone to add an icon to the tabletop plan and for another to move it in the tabletop condition. Instead, the participants in the tabletop condition each took a place around the tabletop at the beginning and remained there throughout. As suggested earlier, they often earmarked a quadrant of the garden design as theirs to fill in but worked together to decide how to design the whole garden.

There was some evidence of ‘turn-inviting’ (Rogers et al., 2004) in all conditions. This is where one participant both verbally and physically asks another to have a turn at manipulating the design. At the tabletop, a turn-invite involved verbally asking another to add an object and pointing at a group of icons to select it from. This was the same for the physical-digital condition but in addition could involve handing someone a physical object to add to the design. For the laptop condition it was restricted to handing over the input device (i.e., mouse). The mean number of turn-invites per condition was 8.8 for the physical-digital condition (SD=5.6), 4.5 for the tabletop (SD= 2.4) and 1.5 (SD=2.07) for the laptop condition.

An example of a turn-invite in the physical-digital condition was where P2 invited P3 to add a physical model of a bench and then she took the initiative to move it to a place the digital counterpart to a specific place on the garden layout:

P1: Now shall we do trees or benches or flowers first? Or what?
P2: “Why don’t we do benches first?”
P3: Picks up a bench model and places it on RFID tag reader. Its digital counterpart pops up on the tabletop.
P2: <talking to P3> “Ok, you got one. Where do you want to put it? Do you want to put it along the sidewalk or where?
P3: “I want it here. The smoking corner” <points to place on garden layout and then moves the digital icon of the bench to it.>

This excerpt shows that the physical-digital condition makes it easier for participants to invite others to take part in contributing to the design task. As found in previous research, when the entry points are constrained to allow only one person to be in control it makes it much more socially and physically awkward for turn-inviting. On one or two occasions, a non-mouse holder was seen to snatch the mouse when the mouse holder momentarily took his hand away. Other times, the offer by the mouse holder appeared to be less of an invite and more a way of explicitly handing over control to another, e.g.,

P1: “Here, you have a go, you’re better”
P1: “Here your go, now go fix the benches.”
Participants also created their own entry points in the physical-digital condition, keeping ideas on ‘hold’ and ‘in the bubble’ until appropriate times arose where they revisited or introduced them to the design space. An example that was seen in several of the groups was the holding of cards, until an appropriate moment when the participant felt she could place one or more of them on the tabletop. Another was placing a set of objects on the table, so that they, too, could be quickly selected. These appropriations of the physical objects enabled the participants to move the conversation or design in another direction, without having to interrupt someone or ‘butt’ in.

The low Gini coefficient found in the quantitative analysis suggested that the physical-digital set up encourages more equal levels of participation in terms of utterances but not necessarily physical participation. Why might this be so? Our next analysis looks at how the physical-digital condition was able to encourage more equitable verbal participation compared to the other conditions in terms of what each said relative to the others.

(ii) The patterns of contribution made by each participant relative to the others in the group over time

To examine participation levels in more detail we looked at how much each participant spoke relative to the others in their group. Figure 11 shows the means and SD of the percentage of total utterances for the least, medium and most speakers for each condition. As can be seen they are uneven across the three conditions but have similar patterns of inequality: being approximately 20%, 35%, and 45% for the least, medium and most speaker, respectively.

Figure 11. Means and standard deviations for least, medium and most speakers as a percentage of the total for each condition

On closer examination of each participant’s verbal contribution over time, however, it was found that there was more variation over time for groups in the physical-digital groups compared with the other two conditions, in terms of changing levels of utterances. A typical group’s varied level of participation sampled at two minute intervals is presented in Figure 12. For the tabletop condition, the level of verbal utterances over time was more fixed, with the least and the most speakers in all groups remaining so for most of the duration of the task (see Figure 13). There was even less variation over time in the laptop condition; the least and most speakers in 80% of the groups remained so for the whole duration of the task (see Figure 14). The greatest speaker (U2), who was also the mouse holder, continued to dominate the conversation for the whole 30 minutes for two-thirds of the groups.

