Displays in the Wild: Understanding the Dynamics and Evolution of a Display Ecology

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Abstract. Large interactive display systems are becoming increasingly pervasive, but most have been studied in isolation, rather than in the context of other technologies in the environment. We present an in-depth field evaluation of large interactive displays within a multi-display work environment used in the NASA Mars Exploration Rover (MER) missions, a complex and authentic use setting. We uncover how the role of such displays evolves in the context of other displays as tasks and collaboration practices change, as well as how tasks migrate among different displays over time. Finally, we present suggestions for how to evaluate the success of large interactive displays and multi-display environments in collaborative work environments based on our findings.

1 Introduction

In January of 2004, the National Aeronautics and Space Administration (NASA) landed two unmanned vehicles on the surface of Mars for the purposes of collecting scientific information regarding the terrain, composition, and atmosphere of the planet. The Mars Exploration Rover (MER) mission has continued for the past 20 months, with the two rovers, Spirit and Opportunity, continuing to transmit data to Earth as they traverse the surface.

The actions of the rovers as well as the data that they collect are guided by mission scientists and engineers, and the mission is based at NASA Jet Propulsion Labs (JPL) in California. To coordinate their activities, scientists and engineers employ a variety of tools for collaboration and information sharing. In the group workspaces designed specifically for the MER Missions, shared displays, including large projection screens, large interactive plasma displays, and shared workstations with multiple monitor setups, are ubiquitous. Together, these surfaces form a "display ecology," in which the uses of individual displays influence the roles of others, despite not having been designed as a unified, seamless system. Of particular interest to us is the MERBoard [14], an example of an emerging class of pervasive computing technologies comprised of interactive large multi-user display systems. Although many such systems have been designed, deployed, and studied in a variety of settings in recent years, the NASA MERBoard system, designed and deployed specifically to support MER Mission science tasks, is unique in its complexity and the extent of its deployment in authentic work settings.

Unlike many other large interactive display systems, MERBoards were deployed to support specific, time-dependent work tasks of real users (Figure 1). MERBoards were integrated into a fast-paced, round-the-clock and often hectic work schedule to support necessary tasks; this is in contrast to many systems that have been deployed primarily in research or test environments as supplemental support for collaboration, rather than a primary medium for accomplishing work tasks. Additionally, many MERBoards were deployed in parallel, with 18 of the displays in use at JPL during the initial months of the mission, whereas other research prototypes have often been single instances of the technology or deployed in small numbers. Finally, unlike many other large display groupware systems, MERBoard has been integrated into a work environment that contains many display alternatives, including several other large display options. All of these factors led us to investigate not only how users interacted with the MERBoard, but also address the greater issue of the role of interactive large display groupware within highly dynamic, complex display ecologies.

Figure 1. MERBoards, projectors, laptops, and workstations in the work environment

In this paper, we present the results and analysis of a year-long field study of the MERBoard and the MER mission display environment in which we uncover an ebb and flow of large display use as collaborative tasks and practices evolve over time. Our findings suggest that:

- Large interactive displays are valuable as interactive support for exploratory tasks for which procedures are ill-defined; as tasks become proceduralized, these displays can be useful sources of ambient information.
- Tasks migrate among displays within a display ecology as tasks and collaboration styles change; this migration is deeply influenced by the other displays in the environment and their respective affordances.

- Evaluation should be based on how well and flexibly the entire ecology of displays supports work tasks, rather than a simple measure of use or disuse of individual displays or applications within the environment.

In the following sections of this paper, we present background information on the MER missions, MERBoard, MER display ecology, and related research. We then present our findings regarding the adoption evolution of use of several MERBoard functionalities within the context of the display ecology. We follow this with a discussion of the implications of our findings for design and evaluation of large interactive display systems and multi-display environments.

