Surface Affordances in Meeting Room Collaboration

Abstract. Surface affordances are characteristics of surfaces that support collaboration. We present three surface affordances (*information management*, *information visibility*, and *information-surface coupling*) derived from an analysis of engineering teams' use of meeting room surfaces such as whiteboards and tabletops. Our analysis articulates collaborative activities that employ these surfaces, and uncovers the roles that surfaces play in support of these activities. The framework we present in this paper allows us to rethink our approach toward the design of large display groupware, and we argue that rather than supporting "tasks", designers should focus on supporting *surface affordances*.

Introduction

Surfaces such as flipcharts, whiteboards, and tables are often used in meeting rooms to support the exchange, generation, and organization of ideas and information. Increasingly, we are beginning to use digital displays to augment, and sometimes replace traditional surfaces in these environments. While a large body of CSCW work in recent years has focused on technical and usability issues regarding the use of these large displays (for reviews, see Czerwinski et al., 2006 and O'Hara et al., 2003), the problem is that we have yet to develop a thorough understanding of how to design useful large display applications. Many existing systems designed to support meeting room activities (Nunamaker et al., 1991; Pederson et al., 1993) have encountered adoption problems (Huang et al., 2006a). In many cases, these systems disrupted existing social and work practice (Tatar et al., 1991). Thus, while there are many reasons why groupware systems have not been adopted (Grudin, 1994), a significant problem is that we, as large display groupware designers, have focused on developing sophisticated ways of interacting with *data* rather than on tools to facilitate *interaction between collaborators* (Streitz et al., 2001).

Many researchers have studied collaborative use of traditional surfaces rather than digital surfaces to understand the work practices that support collaborative activity. This body of work provides insight into how people's behaviours around surfaces help coordinate interaction and manage collaboration without explicit cues otherwise provided by digital technologies. For example, Tang (1991) studied design teams' use of tabletops, revealing the importance of not only the workspace annotations, but also in how the workspace itself mediates collaborative activity. Similarly, Teasley et al. (2000) studied and articulated how collocated teams take advantage of the shared environment to work together in ways that distributed teams cannot. This type of approach provides a direction for the design of collaborative tools grounded in existing work practice.

Our work draws from this analytic approach, and we develop our design philosophy for large display groupware by first understanding how teams use large surfaces in everyday collaboration. We articulate this understanding by deriving a set of *affordances* that traditional surfaces provide to support collaboration. We arrive at these affordances by studying the collaborative *activities* that use surfaces, and then by understanding what *roles* these surfaces play in those activities. To focus our analysis, we studied the collocated work practices of medium-sized teams (3-6 people) involving large surfaces (e.g. whiteboards, tables, etc.) in meeting rooms accomplishing real world tasks. Our analysis validates earlier findings and extends them in three important ways:

(1) We delineate four types of collaborative activities that involve surfaces;
(2) We identify five roles surfaces play in these collaborative activities, and
(3) We derive a set of affordances that surfaces provide to support these roles.

Taken together, this framework links the findings of other researchers studying large display technologies. It introduces a language that supports the design of large display groupware by providing a consistent, coherent understanding of collaborative phenomena involving large surfaces.

In the next section, we describe the teams that we observed as the basis for our work, our analysis approach, our methodological commitments and perspective. Subsequent sections summarize our analysis, and we illustrate these interpretations using real examples drawn from the observations. We then discuss how our framework extends existing findings regarding large displays and collocated collaboration, and then conclude by discussing how practitioners should use the findings of this work.

The Study

We used *in situ* observation techniques combined with contextual interviews and video analysis understand the activities that teams engaged in. At the outset, we had three points of interest: how do activities involving display and work surfaces relate to the larger team project, what role do the surfaces play in these activities, and what is the nature of the interactions taking place with these surfaces?

Participants. We recruited three pre-existing teams of six undergraduate engineers (5 female, 13 males). These students were enrolled in a year-long team-based learning program where they completed four team projects, each taking five weeks. Our study focused on their third project, where teams were building magnetically propelled trains, so teams had well-established team dynamics, and individuals already knew each other well.

Environments. Teams worked in two dedicated workspaces assigned by course instructors: a meeting room (containing two whiteboards, a large table, two computers, and a filing cabinet) and a laboratory workbench (with two computers and electrical equipment). In a given week, each team was allotted two days in a meeting room, and two days in the laboratory space. Teams generally spent at least four hours per day working in the assigned space, and many students reported working independently at home or in other locations after hours.

Method. We took an ethnographically-inspired approach (Holtzblatt & Jones, 1995), observing each team for at least four of their work sessions in context (each session lasting three to four hours), taking field notes and photos of the workspace, paying close attention to the use of large surfaces such as whiteboards, tables, desks, and places where information was posted, such as doors, walls, and even the sides of filing cabinets. We augmented our field notes with opportunistic unstructured interviews with participants for clarification of the team's activities. Finally, we video taped 60 hours of this workspace activity (across the three teams) for later analysis.

Focal points. We focused our observations and analysis in three main areas:

(1) *Activity structure.* How are independent and group activities structured? What signals shifts between activities? How do interactions with the surface play a role in these activities?

(2) *Spatial and temporal content organization.* How is information organized on the surfaces? How does this organization impact the flow or partitioning of activity?