Figure 12. The number of utterances for most (U1), medium and least speakers at the beginning of the task, then sampled at two minute intervals for group 5 in the physical-digital condition

Figure 13. The number of utterances for the most (U2), medium and least speakers at the beginning of the task, then sampled at two minute intervals for group 1 in the tabletop condition
We then examined whether those who spoke the most did more of the physical design task. As the types of physical actions were different across conditions we analyzed the level of utterances for each participant relative to the type of physical movements within each condition: for the laptop it was the mouse movements (e.g., dragging an icon onto the garden layout); for the tabletop it was fingertip movements and for physical-digital condition it was the fingertip movements at the tabletop combined with manipulating the physical objects (e.g., placing a card on the table).

For the physical-digital condition, it was found that the least speakers made the largest number of physical actions, in terms of both moving physical objects and tabletop fingertip moves (see Figure 15). The opposite was true for the tabletop groups, where the participants who spoke the most were those who contributed the least fingertip moves (see Figure 16). In the laptop condition, participants who spoke the most were the ones who used the mouse for the longest time, and the participants who spoke the least were the ones who used the mouse for the shortest amount of time (see Figure 17).

These findings suggest that the physical-digital condition enabled those who make least verbal contributions to the ongoing task to compensate by making more physical contributions to the design task than the other participants in their groups.

(iii) Types of verbal and non-verbal communication

To examine further why more utterances took place in the laptop compared with the other two conditions we looked at what each participant said and did when creating the garden design. In all conditions there was considerable discussion of the criteria for how to design the garden layouts. These included the need for shade, privacy, seating, cost, the importance of symmetry/asymmetry, color, light, combinations and maintenance. Where the conversations differed across the conditions was in terms of how the participant’s plans were executed and the verbal and non-verbal strategies employed to change the designs.
In the laptop condition, the conversations typically involved the mouse user vocalizing to the others what she was planning to do or was doing, with the other two agreeing, directing, querying or suggesting what the mouse holder should do. The greater number of probing questions found in the laptop condition compared with the other two can be explained by the mouse holder (P1) asking more of the other two in their group what they wanted or not since the others were unable to physically add anything to the garden design, e.g.,

P1: “do you want to have a tree behind each bench...is that your idea?”

P1: “you don’t want chairs out there, do you?”

The non-mouse holders (P2 and P3) also made suggestions in the form of directives to the mouse-holder, e.g.,

P2: “You know we could make this one look like that one and then these two the same.”

P3: “Oh yeah, I think you got more summer flowers than you need...which is probably OK...but you probably want to mix some spring flowers...I don’t know which one is which...you just got them everywhere...I cannot tell just from looking <it requires the mouse holder clicking the icons to find out whether they are spring or summer flowers>

In addition, they often asked what the mouse holder was doing, e.g.,

P2: “are you going for the symmetrical look?”

P3: “do you care if we are putting shade-only flowers in the sun?”

There was less evidence of directives or a running commentary being used in the other two conditions; the conversations were largely participants suggesting what to add and the reasoning behind their ideas. In the physical-digital condition, the participants took it in turns to ask one another what they thought of a candidate option, reading the information out aloud displayed on the physical objects and showing it to the others, as a way of validating their choice:

P2: <reading information on card> Tolerates high humidity. You like this one? <passes another card to P1>
P1: It is OK. <reads it> Early summer. Likes sunshine.
P3 agrees.
P2: Here is a late summer one. It’s ugly.
P3: That one I gave you is like May-August. <points to card he has just handed P1>
P2: That will kind of work.

Another difference between the conditions, was how much more difficult it was for the non-mouse holders in the laptop condition to get a desired result when wanting to change the design, sometimes raising their voices in frustration. For example:
P2: “Let him have one of his benches like he wants…no…move one…don't add another one…
P3: “Move one…I don’t think we need…”
P2: “No we don’t need to add another one!”
P1: “So symmetrical here?”

