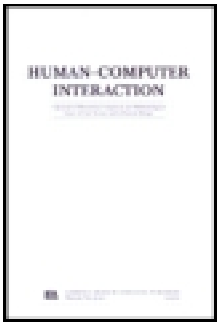

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Equal Opportunities: Do Shareable Interfaces Promote More Group Participation Than Single User Displays?

Yvonne Rogers [a] , Youn-kyung Lim [b] , William R. Hazlewood PhD [c] & Paul Marshall [a]

[a] Open University

[b] KAIST, South Korea

[c] Indiana University

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Yvonne Rogers,[1] **Youn-kyung Lim,**[2]
William R. Hazlewood,[3] and **Paul Marshall**[1]
[1] *Open University*
[2] *KAIST, South Korea*
[3] *Indiana University*

ABSTRACT

Computers designed for single use are often appropriated suboptimally when used by small colocated groups working together. Our research investigates whether shareable interfaces—that are designed for more than one user to inter-

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Yvonne Rogers is a cognitive scientist with interests in the human aspects of ubiquitous computing, the design of external representations, and the critique of theory in human–computer interaction; she is a Professor in the Department of Computing at The Open University. **Youn-kyung Lim** is a design researcher with interests in understanding the nature of design practice, bringing experience-centered approaches into design of novel technologies, and connecting theory and practice; she is an assistant professor in the Department of Industrial Design at KAIST, South Korea. **William Hazlewood** is a computer scientist with interests in the implementation, use, and evaluation of ambient information devices; he is a PhD student in the School of Informatics at Indiana University, Bloomington. **Paul Marshall** is a cognitive scientist with interests in the design and evaluation of novel technologies and representations for working and learning; he is a postdoctoral research fellow in the Department of Computing at The Open University.

CONTENTS

act with–can facilitate more equitable participation in colocated group settings compared with single user displays. We present a conceptual framework that characterizes Shared Information Spaces (SISs) in terms of how they constrain and invite participation using different entry points. An experiment was conducted that compared three different SISs: a physical-digital set-up (least constrained), a multitouch 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. Those who spoke the least contributed most to the physical design task. The findings are discussed in relation to the conceptual framework and, more generally, in terms of how to select, design, and combine different display technologies to support collaborative activities.

1. INTRODUCTION

Most of us have experienced a degree of frustration when trying to collaborate with others in a colocated setting while using a single-user PC. Although 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, and 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 & Henderson, 1995; Rogers & Lindley, 2004; Trimble, Wales, & Gossweiler, 2003). The effect can be suboptimal communication of ideas and activity progression. For example, it can be difficult for the person controlling the mouse to both express to the others what she is doing at the PC and act on 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, Halloran, & Rogers, 2002).

How might more equitable participation and less awkward ways of taking 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, Rogers, & Preece, 2007). The three core technologies developed for this purpose are large wall displays (e.g., SmartBoards), where users interact with gestures or pens; multitouch 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 designed for people who are physically colocated and where it is considered necessary for them to be copresent.

Shareable interfaces are assumed to be better for group work than single-user interfaces because they provide more opportunities for equal and flexible forms of collaboration (Sharp et al., 2007). In particular, multiple input devices to the same display and multitouch surfaces can support simultaneous interaction of digital content by all group members, whereas tangible objects are easy to select, pass around, spatially arrange, and manipulate by all group members (Fernaeus & 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, Rogers, & Hornecker, 2007). The aim of our research is to investigate how groups use different kinds of shareable interfaces when collaborating on a task. To begin, we describe a conceptual framework that we developed to operationalize a shared information space in terms of how it constrains participation through the design of entry points at the display interface. We then describe an experiment that compared how groups collaborated using three different Shared Information Spaces (SISs) that varied in how they were constrained. The least constrained condition was a physical–digital combination of tabletop and tangibles that provided multiple entry points at different interfaces; the medium constrained was a multitouch 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 colocated group meetings by augmenting them with computer technology was the Electronic Meeting System 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, Dennis, Valacich, Vogel, & George, 1991) that built special-purpose meeting rooms. 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 provided.

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 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 to the shared display. The comments were subsequently organized by a 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 farther from the facilitator, being required to sit in front of their 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 & Anson, 2001, p. 285)

Since the early research on electronic meeting systems, there has been a growing interest in how other kinds of less formal, but still technology-rich, meeting rooms can be designed to facilitate colocated 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., 1986), the iRoom (Johanson, Fox, & Winograd, 2002), i-Land (Streitz et al., 1999), and the Interactive Design Collaboratorium (Bødker & Buur, 2002).

Much of this line of research has focused on developing specific kinds of novel functionality for shared displays, such as gesturing techniques (Guimbretiere, Stone, & Winograd, 2001) and knowledge capturing tools (Ju, Ionescu, Neeley, & Winograd, 2004). Other researchers have exploited familiar interaction methods in shared settings, enabling users to transfer data between their personal devices (e.g., pen drives) and shared displays (Izadi, Brignull, Rodden, Rogers, & Underwood, 2003; Shen, Everitt, & Ryall, 2003). The extent to which the newer generation of technology-rich meeting rooms can facilitate collaboration, however, is unclear. Although an objective is to encourage all group members to join in, it may 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 although 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 & 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 & Rogers, 2003). Churchill, Nelson, Denoue, Murphy, & Helfman (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 multitouch tabletops, such as SenseTable (Patten, Ishii, Hines, & Pangaro, 2001), SmartSkin (Rekimoto, Ullmar, & Oba, 2002) and DiamondTouch (Dietz & 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 by 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 & 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 & Mynatt, 2003; Ryall, Forlines, Shen, & Morris, 2004; Scott, Grant & Mandryk, 2003; Shen, Lesh, Vernier, Forlines, & Frost, 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 group members to know what to do at the interface and how to take turns to progress with a collaborative task. 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 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, multitouch surfaces are considered tangible in the sense that they lure people standing around them to manipulate the digital objects represented on them (Rogers, Lim, & Hazlewood, 2006). Physical artifacts are also considered to be highly tangible. Group members may use them as external thinking props to explain a principle, an idea, or a plan to the others that is more effective than using equivalent digital representations (Brereton & McGarry, 2000; Fitzmaurice, Ishii, & Buxton, 1995; Fjeld et al., 2002; Hornecker & 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 & 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).