(3) *Participation structures in surface interaction.* What roles do people play in these activities? How are these roles reflected in their interactions with the surfaces?

For example, when teams were brainstorming or working out a design on the whiteboard, we would note several things: how the team members were positioned around the whiteboard (Focal Points 1, 3), what they looked and gestured at (1, 3), what was being written on the whiteboard (2) and in what order (1, 2), who would actually write on the whiteboard (3), how digressions were handled (1), and so forth. Our goal was to understand the flow of activity, how this was reflected on the surfaces, and finally how that flow was manifest in teams' interactions with the surfaces.

Analysis. We analyzed our field notes using an open coding technique (Strauss & Corbin, 1990) to group together similar classes of activities and uses of the surfaces. We then reviewed our video data in multiple passes using these codes to iteratively distill the categories of interactions and to note particularly interesting or unusual events. Finally, we reviewed our original field notes with the codes to further refine our ideas.

Perspective. Since our interest is in designing meeting room groupware, the focus of our inquiry is slightly different than prior work, where the interest was primarily in understanding the affordances of collocation for the purpose of designing distributed groupware (e.g. Robertson, 1997; Covi et al., 1998; Teasley et al., 2000). Our account assumes the benefits of collocation, and seeks to elucidate the specific purposes that surfaces play in this type of collaboration (as in Wang & Blevis, 2004).

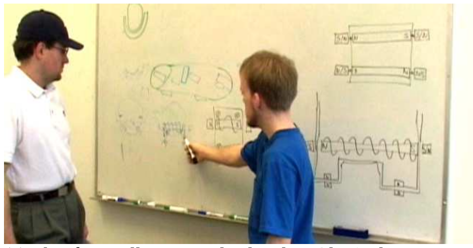
We use the remainder of this paper to discuss our findings, where we present real examples drawn from our observations to illustrate our findings, rather than low-level analysis details. The next three sections outline four specific collaborative activities that teams carry out over surfaces, the five roles that surfaces play in supporting these activities, and then the affordances provided by surfaces that support these roles. We then discuss how designers and practitioners should interpret and use these findings.

Collaborative Activities involving Surfaces

Collaborative activity has been conceptualized in many ways (e.g. McGrath, 1984; Bertelson & Bødker, 2003). Here, we focus on classifying activity based on how large surfaces are used, using classifiers such as how information is organized spatially, how information is used temporally, and how it is operated on. This specific focus on surface use differentiates our classification scheme from prior taxonomies of collaborative activity (e.g. McGarth, 1984). Our analysis distilled four major categories of *activities that used surfaces*:

(1) ***Ideation*** activities involve the generation and development of ideas.
(2) ***Explication*** activities use the surface to explain ideas.
(3) ***Comparison*** activities involve looking at several ideas at once.
(4) ***Execution*** activities use the surface to construct or build an entity.

Our use of the term "activity" is not equivalent to a *project-level task*; instead, an activity classifier describes how a surface was used. For example, in one instance occurring over 10 minutes (Figure 3), a pair of students were soldering a



(a) This frame illustrates idea locales: Alex's design is on the left, Bob's design on the right. Excerpt 1 (below) provides detail on the dialogue of this conversation.

(b) Two teammates work out a design on paper. The near laptop (keyboard visible) has a reference specification loaded.

Figure 1. Examples of ideation activity on a whiteboard (a) and a table (b).

Bob: Oh… I see what you're doing, so the rollers are actually [GESTURE-SURFACE] … The rollers are actually mounted like [MODIFY-SURFACE] mounted on the train like that.
Alex: Right.
Bob: Oh I see—to keep the clearances extremely tiny.
Alex: Except that the rollers look like… I was thinking like [MODIFY-SURFACE] if the magnets are mounted like this [GESTURE- SURFACE], and our locomotion is going to be provided by magnets that are um [MODIFY-SURFACE] [ERASE-SURFACE]… let's say inside the train like this [MODIFY-SURFACE] and outside on the sides [MODIFY-SURFACE] and ideally—and this is something I'm pushing for a little bit—it doesn't have to be vertical, but let's just say vertical [GESTURE-SURFACE] for now, a vertical piece.

Excerpt 1. This coded dialogue from Figure 1a illustrates the draw-alouds common to ideation, and shows how dynamic the surface content was.

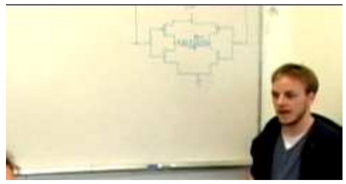
circuit on a table (*execution*). After a series of soldering steps, the pair retrieved a schematic, a reference circuit, and an online manual, and placed these materials side-by-side to understand the next soldering steps (*comparison*). We coded these two activities independently because *how* the surface was being used differed, even though the students were engaged in the same overall project-level task.

This classification scheme therefore tracks the fundamental activities that engage a surface, be it a whiteboard, a table or even the side of a filing cabinet. We describe each of these activities in detail.