In contrast, when the others asked to change the design in the physical-digital set up, it was often as a way of getting approval from the others. For example:

P3: “I think we got too much inside this <gestures at a section on the tabletop> why don’t we move the forsythia outside?”
P2: “Which one?”
P3 points at physical card showing forsythia to show her which one and then starts moving the counterpart icon on the tabletop
P2 at the same time gestures to where it should go and P3 moves it there.

Hence, the way the participants make requests to the others to make changes is easier, enabling more subtle and socially comfortable ways of collaborating.

(iv) Participant’s views of collaborating in the different set-ups

To assess how the participants felt about working together as a group in the three conditions they were asked to write down separately their views. In general, the participants in the tabletop and the physical-digital conditions were more favorable, for example in the physical-digital they pointed out how the interface enabled them to see other’s perspectives while also having easy access to all available options:

“I enjoyed setting up the garden and working with the others. It was a good way to get different views of what different people like and still work together and get an end result that works for everyone.” (P1, GP2)

“It was easy to use the cards. There are your options. You just know that that is all there is.” (P2, GP3).

In the tabletop condition, comments were also made about how the interface enabled them to work together differently as a group and how the tangibility and accessibility of the tabletop allowed them to out things without making a commitment:

“I would have arranged and designed the garden totally differently were I doing it alone. But, I was pleased with the end result…Towards the end I began to think that the end result was going to be better than what I might have done alone, and that was satisfying.” (P2, GP1)

“The purpose of such a tool is to just try things out. There are no commitments. We can move things about. We can easily remove things.” (P3, GP9)
For the laptop condition, comments were made about the frustrations of having to channel one’s ideas through another person and how a different interface might have made contributing easier:

“It might have been easier if there were some way we all could interact... um... and maybe, I don't know, try our own ideas on each other instead of saying, 'can you try to do that?’ ... ” (P3, GP6)

“Or if you could do it just by... pointing... instead of the mouse, that of course might be quite different if you can drag just by using screen instead of mouse...” (P2, GP6)

“I think actually that was my biggest frustration in the task. You know, trying to articulate verbally what it was that I wanted to have done and then just not ... you know ... not being able to convey that really. I mean it wasn't a big frustration, but it was ... just ... you know ... something that ... It would have been easier to be like, ‘oh how about this, what do you think?’ and then you could say ‘no no no, how about this’.” (P3, GP6)

Hence, the participant’s views of how well they worked together, and their understanding of how the interfaces supported them in carrying out a collaborative task were supportive of our ideas about how tangibility and accessibility affect participation.

6. DISCUSSION AND CONCLUSIONS

Our study has shown how shared information spaces that vary in the way they invite participation affects how co-located group members collaborate. It was found that while the laptop condition produced the most utterances over time, the physical-digital condition, i.e., the one designed to have the most tangible and accessible entry points, invited the most equitable participation in terms of verbal contributions. The tabletop condition was shown to have the most equitable participation in terms of physical actions. However, the various quantitative analyses performed on the data showed the effects to be not as marked as we had hypothesized.

One of the problems of using statistical analyses for small numbers of groups, however, is that strong effects are unlikely to be found due to the variability in each group. It will require much larger numbers of groups for each condition to obtain more statistically significant effects. However, finding enough groups of three to run such a large experiment was simply not feasible in our study. Alternatively, we suggest that the use of qualitative analyses is able to demonstrate more effectively group differences in terms of patterns of collaboration and interaction, and coordination mechanisms adopted. In particular, our study showed how the different conditions invited the groups to take turns while also inviting others to take turns, especially in the physical-digital condition.

Another interesting finding was that the participants in the physical-digital condition who spoke the least tended to make the largest number of physical actions in the physical design task, in terms of selecting, adding, moving and removing options from the garden plan. This suggests that it is possible for more reticent members to utilize the tangible entry points (i.e. the physical objects and the pop-up menus) to make a contribution.
without feeling under pressure to have to speak more – especially given that under-participants tend not to increase their level of verbal contribution in small group meetings when provided with various kinds of support, such as awareness visualizations showing who is contributing over time (Norton et al., 2004). The more vocal participants also used the tangible entry points to invite the under-participants to take turns in the physical design task. Hence, tangibility and accessibility are important to take into account when designing technologies to encourage more participation from people who normally find it difficult or who are simply unable to verbally contribute to group settings (e.g., those on the autistic spectrum, those who stutter, are shy or are a non-native speaker).