There has been limited exploration of how the physical positioning of interface and display technologies in space might influence performance and participation. Wigdor, Shen, Forlines, and Balakrishnan (2006) described some of the trade-offs between performance and comfort in environments with nontraditional arrangements of displays and control devices. They suggested the use of multiple control spaces as the number of users increases beyond two. Scupelli, Kieslet, and Fussell (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.

Hence, it appears that two salient properties of shareable interfaces that affect participation levels are locus of control and tangibility. However, to date there has been a lack of suitable experimental paradigms for comparing how shareable surfaces affect group working (Tan et al., 2008). 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 makeup 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 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.

3. THE CONCEPTUAL FRAMEWORK: SHARED INFORMATION SPACES

The conceptual framework of SISs is based on the notion of entry points that draws 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 Web site 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, the layout of newspapers and Web sites 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 flashing e-mail icon on a computer indicating new messages have arrived.

Entry points have also been operationalized as a generative design principle, describing features that on one hand lure people into them and on the other do not deter them from entering (Lidwell, Holden, & Butler, 2005). These include providing (a) minimum barriers, (b) points of prospect, and (c) 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 allows people to become oriented and survey available options in their surroundings before making a choice, and 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 operationalize entry points in terms of the layout of the physical room (e.g., use of tables, walls), the display interfaces, the input devices, and the type of physical or digital information to be interacted with. The physical layout of a room can fix the position of people throughout the duration of a task by providing seating. Alternatively, not having chairs can encourage people to move around a space, thereby allowing them potentially access to more entry points. The size, position, and direction of the displays and the kind, number, and placement of input devices can be configured to reduce barriers and to create lures. A multitouch tabletop display invites different forms of collaborative interactions compared with a single-user display. The type of representations used and form of interactivity offer different entry points that can guide participants more or less to know what to do next and which part of the display "belongs" to whom.

4. EXPERIMENTAL DESIGN

4.1. The Design Task

A collaborative design task was devised that required idea generation, weighing up of criteria, suggesting plans and revising ideas. Groups 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 because 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 items 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, birdbath). Each item was individually priced, ranging from $10 to $500. A budget of $3,500 was set for the task so that the participants had a realistic constraint to guide them in making their design decisions.

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

4.2. The Conditions

The framework was used to design three SISs that varied in how they invited and constrained participation (see Figure 1). The least constrained SIS comprised a physical–digital technological set-up using the whole room. A table with an interactive surface was placed in the middle of the room to provide a central hub for participants to position themselves in relation to one another. Chairs were not provided at the table to encourage the participants to move around the space and have access to all the entry points. There are no physical barriers as all participants can touch the tabletop display simultaneously with their fingertips and interact with the digital information from different sides of the table. It also provides good points of prospect where all participants can see, select, and move the object icons from the different sides of the display. Physical tagged objects representing available options for completing the task were placed on the walls and shelving around the room. They are designed to invite participants to know what to do and to make a contribution; showing them where and what they can browse, select, and interact with. Participants have to move around the physical space—simultaneously or sequentially—to select the physical options that they can then add and ma-

Figure 1. **The three SISs that were compared in the study, characterized in terms of physical arrangement, display, and input device, representational type and form of interactivity.**

Type of SIS	Physical Arrangement of Room	Display Type and Input Device	Type of Representations Used and Form of Interactivity
The laptop Most constrained (C1)	One laptop with mouse on a table with 3 chairs placed in front	One laptop with mouse	Graphical icons and mouse manipulation
The tabletop Medium constrained (C2)	Digital tabletop with 3 sides that group stand at	Shared tabletop that all can interact with simultaneously	Graphical icons and finger manipulation
The physical-digital Least constrained (C3)	Whole room with tagged objects located on walls and shelves in conjunction with digital tabletop and 3 sides that group stand at	Shared tabletop that all can interact with simultaneously plus RFID- enabled tagged physical objects	Graphical manipulation of icons with fingers and physical manipulation with hands of physical objects

Note. SIS = shared information systems.

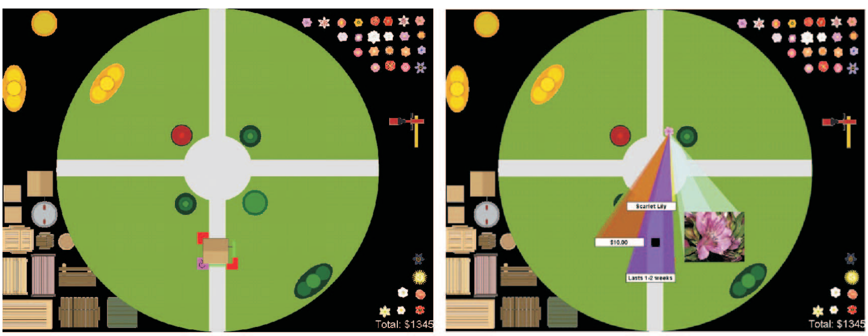
nipulate on the digital interactive surface. The medium-constrained condition used the same table plus interactive surface but provided only digital representations of the options as icons positioned at the edges of the display—that are less tangible and accessible entry points. The most constrained (the laptop condition) had the least entry points: fixed seating, a laptop display, and single mouse for input. Having only one input device available creates a barrier restricting access to the display to only one person at a time. This was chosen to be the control condition.