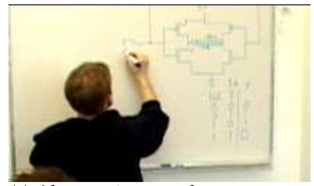
Ideation. A frequent category of activity involving surfaces such as whiteboards or paper on a table was *ideation*. Here, teams make use of the surface as a dynamic work surface, both to record generated ideas (e.g. in a brainstorm), or as a working memory store to work through ideas (e.g. when detail is generated around an idea). We see ideation occurring both independently and in groups. When working in groups, this activity is often carried out on larger surfaces such as a whiteboard (Figure 1a), whereas when working independently or in very small groups, teams might use sheets of paper on a table (Figure 1b). We also often saw instances of *draw-alouds*, when sketching was accompanied by synchronous speech.

Figure 1a and Excerpt 1 illustrate one particularly memorable meeting where a pair engaged in heavy brainstorming about two possible designs. Students worked through both designs by pointing out shortcomings of each, and working out possible solutions. Pointing out these problems often took the form of

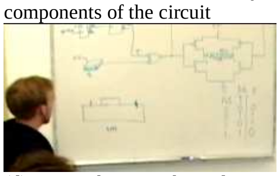
(a) Alex places the circuit he built onto the table for the team to refer to. He outlines the major components of the circuit



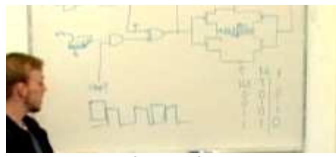
(b) An example of how Alex turns and asks for confirmation before continuing.



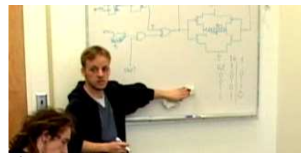
(c) Alex continues to draw some component of the circuit.



(d) Notice the parenthetical on the bottom left. This is erased in the next frame.



(e) Becky asks for clarification about a component, and Alex obliges (notice the bottom left has a different sketch now).



(f) Once the explanation is complete, Alex erases the parenthetical.

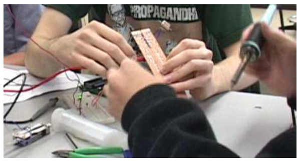
Figure 2. In this sequence, Alex explains the design of a circuit (which he has placed on the table). This sequence illustrates the step-wise process of explication, and the use of transient parentheticals for clarification.

callouts or annotations on the primary sketch. These callouts are examples of implicit organization we call *idea locales*: related ideas are located nearby, and this organic locality of ideas seemed to help coordinate the dynamic use of space on a large surface when several ideas are present simultaneously (Figure 1a).

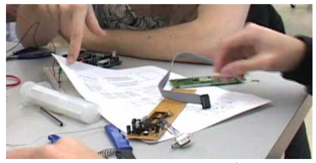
Explication. This category typically involves groups, and characterizes activities where the surface is used to explain an idea. Generally, there are very clear role divisions in this kind of activity (presenter and audience), although the role of presenter is sometimes swapped between group members. Figure 2 illustrates such a sequence. Here, Alex was explaining the design of his circuit to his team. To do so, he placed the circuit on the table, and used the whiteboard to draw attention to particular design decisions in specific areas of the circuit. His use of the whiteboard was careful and deliberate, and he added additional information only after brief negotiation with his audience (e.g. Figure 2b where Alex turns and asks, "Does everyone get this?"). This stepwise process was reflected in how content was laid out on the surface with draw-alouds and idea locales.

We also often saw drawings and sketches we called *parentheticals*, which were used to explain some concept (e.g. a piece of background knowledge). These parentheticals were typically located non-centrally on the surface (Figure 2d,e), and were often erased once a concept was clear (Figure 2f). Their transience reflects their relative importance to the explication activity: they are temporary asides that are intended to support the explanation, but are not intended to detract from the explanation's central flow.

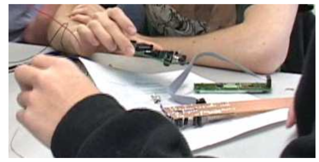
Broadly, we often characterized the flow of an explication activity as being stepwise. It was rare for an entire surface to be wiped clean; changes were



(a) The table provides organizational support for tools and artifacts as Larry and his teammate solder the circuit.



(b) Larry points at an area of the schematic he is uncertain of.



(c) Larry and his teammate now inspect both a reference circuit and the schematic to understand the circuit.

Figure 3. This sequence of frames illustrates (a) the *execution* activity, and (b-c) how multiple sources of information are brought together during a *comparison* activity.

generally evolutionary. For instance, on whiteboards, idea locales are typically wiped clean as units (as in parentheticals), whereas the rest of the surface is not disturbed. Similarly, clearing an entire surface of its contents indicates that the task focus is to change drastically, so is quite rare to see in the collaborative flow.

Comparison. When participants brought reference material or several sheets of paper together to examine in parallel, we classified these segments as comparison activities. This category comprised decision making activities, where teams or individuals compared several alternatives, and activities involving the synthesis or consolidation of several different pieces of information. In one instance, a team was making a decision between two designs, and to do so, the team had drawn both of the designs side-by-side on the whiteboard (Figure 1a). Doing so facilitated a discussion of the merits and weaknesses of each design, and to determine whether a compromise solution could be reached. This simultaneous visibility serves to help contrast choices, be it to remind teams of all options, or to explicitly differentiate between them.