2 Background on MER Missions

The gathering of scientific information on the MER missions has entailed highly dynamic procedures, especially during the “nominal mission”- the initial three months following the rover landings. Working on a 25-hour cycle (the length of a “Sol”, or Martian day), teams of scientists and engineers would receive, process, and analyze downlink data from the rovers and Martian satellites, decide the next course of action for the rovers as well as what data should be collected next based on this information, convert these decisions into sequences of instructions for the rovers, and send this information to the rovers via the data uplink. Each of the steps in this cycle was highly collaborative, and required significant coordination between groups of collaborators working on various steps of the cycle, as well as among group members working together on a single task.

Scientists and engineers generally had distinct responsibilities, although there was considerable collaboration between them. The mission science teams were composed of five theme groups: Atmospheric Science, Geology, Minerology and Geochemistry, Soil and Rock Physical Properties, and Long Term Planning. These groups were responsible for the scientific aspects of the mission, such as analyzing the data gathered by the rovers, deciding what further data goals and exploration should be pursued, and determining at a relatively high level what course of action the rovers should take. In contrast, engineers were responsible for the more tactical aspects of the mission, including determining the rovers’ exact sequences of action, controlling the instruments on board the rovers, sending the information to rovers, and collecting the downlink data.

In addition to the distinct responsibilities of the scientists and the engineers, there were also several other differences between the two groups that affected collaboration. For example, the engineering teams consisted primarily of NASA staff and contractors who were resident at JPL; many of them had collaborated previously on other missions. In contrast, while some of the scientists were also NASA employees, the majority came from other institutions all over the country and were working together for the first time. Furthermore, from the standpoint of the engineers, the tasks in which they engaged bore resemblance to their tasks for previous NASA missions. For the scientists, the tasks that they engaged in were highly novel and bore considerably less resemblance to the scientific activities of other NASA missions. For these reasons, work relationships in the science teams were more dynamic and practices less established and proceduralized than those of the engineering teams. This was particularly true in the nominal mission, thus affecting the ways in which collaborative technologies were used and adopted.

During the nominal mission, all scientists working on the mission were resident at JPL, with all of the science theme groups for each mission collocated within large science assessment rooms. Within these rooms, each theme group had its own area, each with a MERBoard, several workstations, and two projection screens. Additionally, there was a MERBoard and a pair of projection screens in the front of the room used for presentations and meetings. At any given time during the nominal mission, several dozen scientists were present in the space; this number decreased steadily after the end of the nominal mission. Engineers worked in teams in several other smaller spaces at JPL, including Mission Control and Sequencing areas. These rooms had different configurations of displays, with at least one MERBoard and one projector; some had multiple of each.

During the extended mission that followed the nominal mission, some scientists returned to their home institutions and began to work remotely; science activities were distributed across JPL and other laboratories, while the engineering tasks continued to take place at JPL. As the mission was further extended, science collaborations became increasingly distributed.

Prior to the start of the mission, many of the scientists and engineers participated in a set of mission simulation exercises called the FIDO (Field Integration Design and Operation) trials. During the exercises, the teams engaged in simulated mission activities, on a compressed time cycle. They were also trained on and exposed to the tools and systems that they would be using during the actual mission, including the MERBoard.

Table 1. Summary of the MERBoard functionalities focused upon in this study

Functionality	**Intended Users**	**Tool Summary**
SolTree Tool	Scientists	Tool for building graphical tree structures to represent possible next actions for the rovers. Plans were visualized as nodes, paths, and branches with annotations to keep track of information associated with each plan. Plans, also called "SolTrees," could be saved, and later modified
Whiteboard	Scientists, engineers	Tool for authoring documents and images with stylus for freehand drawing and writing, graphical tool palette, or a keyboard as input. Content on personal machines could be put into a shared directory and accessed on MERBoard. Whiteboard content could be saved and retrieved. A tabbing mechanism permitted switching between multiple boards.
Mars Clock	Scientists, engineers	Full-screen, persistent clock that displayed the current Earth time at JPL, Mars time for the Spirit rover, and Mars time for the Opportunity rover.
Schedules	Scientists, engineers	MERBoard could be used to access and display CIP (Collaborative Information Portal) and other schedules, which showed the daily schedule of deadlines, meetings, and events.