It was hypothesized that the least constrained SIS (the physical–digital set-up) would encourage the most equitable participation because it offers the most accessible and tangible entry points and the most constrained SIS (the laptop condition) would result in the most inequitable participation through having the least accessible and tangible entry points.

Figure 2 shows a photo of the laptop condition. A wired mouse was positioned centrally in front of the laptop enabling all three seated participants to interact with the garden plan using default graphical user interface operations, that is, dragging and clicking. The display size was a standard 15″ with 1024 × 768 resolution. Piles of icons representing the available options were provided in the four corners outside of the display interface (see Figure 3a). To

Figure 2. **The laptop set-up. (Figure available in color online.)**

Figure 3. **(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 available in color online.)**



(a) (b)

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 such as *perennial*, *likes shade*) and a photographic image could also be obtained by double clicking and appeared as a pop-up image (see Figure 3b). To avoid cluttering the display the pop-ups could be made to disappear 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 multitouch tabletop display (see Figure 4). The standard sized MERL DiamondTouch tabletop was used. The display size that was usable measured 65 × 50 cm 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 is shown in Figure 5. Equivalent information to the other two conditions was provided but with the options being represented as a set of RFID tagged physical artifacts, placed on three walls and two sets of shelves. The distance between the tabletop and each wall was slightly less than 1 m, requiring a couple of paces to reach from each side of the table. The table measured 152 × 86 cm. 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).

Figure 4. **The tabletop set-up. (Figure available in color online.)**

Figure 5. **The physical–digital set-up. (Figure available in color online.)**

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 3D 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.

4.3. Participants

A between-subjects design[1] was used where six groups of 3 participants took part in each of the three conditions (54 participants in total).[2] The groups

[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 3 participants to return all together on two further occasions. Each session required a total of 1 hr. 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 6. **Examples of a (a) physical card and (b) objects used in the physical–digital condition. (Figure available in color online.)**

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 condition there was two all-male groups, two 2-male/1-female groups, and two 1-male/2-female groups. The ages of the participants varied between 22 and 60. All were experienced with using PCs, although none had used a multitouch 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 participants having a lot, a moderate amount, 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 display 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 physical–digital and tabletop 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 min to complete the task, allowing sufficient time for patterns to emerge and change over time (cf. Arrow, McGrath, & Berdahl, 2000; McGrath & Hollingshead, 1993). Following the completion of the task, a 10- to 15-min open-ended group interview was conducted with the participants to discuss their experiences. The following day each participant was sent a short online questionnaire to reflect upon, individually, their experiences of working as a group.

The sessions were videotaped 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.

5. FINDINGS

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

5.1. Quantitative Analyses

In the quantitative analyses described next, 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 analysis of variance (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, $F(2, 45) = 4.72$, $p < .05$, $\omega = 0.37$. 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 normalized over time.

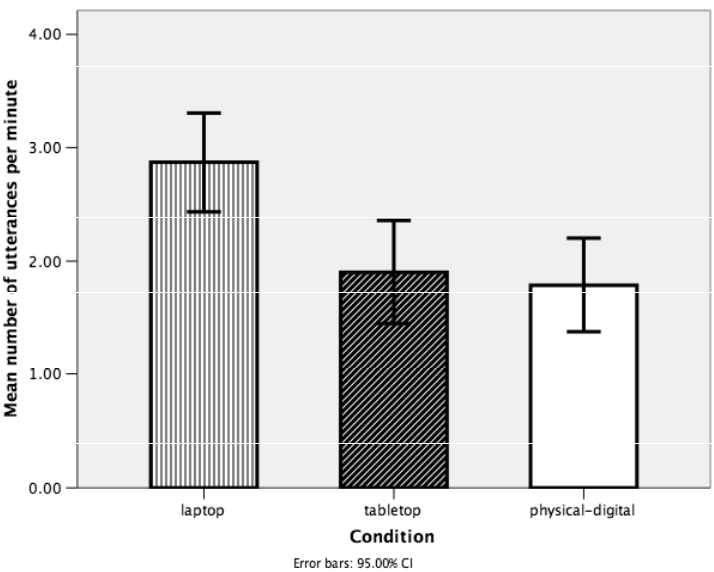
To investigate the types of collaborative discourse produced by participants using the different interface configurations we carried out an analysis of (a) the quantity and type of discourse produced while carrying out the task and (b) the inequality of participation for both verbal contributions and interface activity.

The Quantity and Type of Discourse Produced While Carrying Out the Task

The total number of utterances made by each participant was 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 suggesting that participants in the laptop condition tended to produce dialogue at a faster rate than those in the tabletop and physical–digital conditions.

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,

Figure 7. **Mean number of utterances produced by participants in each interface condition. *Note.* CI = confidence interval.**



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 ($M = 1.89$, $SE = 0.28$), $t(45) = -2.06$, $p < .05$ (two-tailed), $r = .29$; or the physical–digital condition ($M = 1.79$, $SE = 0.27$), $t(45) = -2.27$, $p < .05$ (two-tailed), $r = .32$. No difference was found between the rate of dialogue production for participants in the tabletop and physical–digital conditions, $t(45) = -0.20$, $p > .10$, $r = .03$.