The latter type of activity we included in this category involved the synthesis of multiple sources of information (e.g. diagrams, text descriptions, schematics, etc.), often spread out so that many pieces of information were visible simultaneously. We call this kind of activity *triangulation* since it seemed like individuals (or teams) were trying to triangulate upon a coherent understanding of a concept or design. Figure 3 depicts a sequence where the teammates examined both the paper-based schematic and the physical reference circuit simultaneously.

Execution. When tasks used the surface to aid the active assembly, construction, or fabrication of a substantial entity, we classified these as *execution* activities. For instance, construction of a circuit board and writing code were both classified as execution since the use of a table surface in these cases were similar. In particular, individuals engaged in these kinds of activities frequently used reference materials, tools, or raw materials that were placed on the surface near the main execution area (e.g. Figure 3a: note the paper and raw materials). These artifacts differed in terms of the frequency with which they were used, but shared how they were stored and placed in the workspace when not in use. Frequently, these tools and raw materials were stored in toolboxes, like pencil cases, and these

Activity	Characteristic	Example
Ideation	Using a surface to generate or aid development of an idea.	Using a whiteboard to brainstorm or to sketch out an idea.
Explication	Using a surface to explain concepts or ideas to others.	Using a whiteboard to explain a design to teammates.
Comparison	Bringing together multiple pieces of information on the surface simultaneously.	Opening up several reference materials to understand a design.
Execution	Using the surface to construct or build something.	Soldering a circuit together on a table.

Table 1. Summary of collaborative activities involving surfaces.

toolboxes were brought in close proximity in advance. The tools were taken out of toolboxes often in a just-in-time manner, but then *not replaced* since they would subsequently be re-used (Figure 3). By not replacing the artifacts into the toolbox, our participants were applying a "most-recently used" type of replacement policy with the artifacts and workspace: those tools used recently were often placed in easy to reach locations, with tools used earlier being pushed outward. Only after the nature of the task changed substantially would these artifacts be tidied up.

Summary. Taken together, these four activity categories comprise the high-level activities involving surfaces of the undergraduate teams during their project activities (Table 1). This classification of activities was based primarily on how the surfaces were used spatially, independent of the specific task the teams were engaged in. We have taken care to characterize how information was organized or arranged (or not arranged) in order to illustrate our classification scheme.

In the next section, we describe a set of five roles that surfaces play in these activities. What will become clear is that the surfaces play these roles *in support of* the activities we have discussed here, and in many cases, will have played several roles simultaneously.

Roles of Surfaces in Collaborative Work

During a collaborative activity, certain individuals play specific roles in the process (e.g. moderator, transcriber, critic, etc.); similarly, we found that the surfaces seemed to play very specific roles in collaborative activities. We arrived at these role classifications by coding how surfaces were used, and grouping related observations together until meaningful themes arose. The reader will likely find these roles intuitive, which should be unsurprising since these themes capture *how* we use surfaces in our everyday activities:

(1) ***Presentation***, where information is explicitly on display for others.
(2) ***Scratch***, where the surface "stores" information as working memory.
(3) ***Organization***, where spatial organization carries semantic meaning.
(4) ***Reference***, where the information is stored on the surface for later use.

(5) ***Notice***, where the surface is used to communicate to others who are not present (and sometimes to oneself at a later time).

The relationship between an activity, a surface, and a role is not a 1-to-1 mapping; instead, we often see a surface fulfilling many roles simultaneously, or that a surface's role changes during the course of use. For instance, in Figure 2 during an explication activity, the whiteboard fulfills two roles (*presentation* and *scratch*). Similarly, the table in Figure 3 supports the *organization* of tools and artifacts, but also the *reference* role since it stores the paper schematic and various tools that are used. Thus, while these roles clearly support the activities, it is still useful to consider these roles in isolation of any particular activity.

We describe each of these roles, and illustrate them using examples drawn from our observation sessions.

Presentation. Information is often intended to be exhibited and shown to others, and when a surface is used to exhibit information to others, it is said to be fulfilling a presentation role. In our observations, when a surface was being used in a presentation role, distinct roles of presenter and audience emerged, and these were related to the kinds of interactions taking place with the surface: presenters changed content of the surface, and the audience merely viewed (Figure 1d). The information on the surface was therefore the focal point of discussion, and so during any discussions that might occur, the information on the surface was often referred to explicitly (by pointing gestures and so forth).

In our observations, the presenter generally stood closer to the surface (typically a whiteboard) itself, and so was generally tasked with any interaction with the surface. In contrast, the audience was generally further away from the surface, and so their interactions with the surface were restricted to viewing and pointing at the surface. Thus, the surface conveys a differential power role: since the presenter was generally closest to the surface, he or she was also the one that controlled the surface content, and therefore the flow of dialogue.

We also noted that information on the surface in this role was generally larger. The large information size is likely related to the fact that the audience generally sits far away enough from the surface that up-close interaction is not possible; secondly, the size relates to the information density: the relative density of information on a presentation surface is considerably lower than on a piece of paper (for example, measured in words per square centimeter). In several instances, a presenter would work from his or her notes, suggesting that information being *presented* on a surface is generally prepared in advance.