MERBoard hardware consisted of 50" 1600x900 resolution plasma screens with touchscreen overlays. Developed specifically for the anticipated needs of MER scientists, MERBoard provided several functionalities to support collaboration and work tasks [14]. In this research, we focus on a subset of applications (Table 1) and how their use evolved in the context of the multi-display environment. The functionalities presented below represent a cross section of the applications available on MERBoard, spanning passive to interactive value, providing both freeform and structured support.

3 Related Research

Our evaluation of the MER mission display ecology was designed to complement an earlier observation-based evaluation of the MERBoard conducted by the designers of the system [13]. This study examined the knowledge and data management practices surrounding document creation and use on the MERBoard, whereas our study sought to focus more generally on users' perspectives of the tasks, tools, and collaborative practices over time, as well as the interplay among the many situated displays in the ecology.

Several other interactive multi-user display systems and multi-display environments have been designed for the purposes of supporting work tasks or collaborative work. Like MERBoard, systems such as BlueBoard [10] and Tivoli [9] offer whiteboard-type tools for collaborating on shared artifacts. Designer's Outpost [8] offers scaffolding tools for the purpose of supporting preliminary website design. Tools such as MessyBoard [2] and the Notification Collage [3] support synchronous and asynchronous communication for collaboration. Projects like CoLab[12], ARIS[1] and iRoom [7] focus on the architecture, system design, and interaction techniques of multi-display environments with a focus on how users can interact across the displays. These systems and environments have been evaluated primarily in laboratory studies, used only in research settings (often the home laboratories of the researchers), or in limited-term experimental trials. While the evaluations of these systems have yielded valuable findings regarding the value and use of large interactive displays for supporting group work [4], we still lack a deep understanding of what role these systems play in natural work environments over time. A recent workshop on multi-display environments (both single-user and collaborative) [5] included position papers that identified common types of multi-display environments [11], as well as technical design considerations for such environments [6]. We believe our work builds upon the existing research by providing an in-depth examination of how one of these systems is used in context and in real use. Our findings can help better inform the design of such systems and tools by uncovering the evolving use of multi-display environments over time by users who were not involved in the design of the system, and whose work tasks are so critical that they will only use a tool if it provides a clear benefit in helping them accomplish these tasks.

4 Study Description

This study was designed as a summative inquiry into the overall value of the MERBoard and other display technologies used in the mission, as well as a reflection upon how the roles and perception of these tools changed over time. The study was designed to complement earlier field studies conducted by the designers of the MERBoard, which focused primarily on MERBoard interaction in the early months of the mission, following their initial deployment [13]. The primary motivation for conducting an evaluation retrospectively, after much of the collocated collaboration had ended, was to understand the overall impact that the displays had on the mission and work activities as a whole; understanding the users' perception of the system on the mission in general allowed us to make design recommendations that are currently being used to influence the design of new iterations of the tool for other NASA workgroups and future missions.

We conducted semi-structured interviews with sixteen scientists and engineers on the MER Mission project, as well as initial background interviews with six NASA researchers involved in the original design and deployment of the NASA MERBoard. Two of the scientist interviews, as well as all of the designer interviews took place onsite at NASA laboratories, while the remaining interviews with scientists and engineers were conducted over the telephone. All interviews lasted between 30 and 60 minutes. Interviews with scientists and engineers took place between twelve and sixteen months after the start of the mission, and were conducted by a researcher who had not been involved in the original design or deployment of the MERBoards, and was otherwise unaffiliated with NASA.

5 The Evolving Uses of MERBoard Over Time

In this section, we present an overview of the use of the MERBoard within the context of the display ecology. Because the functionalities that we examined each displayed some unique uses and patterns of evolution, we break the presentation down by the individual applications, and describe the overarching themes and general implications in the sections that follow.