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 the kinds of utterances that took place as part of the design task. 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, for example, "Let's have a private area for people who want to be alone." An utterance that supported a suggestion was classified as a confirmation, for example, "Sure, why not." A probing question was distinguished from a suggestion if it was an explicit request for a suggestion from the others, for example, "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, for example, "What was the name of that red flower?" Answers were defined as replies to queries, for example, "It's called a Scots pine." The category of "other" was used to describe miscellaneous utterances, for example, comments about the weather.

The classification of utterances was initially derived through iterative classification of a sample of the transcripts by all members of the project team. 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 interrater reliability. Figure 8 lists Cohen's κ scores calculated for each utterance category. These are in the range described by Fleiss (1981) as good ($\kappa > 0.60$) or excellent ($\kappa > 0.75$).

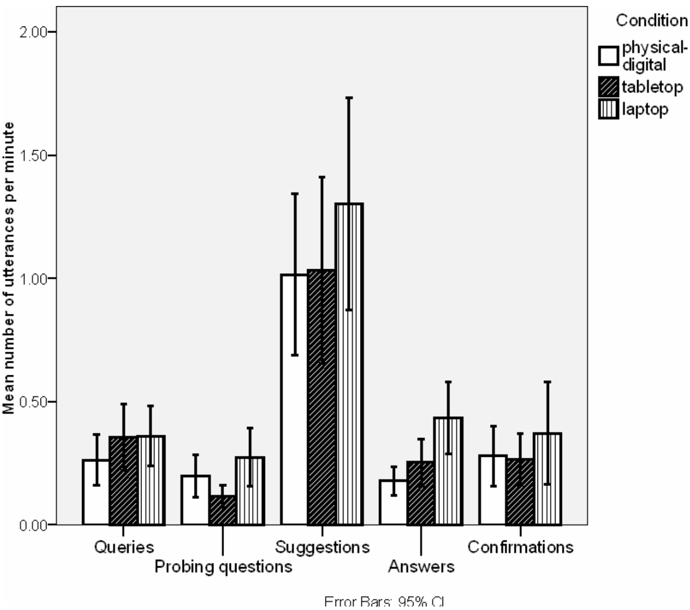
Normalized values were calculated for each of the utterance categories for each participant by dividing the number of utterances by the time spent carrying out the task. These are shown per condition in Figure 9 revealing the most common utterance for all three conditions was a suggestion.

A multivariate analysis of variance 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 in-

Figure 8. **The interrater reliability scores using kappa for utterance categories.**

Utterance Type	Kappa Score
Suggestions	0.82
Confirmations	0.72
Probing questions	0.78
Queries	0.79
Answers	0.70
Other	0.77

Figure 9. **The mean number of utterance types per minute for each condition.**



terface condition on the number of answers produced by participants per unit time, $F(2, 45) = 6.55$, $p < .01$, $\omega = 0.43$. 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, $F(2, 26.8) = 4.37$, $p < .05$, $\omega = 0.29$. 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 the occurrence of more probing questions and answers than in the other conditions. In some ways this is to be expected, as 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 next section.

The 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, whereas 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 conditions 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 the top graph in Figure 10, the lower Gini coefficient for the physical–digital condition indicates the most equitable participation in terms of verbal contributions. This difference was found not to be statistically significant, $F(2, 13) = 1.02$, $p > .10$, $\omega = 0.33$. 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.

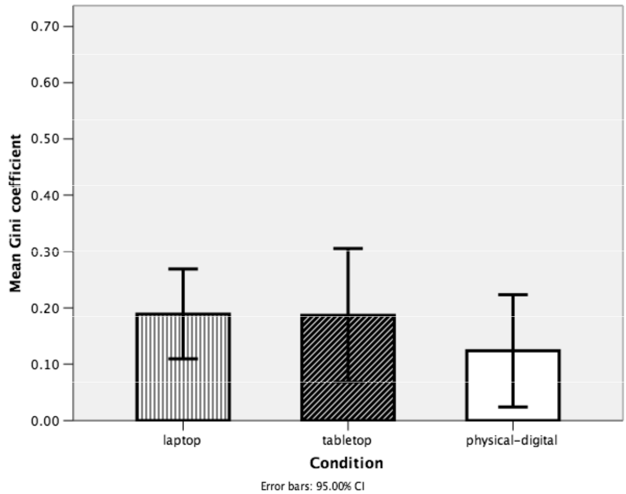
Physical Participation. In contrast to the verbal utterances, the bottom graph in Figure 10 shows the Gini coefficients calculated for groups in the laptop condition ($M = 0.48$, $SE = 0.09$) to be considerably larger than those in the tabletop condition ($M = 0.15$, $SE = 0.06$) or the physical–digital condition ($M = 0.21$, $SE = 0.03$).