Our findings also suggest, however, that equitable participation does not happen through providing multiple entry points that are dispersed throughout a room even though this makes them easily accessible by all. As emerged in the physical-digital condition, such arrangements can sometimes result in a division of labor, where groups evolve distributed working patterns. One such example was the distributed way options were placed on the garden layout design that the groups adopted at certain times during the task. It should be noted, though, that although the strategy resulted in physical participation levels being less equal at the tabletop it was a highly effective form of coordination within the collaborative task. In other kinds of tasks such as collaborative learning, however, having too many entry points dispersed throughout a workspace could result in group members working more on their own. The foci of attention are potentially multiplied, making it more difficult for all to be aware of who is in control or who is doing what in the space. The group members may also become intimidated by an array of devices and controls, not wanting to be seen in public as not knowing how to control a device or display.

A key question, therefore, is how many entry points to provide and in what form? As with the design of any interface, it ultimately depends on the user group, the type of task and the context. If it is necessary to have someone in charge and for the task to be solved rapidly (e.g., a ‘command and control’ center for the police force) then having a more constrained technological set-up that has few access points is optimal. If, as in our case, the task is more open-ended and where it is desired for everyone to have a say (e.g., a meeting space for focus groups) then less constrained information spaces that invite all to take part are preferable. If there are particular group members who find it hard to talk (e.g., non-native speakers and children with learning difficulties) then entry points should be designed to be highly tangible and accessible, letting them participate more easily and flexibly in non-verbal ways.

There are many ways that multiple displays and devices can be designed and configured. There are also a number of specific dimensions they can vary along, including number, size, orientation, personal/public and physical/digital. Instead of attempting to match all of the various permutations to task types, user groups and contexts, we proposed a conceptual framework by which to initially consider the requirements of a work or other setting. The framework provides a way of thinking about how to constrain a shareable interface that invites people to collaborate. It is particularly useful for explaining how entry points are able to invite different kinds of participation.
The dimensions by which to configure a space can be operationalized at a practical level – in terms of the physical arrangement of the room, the display types and input devices used and the types of representations to use. Designing the physical arrangement of the room to explicitly show people on first entering it, where to sit or stand, can position them in relation to each other such that they have equal access to input devices and the displayed information. Conversely, providing seats at a table can have the effect of fixing who has access to certain entry points to the information, simply by their physical proximity to the displays and devices. When seats are not provided, people are freer to move and mingle in the space, enabling them to orient themselves to the various entry points in the physical and digital spaces at different times. A consequence is that there is less of a tendency towards claiming or carving off parts of the shared information space as one’s own. The use of physical walls and other surfaces (e.g., shelves, tables) can allow group members to stand beside each other while scanning, evaluating, choosing, showing and comparing items.

The availability of physical objects spread around a room was found to enable groups to systematically consider all of the options and discuss their merits – which simply did not happen when they were digitally stacked up as icon piles on a shared tabletop or a single user laptop. Moreover, the physical objects were found to invite holding up to command the attention of others and to seek approval of whether they should be added to the design. Participants also appropriated the physical devices to enable them to make a contribution to the ongoing task. Holding cards in their hands while at the tabletop or placing objects on the table enabled them to have their ideas ‘ready-at-hand’ for when an appropriate opportunity arose to contribute to the ongoing task by transforming them into digital representations and talking about them.