5.1 SolTree

The SolTree Tool is frequently mentioned by MERBoard designers and MER Scientists as the most utilized tool available on the MERBoard early in the mission. Used regularly during approximately the first 70 Sols of the MER missions for planning activities primarily by the Long Term Planning (LTP) theme group, SolTree can be considered the closest to a "killer app" provided by MERBoard.

This design of a structured scaffolding tool on a shared display surface entails several assumptions; it assumes that the task that it supports will be done by a group of people, rather than an individual. It also assumes that this collaboration will be synchronous and co-located in such a way that a shared visual surface will be beneficial to the collaboration. Additionally, the design of this tool assumes everyday or near-everyday use during the mission, since it was intended to support planning on a Sol by Sol basis. We found that these assumptions did not hold throughout; the nature and timing of the Sol planning task evolved over the course of the mission, as did the type of collaboration used to accomplish the task. The evolution of task and practice eventually caused Sol planning to migrate off of the MERBoard entirely, as the scaffolding provided by the tool and the shared visual surface offered by the large display ceased to fit the task in the later part of the mission. For this reason, SolTree unexpectedly proved to be most effective as a “ramp-up” tool, rather than the steady-state support tool for daily use for which it was intended.

Display size and group size: The process of SolTree planning in the MERBoard involved a small group of collaborators, generally between three and a dozen people. It is clear from the scientists’ comments that the number of people involved in SolTree planning decreased during the course of the mission. LTP scientists agreed that the MERBoard’s physical size was well-suited to the size of the groups involved in these activities early in the mission.

The actual authoring process varied between instances; in some cases, the group would convene around the board, either sitting or standing, while a single person “drove” the display, building the tree based on input from the group (Figure 2). As the mission progressed, an individual would often draft a plan alone using SolTree, and then collect other planning scientists around the MERBoard for feedback and editing. The role of the display changed from that of a shared authoring surface that allowed many people to take part in the authoring and decision-making process, to a visual display space for presenting a nearly-finished artifact to the workgroup.

Migration to projection screen for large meetings: Although MERBoard was well-suited for the planning task early in the mission, images of SolTrees were often exported as images or transcribed into PowerPoint for the purposes of displaying them on the projectors during meetings when the plans were being presented to larger workgroup. The size and resolution of MERBoard simply was not sufficient to make MERBoard a valuable presentation tool for this type of viewing. The migration to projection was difficult, however. Scientists complained of the overhead necessary to convert the SolTree into a format that could be shown on a projector; there was no simple way to integrate a plan created on the MERBoard into a presentation.

Figure 2. Scientists collaborating on a plan using SolTree

Tool structure supports early collaborative work: Most of the LTP scientists appreciated SolTree’s ability to keep track of all of the possible branches and options, especially in the earlier parts of the mission. Others praised the fact that SolTree imposed a structure on brainstorming options; it required planners to think down each linear path and consider and annotate all of the possibilities. One user of the tool said that it “forced explicit logic” and required the scientists to consider all possible ramifications. Another scientist emphasized the importance of the tool soon after the rovers landed because the tool “offered scaffolding” for a process that was still new to the scientists and not yet routinized.

Persistence and evolution of plans: Though the general perception of the SolTree tool among scientists is that it was provided as a way to interactively author plans for Rover activities, their descriptions of use illustrate a broader value of the tool as a persistent information display for community awareness. SolTrees were often left open on the LTP theme group’s MERBoard even after the planners had completed their planning for the day, simply as a way of maintaining awareness of the planned activities and options, and also as an informal way of making that information available. One scientist described it as a service to others so that they would “absorb it.” The SolTrees were often left visible until someone needed the display for another purpose.

The persistence of the artifact also created continuity from day-to-day between the various LTP leads, particularly as the mission progressed and the planning process stabilized. The SolTrees were not only a data product; they were input for the following day’s planning and a way of getting an incoming LTP lead up to speed on the previous day’s plans. SolTree authoring was sometimes described as an “evolution”, with an existing tree repeatedly being pruned, added to, or otherwise edited based on new data, rather than being created anew in each planning session.