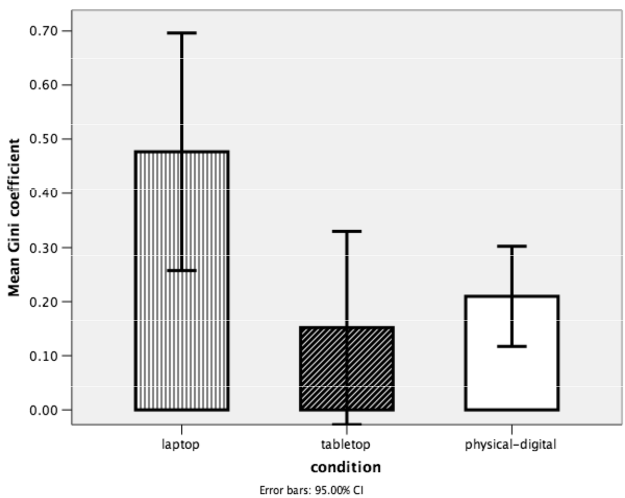
The assumption of homogeneity of variance was violated for the physical participation Gini coefficients and therefore the Welch F-ratio is reported. There was a significant effect of interface condition on the inequality of physical participation, $F(2, 7.72) = 4.69$, $p < .05$, $\omega = 0.65$. Planned contrasts indicated that inequality was greater in the laptop condition ($M = 0.48$, $SE = 0.09$) than in either the physical–digital condition ($M = 0.21$, $SE = 0.03$), $t(6.46) = -2.91$, $p < .05$, $r = .75$, or the tabletop condition ($M = 0.15$, $SE = 0.06$), $t(8.75) = -3.04$, $p < .05$, $r = .72$. There was no difference detected in the inequality of physical participation between the tabletop and physical–digital groups, $t(6.02) = 0.81$, $p > .10$, $r = .31$. 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 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 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 condition might support more equitable participation among groups in terms of verbal utterances. Although 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

Figure 10. **The Gini coefficients for (top) utterances and (bottom) physical participation.** ***Note.*** **CI = confidence interval.**





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. In contrast, the tabletop, having a less dispersed set of entry points, may not invite the creation of particular roles.

Further qualitative analyses were carried out to examine the patterns of collaboration that evolved over time in relation to the ways the entry points were used by the participants to make a contribution. Compared with the quantitative analyses, they are able to reveal the intricate patterns of interactions and conversation and how these can affect participation levels.

5.2. Qualitative Analyses

Qualitative analyses of the video data and questionnaire responses examined (a) the collaboration and coordination strategies that emerged, (b) the patterns of contribution made by each participant relative to the others in their group, (c) the types of verbal and nonverbal communication, and (d) the participants' views of how they worked together.

The Collaboration and Coordination Strategies That Emerged

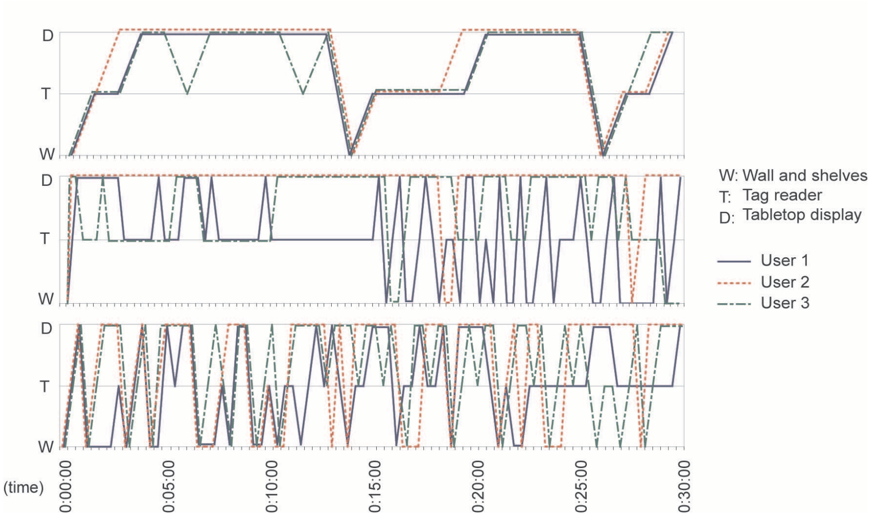
The way the groups initiated and managed their participation was found to vary across conditions. In the physical–digital condition, the invitation to look at the available options was found to be very compelling, drawing the groups initially to view all the physical objects on the walls and shelves 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. They then opened up the pop-ups for some 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, whereas 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 11 shows

Figure 11. **The trajectories of three groups over the duration of the task in the physical space (C3). (Figure available in color online.)**



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 whereas 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 tended to have more interactions at the tabletop. However, when the group was standing at the tabletop, all the participants 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, often earmarking a quadrant of the garden design as theirs to fill in but working together to decide how to design the whole garden. This suggests the space in front of each participant becomes their personal responsibility whereas other parts of the tabletop remain shared (cf. Scott, Carpendale, & Inkpen, 2004).

There was some evidence of "turn-inviting" (Rogers, Hazlewood, Blevis, & Lim., 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 it 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 invites P3 to add a bench to the garden layout and encourages her to say where it should be placed in the garden plan:

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 how the physical–digital condition makes it easier for participants to invite others to take part in contributing to the design task. In contrast, when the entry points are constrained to allow only one person to be in control, it makes it 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, an offer by the mouse holder appeared to be less of an invite and more of a way of explicitly handing over control to another, as indicated by the following two utterances during one session:

P1: "Here, you have a go, you're better."
and
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 of this observed 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 appear to be butting in.

The low Gini coefficent 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 with the other conditions in terms of what each said relative to the others.

The Patterns of Contribution Made by Each Participant Relative to the Others in Their 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 12 shows the means and standard deviations 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—approximately 20%, 35%, and 45% for the least, medium, and most speaker, respectively.

On closer examination of each participant's verbal contribution, 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 2-min intervals is presented in Figure 13. 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 14). 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 15). The greatest speaker (U2), who was also the mouse holder, continued to dominate the conversation for the whole 30 min for two thirds of the groups.