Scratch. Surfaces being used in the scratch role were generally quite dynamic, with constant addition, editing, removal of information occurring, and at times co-occurring (e.g. a whiteboard in an ideation activity). When surfaces were playing this role, individuals were within close proximity of the surface itself, all able to essentially touch, point, and make changes to the surface if they so desired (e.g. Figure 1b). To some extent, this interaction was mediated by certain interaction

(a) Darcy makes use of information the team had created earlier on the whiteboard.

(b) Frank has arrived late to the meeting; however, he can see what has been discussed, and actually contributes to the discussion.

Figure 4. The whiteboard plays the reference role in (a), and in (b) by retaining a list of the action steps. In (b), it plays the notice role for Frank.

artifacts (e.g. an eraser or pen), but this did not appear to adversely affect the flow of activity—the transitions were quite smooth (e.g. Excerpt 1).

In our observations, the use of a surface as in the scratch role was generally limited to the number of people who could comfortably use the surface, but the number of participants ranged from a single individual right up to that upper limit. In this role, the surface provides support as a form of working memory, storing information for immediate use (i.e. within a few minutes). Ideas were often modified in place (Excerpt 1), and in the form of changing sketches, words, and at times, the addition of detail. The surface therefore lends itself to a form of transient storage, since information only persists for the extent of the discussion. A good example of this transience is the *parentethicals* described earlier.

Thus, the scratch role provides support to explore ideas without commitment, allowing ideas to be removed in part or wholesale at any time.

Reference. The reference role appears when a group or individual's activity changes dramatically from when information was *placed* on the surface to when the information is *used again*. For instance, Figure 4a shows an example of a student making use of a sketch the team had made earlier on the whiteboard. Use of the surface in this way is not always planned: often, the information being used as a reference was the result of prior work using the surface in the scratch role; in other cases, information is explicitly placed on a peripheral surface for later use. In another example, we observed an engineer returning to a chalkboard to review a sketch drawn earlier by an instructor.

Figure 3b illustrates how the table surface is used to review reference information contained on a sheet of paper. Thus, tables support this role by virtue of providing visual space for reference information.

Notice. This role overlaps with the reference role in terms of the nature of information on the surface, but is unique in the motivation: in this case, the surface is *deliberately* being used to communicate with others who may not be present (and in some cases with oneself at a later time). Information in this case generally brief and often left on the surface for long periods of time, edited rarely

Role	Characteristic	Example
Presentation	The surface shows information to others.	Drawing a design on the whiteboard to show others.
Scratch	Information is placed on the surface for short-term storage and immediate use.	Working through several possible designs on a whiteboard.
Reference	Information is stored on the surface for later use.	"Storing" a design from a flip-chart by posting it on the wall.
Notice	Ambient information displayed over time.	Posting a task-assignment list on the whiteboard.
Organization	Using spatial relationships semantically.	Reorganizing the artefacts in a workspace.

Table 2. Summary of surface roles in collaborative work.

and subtly, and often used to provide awareness of a group's activities or intentions. Thus, surfaces used in this way provide information in an ambient fashion.

In Figure 4b, Bob is outlining the remaining tasks for the week, and leaves bullet points after explaining each task. Because the bullet points are retained on the surface, the perpetually late Frank can determine the remaining tasks, who is assigned to which tasks, and importantly, what tasks were assigned to him.

Organization. Surfaces such as tables are also often used as large workspaces where the spatial relationships between units of information and content can be interpreted semantically. Depending on the particular type of surface and the content that is used, this information can be organized in an ad-hoc fashion (while the information is being created or added), or in a post-hoc fashion (after the information has already been created or added, the location of the information is changed). This role is evident both when teams are attempting to structure ideas and information, as well as when tools and raw materials are being organized. Figure 3 shows reference materials placed around the working area, providing the necessary visibility to reference materials: close at hand if the individual wants to examine them in detail, and available at a glance. Their peripheral location denotes their relative importance to the execution activity.

Similarly, idea locales on whiteboards (Figure 1b) reflect how spatiality and location of information can contain or maintain semantic metadata about the information. Traditional physical surfaces such as tables support this organization role well by providing fine-grained means to locate and orient information.

Summary. These five roles comprise the main functions that surfaces play in collaborative work (Table 2). The roles themselves are actually fairly intuitive, which, as we argued earlier, is a good thing: first, if they were unusual, one might question the validity of the roles; second, as we discuss later, they align well with existing efforts in large display groupware research. In the next section, we discuss the three affordances that surfaces provide to support the roles we have discussed in this section. In particular, these affordances suggest how digital surfaces can be designed to support the various roles and therefore the activities one intends to support.

Surface Affordances that Support Collaboration

To this point, we have described what activities surfaces were used for, and the roles the surfaces played in these activities. In this section, we discuss the basic low-level affordances provided by surfaces to support these roles in collaboration, and consequently the activities we described earlier. We arrived at these affordances by considering the roles we established earlier, and how the specific surfaces we saw the teams use supported or did not support particular roles. As we iteratively re-organized our observations, the following three themes arose:

(1) **Information Management**: How easy is it to perform basic interactions with information and content on the surface?

(2) **Information Visibility**: How easy is it to see information on the surface?

(3) **Information-Surface Coupling**: To what extent can information be manipulated independently of the surface?