Finally, we consider the question of whether more is less or less is more. Are technology-rich rooms more effective at supporting equitable participation compared with simply providing a co-located group with a flip chart and a set of stickies? Or, is a combination of physical and digital representations optimal, as our study demonstrated? Instead of addressing this question by trying to work out how many and what kinds of displays, or what kinds of interaction methods to provide it may prove to be more useful, initially, to consider how groups engage with the task and each other when the set-up is constrained differently. To this end, the conceptual framework of shared information spaces operationalized in terms of entry points provide a useful design heuristic. Clearly, for certain types of collaborative tasks, such as those involving command and control systems, a constrained number of entry points may be required, that are not accessible to all, but which invite a clear division of labor and fixed roles. In addition, physical representations may not be the most effective way of accessing and creating multiple text-based documents. For this kind of activity, providing entry points (in the form of pop ups and other graphical tags) via interlinked displays may be more suitable. However, for design-oriented, planning, layout and selection-based tasks (similar to the one we conducted), and where creativity and democracy are valued, then having tangible and easily accessible entry points within information and physical spaces can be an effective way of facilitating collaboration.
NOTES

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FOOTNOTES

1. Arguably, a within-subjects design might have been better for comparing the conditions, but for practical reasons it was not possible to get all of the groups of three participants to return all together on two further occasions. Each session required an hour in total. Conversely, a between-subjects design allowed for a larger pool of participants.

2. This was the number of groups we could assemble within the study time frame.
FIGURE CAPTIONS

Figure 1. The Electronic Meeting Room set up as part of the Arizona Project (Nunamaker et al., 1991, p 42)

Figure 2. The laptop set-up

Figure 3. The tabletop set-up

Figure 4. The physical-digital set-up

Figure 5. (a) Bird’s eye view of the garden plan with icons of spring and summer plants in two corners and garden furniture and trees and shrubs in the other two corners, and (b) a pop-up detail for a scarlet lily flower, showing color photo, price and flowering details

Figure 6. Examples of a (a) physical card and (b) objects used in the physical-digital condition

Figure 7. Mean number of utterances produced by a participant in each interface condition

Figure 8. The mean number and SD of utterance types per minute for each condition

Figure 9. The Gini coefficients for (top) utterances and (bottom) physical participation

Figure 10. The trajectories of three groups over the duration of the task in the physical space (C3)

Figure 11. Means and standard deviations for least, medium and most speakers as a percentage of the total for each condition

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participants who spoke the most, medium and least in the physical-digital condition (C3)

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![C1 Group 1 Utterances](image)
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TABLE CAPTIONS

Table 1. The three shared information systems (SISs) that were compared in the study, characterized in terms of physical arrangement, display and input device, representational type and form of interactivity

Table 2. The inter-rater reliability scores using Kappa for utterance categories
Table 1. The three shared information systems (SISs) that were compared in the study, characterized in terms of physical arrangement, display and input device, representational type and form of interactivity

<table>
<thead>
<tr>
<th>Type of SIS</th>
<th>Physical arrangement of room</th>
<th>Display type and input device</th>
<th>Type of representations used and form of interactivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>The laptop</td>
<td>One laptop with mouse on a table with 3 chairs placed in front</td>
<td>One laptop with mouse</td>
<td>Graphical icons and mouse manipulation</td>
</tr>
<tr>
<td>Most constrained (C1)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The tabletop</td>
<td>Digital tabletop with 3 sides that group stand at</td>
<td>Shared tabletop that all can interact with simultaneously</td>
<td>Graphical icons and fingers manipulation</td>
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<tr>
<td>Medium constrained (C2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The physical-digital</td>
<td>Whole room with tagged objects located on walls and shelves in conjunction with digital tabletop and 3 sides that group stand at</td>
<td>Shared tabletop that all can interact with simultaneously plus RFID-enabled tagged physical objects</td>
<td>Graphical manipulation of icons with fingers and physical manipulation with hands of physical objects</td>
</tr>
<tr>
<td>Least constrained (C3)</td>
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Table 2. The inter-rater reliability scores using Kappa for utterance categories

<table>
<thead>
<tr>
<th>Utterance type</th>
<th>Kappa score</th>
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<tr>
<td>Suggestions</td>
<td>0.82</td>
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<td>Confirmations</td>
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<tr>
<td>Probing questions</td>
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<tr>
<td>Queries</td>
<td>0.79</td>
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<tr>
<td>Answers</td>
<td>0.70</td>
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<tr>
<td>Other</td>
<td>0.77</td>
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</tbody>
</table>