Figure 12. **Mean quantity of dialogue for least, medium, and most speakers as a percentage of the total for each condition.** ***Note.*** **CI = confidence interval.**

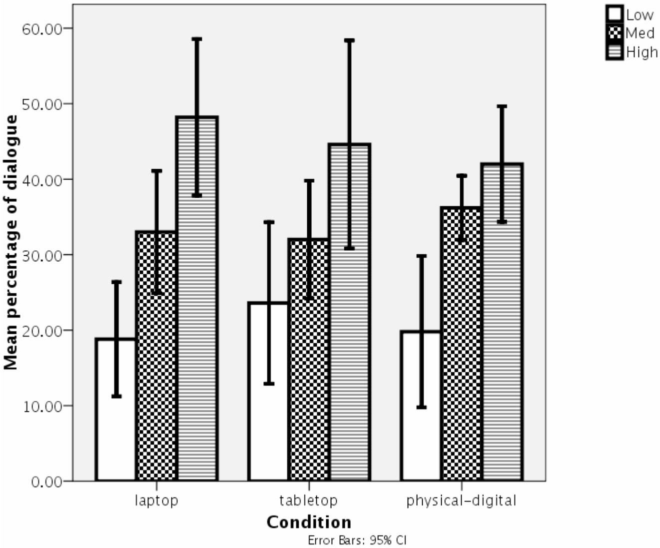
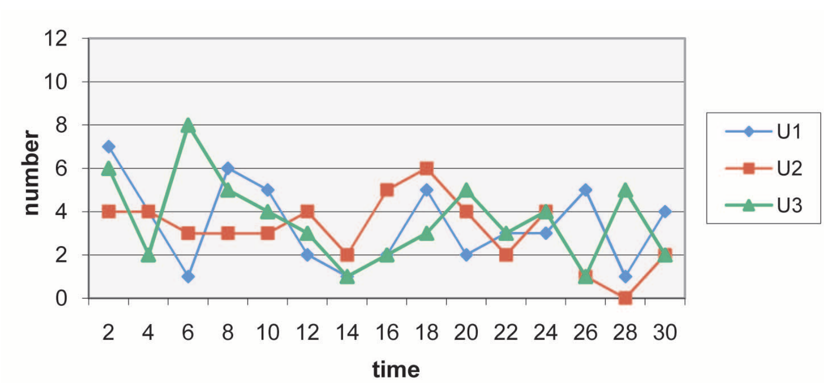


Figure 13. **The number of utterances for most (U1), medium, and least speakers at the beginning of the task, then sampled at 2-min intervals for Group 5 in the physical–digital condition. (Figure available in color online.)**



We also 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

Figure 14. **The number of utterances for the most (U2), medium, and least speakers at the beginning of the task, then sampled at 2-min intervals for Group 1 in the tabletop condition. (Figure available in color online.)**

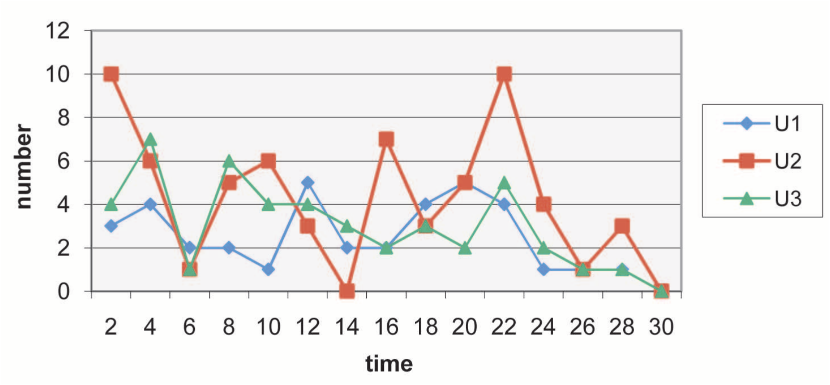
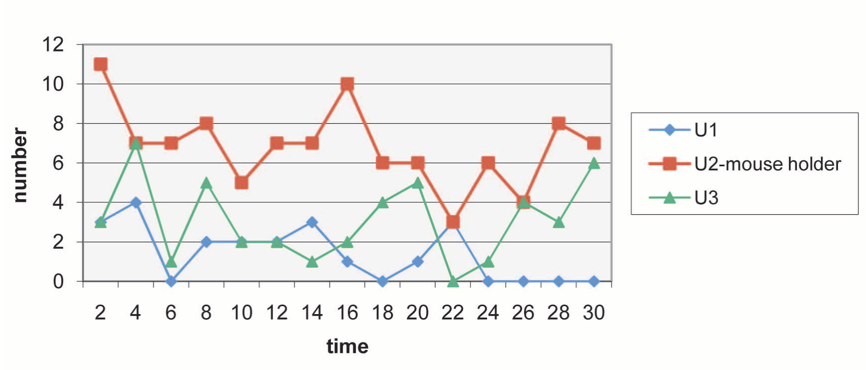