As will become evident in the subsequent discussion, a surface's character is a combination of how these factors are manifest, and these combinations contribute to which roles a surface is best suited for.

Information Management. This affordance relates to the basic interactions one has with information and content on a surface. Specifically, it relates to the questions of: how easy it is to add or create information, modify or edit information, remove information, and clear the entire surface of information. How easy it is to perform these basic tasks affects a surface's utility in supporting the various roles articulated above.

When a surface provides a simple means to add and remove information, it can support the *scratch role*, because it allows individuals to rapidly modify ideas and information. Similarly, we may consider this ease in terms of how easy it is to provide others or multiple users with this ability to add information. Systems that make it difficult to switch editing roles or contribute overhead to the addition, editing or otherwise management of information inhibit this affordance. Yet, the inverse may not be a bad; sometimes, as in a *presentation role*, it is undesirable for others to modify the information on the surface.

Another key part of this affordance that is often overlooked is the ability to remove information and to clear the entire surface of information. On first blush, one might consider one to be subsumed by the other, but they actually perform different functions. The ability to incrementally remove information from a surface allows parts of ideas to be reformulated without affecting the rest of the surface (as in a *scratch role*). This distinction clarifies why a whiteboard is somewhat unsuitable for certain types of presentation tasks—since it only provides the means to incrementally remove information, switching from the presentation of one idea to the next is time-consuming.

The ease with which it is to perform these management operations is often *not symmetric*. This asymmetry provides surfaces their unique character. For example, a whiteboard provides a very easy means to create information, to modify it, and to remove it, but makes it difficult to add information from external sources or to remove all information from the surface at once. Consequently, we often saw it being used in the *scratch*, *reference* (when information from the surface was used later) and *notice roles* (ambiently consumed information). In contrast, we might consider how a flipchart, when paired with a marker, makes it easier to clear the entire surface of information (i.e. by flipping the paper), but simultaneously makes it difficult to remove pieces of information. Thus, flipcharts are more readily usable in the *presentation role* (where ideas are static and can be prepared in advance), whereas whiteboards are more suitable in a *scratch role* (where ideas evolve).

Information Visibility. This theme relates to how the visibility of information (specifically the orientation and size of information) affects participation structures in collaborative activities. The visibility of information on surfaces enables or restricts the participation of members of the group: when information is more visible, more people can be involved in an activity. The inverse is also true: when information is less visible, fewer people can be involved in the activity. Implicitly, this seems understood: when more people attempt to get involved in an activity, team members make room for others to join by moving their seats, re-orienting information (Kruger et al., 2004), and writing or sketching larger.

While prior work has focused on the orientation of information on surfaces (Kruger et al., 2004), our observations suggest that the orientation of surfaces themselves are associated with particular participation patterns. Upright surfaces, such as whiteboards, flipcharts and so forth, were frequently used when the entire team was to be involved in discussion. This involvement is likely due to the visibility of this information without requiring proximity to the surface. In contrast, tabletops were used primarily for independent or very small group (i.e. two to three people) work. Since information on tabletops is oriented horizontally, visibility of this information generally necessitates close proximity.

This use of the tabletop for independent work also relates to the size of the information on the surface. On upright surfaces, we observed that text was written in a very large font, and visible from a reasonable distance (5m). In contrast, text written and used on a horizontal surface (i.e. paper from notebooks or textbooks) was generally small, and only visible from fairly close (<1m). The size of the information and consequent density of this information influences how close one needs to be to deal with and make sense of the information. Thus, the size and orientation of information serves to enable or limit others access to it.

Yet these patterns are by no means rules: in one instance, an entire team's conversation revolved around a paper artifact (a set of requirement specifications) that was placed on the table surface so that every team member could touch and hold the artifact. In this case, the focus of the conversation was the information contained in the document (although no one was reading the document itself). If they were to carefully inspect the information, we would expect the information to appear on a vertical surface to support this *presentation role*.

The orientation and size of information interact to produce the participation structures we see. When a whiteboard was used in the *notice role*, text was written largely. When surfaces were used in the *reference role*, the information was generally smaller, but was also sometimes found on tabletops (on paper) in addition to text placed on whiteboards. In the former case, this information was visible from a distance; in the latter, the information was generally viewed and used from very close proximity.

Information-Surface Coupling. On some surfaces, information on the surface is decoupled from the surface itself, supporting rich modes of interaction. Put simply, when information or content is added to this surface, does the information *become a part of the surface*, or does it *remain atop the surface*? Surfaces can support this decoupling in two ways: spatially or temporally.

Spatial decoupling allows information to be moved and reoriented independently of the surface. This affordance facilitates the interpretation of the spatial relationships semantically. Here, we refer to the specific ability to move the information *after* it has been added to the surface. For example, corkboards allow information to be moved arbitrarily. In the same way, tabletops allow artifacts to be placed on and then moved independently of the surface. Whiteboards, in principle, do not support this affordance: information must be rewritten to “move” it. Spatial independence supports the *organization role*.