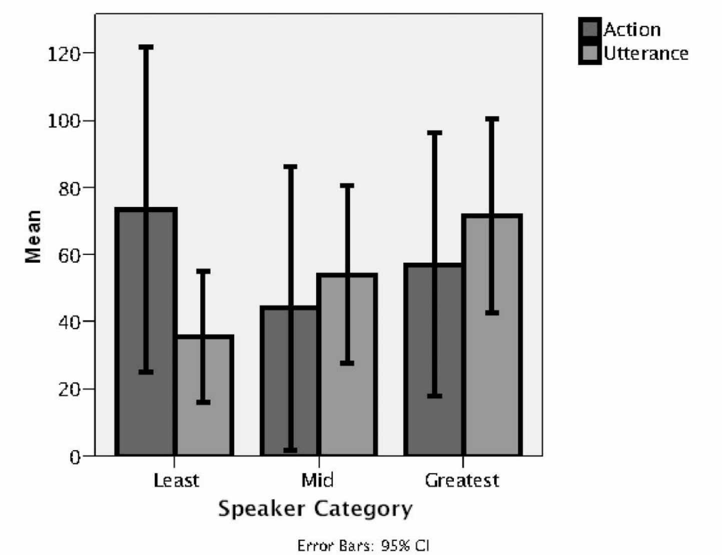
Figure 15. **The number of utterances for most, medium, and least speakers at the beginning of the task, then sampled at 2-min intervals for the Group 1 in the laptop condition. (Figure available in color online.)**



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 16). A different pattern emerged for the tabletop groups, where the participants who spoke

Figure 16. **The relative levels of fingertip moves at the tabletop and physical artifacts interactions (e.g., picking up a card, placing it on the tabletop) to utterances for the participants who spoke the most, medium, and least in the physical–digital condition (C3).** ***Note.*** **CI = confidence interval.**



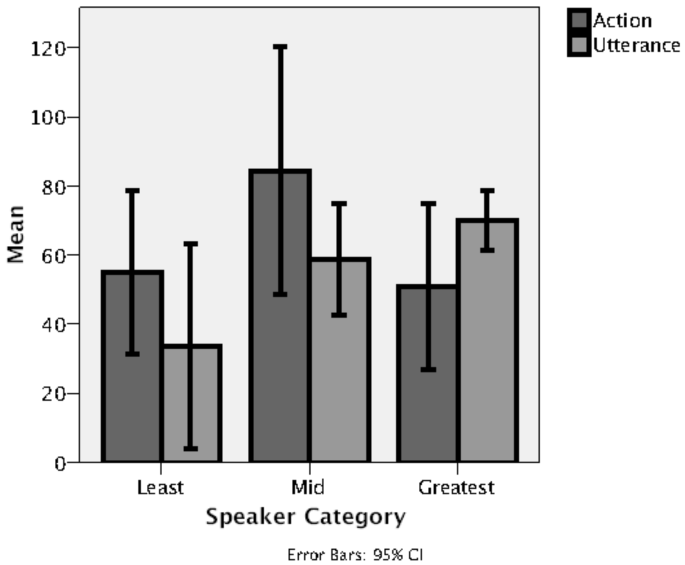
the *most* were those who contributed the *least* fingertip moves (see Figure 17). In the laptop condition, participants who spoke the *most* were the ones who used the mouse for the *longest* time, and the participants who spoke the least were the ones who used the mouse for the shortest amount of time (see Figure 18).

These findings suggests 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.

The Types of Verbal and Nonverbal 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 partici-

Figure 17. **The relative levels of fingertip moves to utterances at the tabletop for the participants who spoke the most, medium, and least in the tabletop condition (C2).** ***Note.*** **CI = confidence interval.**



pant's plans were executed and the verbal and nonverbal strategies employed to change the designs.

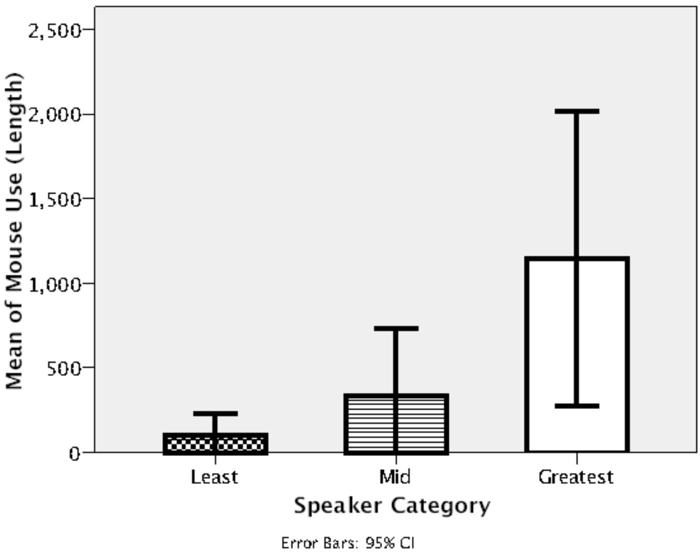
In the laptop condition, the conversations typically involved the mouse user vocalizing to the others what she was planning to do or was doing, with the other two agreeing, directing, querying, or suggesting what the mouse holder should do. The greater number of probing questions found in the laptop condition compared with the other two can be explained by the mouse holder (P1) asking more times what the other two in their group wanted or not because the others were unable to physically add anything to the garden design. For example,

P1: "do you want to have a tree behind each bench…is that your idea?"
and
P1: "you dont 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. For example,

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

Figure 18. **The relative levels of mouse movements to utterances for the participants who spoke the most, medium, and least in the laptop condition (C1).** ***Note.*** **CI = confidence interval.**



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. For example,

P2: "are you going for the symmetrical look?"
and
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 each other 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." <reading it> "Early summer. Likes sunshine."
P3; "Yes"
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 observation was how difficult it was for the non–mouse holders in the laptop condition to get a desired result when wanting to change the design, sometimes causing them to raise their voices. For example (the non–mouse holders are P2 and P3),

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?"

Such frustration did not surface in the physical–digital condition. In contrast, when a participant asked the others for permission to change an aspect of the design it often resulted in one of the others helping to make the change. Moreover, they jointly decide how to make the change, using an intricate combination of talk, physical interaction, and gesturing. 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 with forsythia on it to show her which one and then starts moving its digital icon on the tabletop
P2 at the same time gestures to where it should go and P3 moves it there.

Hence, the way requests are made to make changes to the design at the tabletop display is more subtle and socially comfortable, and that can result in coordinated joint actions.

The Participants' Views of How They Worked Together

The questionnaire results showed the participants' views on how they worked together in the physical–digital (C3) and tabletop (C2) conditions to be more favorable than for the laptop condition (C1). It was commented on how the tabletop interface enabled them to see each other's perspectives whereas the cards allowed for 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, C2)
>
> It was easy to use the cards. There are your options. You just know that that is all there is. (P2, C3)

In the tabletop condition comments were also made about how the interface enabled them to work together differently as a group:

> 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, C2)

The accessibility of the tabletop was also commented on in terms of how it let them explore options easily. For example,

> 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, C2)

In the laptop condition, comments were made about the frustrations of having to channel one's ideas through another person. For example,

> 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 easer to be like, 'oh how about this, what do you think?' and then you could say "no no no, how about this." (P3, C1)

They also made suggestions on how a different interface might have made contributing easier. For example,

> 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, C1)

The participants' views of how they worked together and their understanding of how the interfaces enabled them to carry out the design task collaboratively provide further evidence of the important roles that tangibility and accessibility play in affecting group participation.

6. DISCUSSION AND CONCLUSIONS

Our study has shown how shared information spaces that vary in the way they invite participation affects how colocated groups collaborate. A main finding was that the physical–digital condition, that is, the one designed with 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 interaction with the digital information. Unexpectedly, the control condition (i.e., the laptop) produced the most utterances, although this was explained by the mouse holder needing to vocalize what she was doing or planning to do to the others.

The various quantitative analyses performed on the data revealed the effects to be not as marked as hypothesized. One of the problems of using statistical analyses for small numbers of groups is that strong effects are unlikely to be found because of 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 can demonstrate more effectively group differences in terms of patterns of collaboration and interaction and coordination mechanisms adopted. For example, our analysis of the video data was able to demonstrate how collaboration, as indicated by the type and amount of turn taking, turn inviting, and coordinated joint actions, varied across conditions.

The finding that 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—shows how group participation levels can be changed through providing different configurations of entry points. In particular, it 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 underparticipators 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, Di Micco, Caneel, & Ariely, 2004). The more vocal participants also used the tangible entry points to invite the underparticipators to take turns in the physical design task. More generally, it suggests that having more tangible and accessible interfaces may be able to encourage greater 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 nonnative speaker).

Our qualitative findings also revealed highly coordinated forms of collaboration emerge where all group participants were involved, for the setting that provided multiple entry points dispersed throughout the room. An example was when groups added an option to the garden layout design; one participant selected a physical object from the wall and passed it onto another, who then added it to the table, and the third participant in the group collected the digital icon as it appeared on the tabletop and moved it to a place on the plan. To enable this form of collaboration to happen requires the group having a high level of awareness of each other's intentions. In other kinds of tasks, such as collaborative learning, however, having a large number of entry points dispersed throughout a shared information space might result in the group members working more individually, resulting in less awareness of what the others are doing in the group. The foci of attention are potentially multiplied, making it more difficult for all to be aware of who is in control or what each is doing in the space. To resolve such uncertainty, a division of labor may ensure where individuals claim parts of the space or carve off parts of a shared display as their own.

A central question, therefore, is how many entry points to provide and in what form? As is the case when designing any interface, it depends on the user group, the type of task, and the context. If it is necessary to have someone lead and for the task to be solved rapidly (e.g., a "command and control" center for the police force), then a constrained number of entry points may be optimal that are not accessible to all but that invite a clear division of labor and fixed roles. 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 participants who find it hard to talk (e.g., nonnative speakers and children with learning difficulties), then entry points designed to be highly tangible and accessible may encourage them to participate more in nonverbal ways.

Another benefit of having physical objects spread out around a room is to enable groups to systematically consider all of the options and discuss their merits—which does not happen when they are represented as digital icons in an array on a tabletop or laptop display. In our study, the physical objects were held up in the air to command the attention of others and to seek approval of whether they should be added to the design. Participants also appropriated the physical objects to increase their opportunities of being able to make a contribution to the ongoing task. By holding cards in their hands while at the tabletop or placing objects on the table close to the layout plan, they were able to place their ideas "ready-at-hand" for when an appropriate moment arose to contribute to the task.

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, our conceptual framework of shared information spaces is intended to provide a design heuristic by which to initially consider the requirements of a work or other setting. It does this in terms of suggesting how to constrain the technology and the physical space to invite people to collaborate in certain ways and to consider their possible consequences on participation.

NOTES

Background. This article is based on a user study conducted while the first three authors were working on the Co-Space project in the School of Informatics at Indiana University.

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Authors' Present Addresses. Yvonne Rogers, Computing Department, Open University, Milton Keynes, MK7 6AA, United Kingdom. E-mail: y.rogers@open.ac.uk. Youn-kyung Lim, Department of Industrial Design, KAIST, Daejeon, South Korea. E-mail: younlim@gmail.com. William R. Hazlewood, 901 East 10th Street, Bloomington, IN 47408. E-mail: whazlewo@indiana.edu. Paul Marshall, Computing Department, Open University, Milton Keynes, MK7 6AA, United Kingdom. E-mail: pmarshall@open.ac.uk.

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