Temporal decoupling denotes the information’s ability to “stay together” over time, in some cases independently of the surface. This affordance facilitates archival and storage of information, and the use of the information at a later time (*reference* and *notice roles*). A flipchart, for example, allows information to be removed from the surface (spatial decoupling), or to be simply flipped and viewed at a later time (temporal decoupling). All information and the relative spatial organization of information on these flipcharts remain intact. A whiteboard does not support this property since retaining content inhibits further use of the surface: we often saw cases where information was cordoned off by drawn borders and phrases such as “Please do not erase”. In such cases, teams were making up for the whiteboards’ apparent lack of temporal independence so that they could use the information from the surface in a *reference role*.

This decoupling is powerful since it allows information to be created and used in a different time and/or space. Post-it notes, which have a strip of semi-adhesive on the underside, allow notes to be temporarily attached to (and therefore moved on) surfaces. This flexibility allows post-its to be used on a variety of surfaces that would otherwise not support this type of information-surface decoupling.

Affordance	Components of Affordance	Example
Management	• adding information • modifying information • grouping information • removing information • removing all information	Flipcharts make it easy to add information, but not to remove information.
Visibility	• orientation of surface • proximity of surface	More people can see information on a whiteboard than on a table.
Coupling	• spatial decoupling of surface and information • temporal decoupling of surface and information	What happens on the whiteboard stays on the whiteboard.

Table 3. Summary of surface affordances in collaborative work.

Summary. Taken together, these three affordances comprise the basic building blocks that traditional surfaces provide in supporting the five collaborative roles we described earlier. What should be clear is that these affordances should not be considered as "Boolean" in terms of features-to-be-implemented. Instead, they are really design points to consider when designing groupware systems for large displays. Certainly *whether* these affordances are supported plays a role in determining whether the various surface roles will be supported, but *how* the affordances are designed and supported by the system will also play a role.

In the next section, we illustrate how our framework relates to existing work that explores collaboration involving large work surfaces and large collaborative display surfaces. We demonstrate how our framework can be seen as an extension of existing work, and how it frames many of the existing large display groupware systems with a coherent vocabulary.

Extending and Confirming Related Work

In this section, we situate our framework in two bodies of work by showing how it first, extends the findings of naturalistic studies of collocated group work, and second, extends our understanding of work exploring the design of large display groupware environments.

Collocated Group Work. Teasley et al. (2000) explored work practices of collocated teams in so-called "warrooms." They identified nine types of work, of which the three involving surfaces relate to our framework (problem solving on whiteboards, simultaneous problem solving, and status meetings/TODO lists). For instance, the authors discuss how whiteboards and flipcharts were used to maintain visible and permanent records of activity and decisions (*notice role*). We expand on their descriptions of whiteboard use with the *ideation activity*, and further decompose this into the *scratch* and *presentation roles*.

Covi et al. (1998) also studied teams working in dedicated rooms, and discuss the use of surfaces (particularly whiteboards and flipcharts) as cognitive artifacts. Their descriptions of action lists, comparing flip charts, and the retention of historical records accord with our descriptions of the *notice role*, *comparison* *activity*, and *reference role*. Additionally, they mention four design factors for display technologies (creation, editing, persistence, and flexibility), which we expand on with our affordances, in particular by showing how the affordances relate to roles played by the surface.

More recently, Wang & Blevis (2004) articulate a number of factors in collocated design work that more generally reflect how collocation supports designers. In particular, they discuss seating orientation and reach (*information management*), simultaneity of interaction, the use of physical objects (*information-surface coupling*), and the "one concept per sheet" work practice (which supports the *comparison activity*).

Finally, our work was motivated by Robertson's characterization of embodied actions in cooperative work (1997). We consider her taxonomy of embodied actions (particularly the group actions) to be the basic component parts of the kinds of interactions we saw in our own observations. For example, the *ideation activity* would be comprised of conversing, looking at the same thing at the same time, creating a shared representation, and focusing group attention.

Large Display Groupware. In due consideration to the large body of work involving large display environments (for reviews, see O'Hara et al., 2003; Czerwinski et al., 2006), we draw on three specific examples to illustrate how our framework provides insight into the understanding of these systems in use. The first illustrates how *information visibility* affords different collaborative interactions, the second aligns existing prototyping work with the *information management* affordance, and the last provides clarity into the evolutionary use of a large display system.

Rodden et al. (2003) built eSpace to explore the collaborative affordances of a redesigned travel agency computer. In the standard vacation planning process, asymmetries in access to and visibility of information create awkward power relationships in terms of having to share and communicate ideas, and synthesizing of information. By reconfiguring how information was displayed (i.e. by changing the *information visibility*), the authors mitigated these power relationships, enabling synchronous and complementary planning while reducing cognitive effort. This case study is a fascinating example of how *information visibility* allows the surface to play the *scratch* and *reference roles* in addition to the *presentation role*, thereby changing individuals' roles in collaborative work.

Johanson et al. (2002), reporting on the experiences of the Stanford Interactive Workspaces project, articulate three specific interactions that they endeavored to support: moving data, moving control, and application coordination. The first two of these relate highly to the *information-surface coupling* and *information management*. The authors implemented iCrafter to facilitate smooth movement of information across displays, thereby supporting spatial reorganization of information. Further, PointRight is an example of extending the *information management* affordance by providing an additional means to control information on different surfaces. Similarly, Streitz et al. (2001) develop similar mechanisms of remote control and remote display.

Finally, Huang et al. (2006b) provide an insightful study of the deployment of the MERBoard system, used by NASA scientists to support the MER Mission science tasks. The authors found that the use of the system evolved based on the changing needs of the scientists and engineers. Early on, a structured whiteboard tool was used since scientists had not yet established a routine. While the whiteboarding system was originally used for this kind of *ideation activity*, the information was later moved to larger projection systems for easier viewing by others (*presentation role*) when it was clear that editing was not required (*information-surface decoupling*). Over time, the system was only infrequently used for routine tasks, and instead, the system was co-opted for the display of information in an ambient fashion, providing scientists with ongoing status information (as in a *notice role*).

Summary. Taken together, these examples demonstrate how our framework fits within our current understanding of collocated work, and how much of the design work with large display groupware can be taxonomized using the framework. In the final section, we discuss how practitioners should take our findings and apply them in further work.

Practitioner Implications

We are at a point where it is not prohibitively expensive to build or difficult to design computer interfaces for large displays and multi-display surfaces. Instead, the problem is to understand *how* these digital surfaces can fit into and extend existing work practices, and to build systems that fulfill this promise. In this paper, we articulate three specific areas that designers can build on as they develop large display groupware systems (activities, roles, affordances). Each of these areas builds on observations of real users' uses of large surfaces in collaborative work. Yet while the analysis approach yielded these three areas, we believe a specific approach may be warranted: specifically, instead of designing for activities or roles, simply design for affordances.

We have seen many cases where providing activity structure to existing meeting room work practice has been problematic (e.g. Tatar et al., 1991; Nunamaker, et al., 1991). If we consider how traditional meeting room surfaces were designed, it is unlikely that they were designed for specific activities. Instead, designers likely committed to building specific *affordances* for these surfaces, and the way in which the surfaces ended up being committed to use were evolutionary (as in Huang et al., 2006b). For instance, chalkboards were likely not developed by thinking about what tool would be best suited for presentation or retention of information; instead, designers likely considered how to best support easy addition and removal of sketches (i.e. *information management*). Because of this flexibility and through evolved use, the chalkboard took on many roles and fundamentally changed work practice.

Similarly, we argue that carefully designing these surface affordances into our large display groupware is very promising. While the framework does not provide specific design guidance, it does provide a means for practitioners to analyze designs. By carefully considering the design in terms of surface affordances, it is possible to predict which *roles* the system could support (or inhibit) *before building* the actual system. For instance, providing an easy means to move digital content (*information-surface coupling: spatial-decoupling*) from remote surfaces (such as a laptop) to the large display (*information management: adding information*) would support the *presentation* and *reference* roles since it would allow arbitrary individuals to place prepared information onto the large surface, potentially as a presentation vehicle or as a reference for ongoing work. Similarly, by simply allowing this digital content to be resized, repositioned or to persist (*information-surface coupling: temporal-decoupling*), the surface can function in both the *notice* and *organization* roles. Providing this type of functionality is not beyond our capacity (e.g. Streitz et al., 2001; Johanson et al., 2002), the challenge is designing this functionality into the system so that users can both discover this functionality, and adopt it into their work practice without unnecessary overhead (Grudin, 1994; Huang et al., 2006a).

The flipside of this argument is to consider designing systems that deliberately inhibit certain affordances. For instance, one drawback of the whiteboard is that information is irretrievably lost once it is erased (it has very tight *information-surface coupling*). Yet a whiteboard is still useful, and is a better tool (compared to a flipchart) specifically *when information is not intended to be retained* (i.e. when tight *information-surface coupling* is desired)—a user can be confident that confidential information on a communal whiteboard is gone if he or she erases it *If* we were to design a large display to support this type of transient use, users would need to be confident that information placed on the display would not be retained and used later (i.e. *information-surface coupling: temporal-decoupling*). For example, rather than force presenters to place electronic slides onto a shared machine, many conferences allow presenters to connect their own laptops to the projector—doing so allows presenters to maintain control over content.

With increasing interest in designing large display groupware systems, this framework provides a set of descriptions of activities, roles, and affordances which can be used to discuss, analyze and predict how teams will make use of a given design. It does so by drawing on observations of teams using large traditional surfaces in team collaboration, and teasing out these functions in terms of activities, roles, and affordances.

Conclusion

To understand how to design large display groupware for collocated work, we undertook a naturalistic study of undergraduate engineering teams as they progressed through a five-week project. We found that the activities involving surfaces could be labeled with four classifiers: ideation, explication, comparison, and execution. By studying these particular categories of activities carefully, we saw that surfaces played five specific roles in these processes: presentation, scratch, organization, reference, and notice. Underlying these five roles were three basic affordances that the various surfaces had to support the roles: information management, information visibility, and information-surface coupling.

Taken together, this framework forms a basis upon which we can inform the design of new large display groupware tools for collocated teams. Using this framework, we can analyze how teams might use our display technologies, and to understand how subtle changes may affect collaborative dynamics. As we continue to design large display technologies for collaborative work, we argue that designers need to carefully consider how to provide these affordances. Designing affordances for large display systems well will provide a solid platform upon which effective collaborative dynamics can evolve.

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