Tasks migrate to other displays as collaboration changes: The planning process evolved during the course of the mission, shifting gradually from unfamiliar and exploratory to familiar and proceduralized. As mission goals solidified, planning became more tactical, and scientists generally confined their planning to the consideration of a few potential options rather than a full-blown exploration of all possible next steps. They were better able to anticipate these steps and their implications and the decision making process became increasingly streamlined.

The method of visualizing these plans evolved as well. Scientists described how the tree-shaped plans with their many-branched possibilities gave way to linear path-shaped plans that often spanned multiple Sols. Because they were considering fewer possibilities, the need to specify all of the possibilities in detail decreased. The “inflexibility” of the tool that forced scientists to specify all of the details of the plans became unnecessary overhead. Additionally, the planning process became predictable enough that scientists no longer needed to create them together; it was sufficient for an individual to create the plan on his own and get it approved by the group later. As a result of this evolution of the task, the group use of the SolTree tool on MERBoard for planning eventually gave way to the individual use of PowerPoint on laptops for creating “Sol Paths.” In the transition from MERBoard to PowerPoint, some scientists took the intermediary step of using the freeform whiteboard drawing tool to create plans; this supported the collaborative building of trees, while freeing them from the tight scaffolding of the SolTree tool.

5.2 Whiteboard and Image Display on MERBoard

In contrast to the SolTree tool, the MERBoard whiteboard application was not designed to support a specific task, but rather to provide flexible, *ad hoc* support for collaborative tasks. Even so, the design of the tool reflects some of the same assumptions as the design of the SolTree, namely that the use of authoring tools on a shared display surface would be useful for synchronous, collocated collaboration. The fact that the application was not designed to support any specific tasks suggests that it could be useful for any collaborative tasks that might involve shared authoring of artifacts throughout the course of the mission. As we discovered, however, the tasks for which this use of a shared authoring surface were largely exploratory in nature, and thus clustered primarily in the pre-mission work and early in the mission. The whiteboard evolved from a freeform support tool that helped collaborators with tasks for which procedures were not well-defined to a passive information display, as collaborative tasks became more highly proceduralized and moved off of the shared display space. As with SolTree, the interactive uses of the whiteboard proved to be most valuable for exploratory work, in which the MERBoard served as a ramp-up tool while procedures were not yet routinized.

Flexible support for exploratory tasks: During the pre-mission FIDO tests, scientists and engineers used the whiteboard heavily as a support tool while learning how to operate the rovers. In this case, MERBoard served as a learning tool; it was used by the scientists for creating documentation as the training progressed. MERBoard was a good fit because there was no established procedure for creating documentation within the workgroup, and the whiteboard functionality imposed no structure on the note-taking or resulting product. Additionally, this was the type of task for which having a persistently visible representation of collective knowledge was of value. The whiteboard functionality of MERBoard was also used for brainstorming activities during these tests; MERBoard allowed scientists to do freeform sketches with a group, and save and share the designs. The tool’s flexibility was valuable for these types of unstructured preliminary planning activities.

During the actual mission, use of the whiteboard was less frequent and decreased over time. As procedures for accomplishing tasks became routinized and streamlined the exploratory aspects of the whiteboard became less necessary. Scientists’ practices and procedures became routinized and the need for *ad hoc* support decreased.

Support for transient information and transitional procedures: Early discussions with designers of the MERBoard seemed to suggest that designers were disappointed with the uptake of the whiteboard during the actual mission, and that few documents were created using it. Discussions with several of the scientists suggest, however, that while interaction with the whiteboard may not have been frequent, many scientists perceived the tool to be valuable to work processes during the mission, with one scientist even calling the tool “imperative” to his work activities.

People rarely chose to save the artifacts that they produced, preferring instead to transcribe them into PowerPoint after the collaboration was finished. It seems possible then that part of the reason the whiteboard was perceived by some as not valuable was because the products created on it were highly transient. Unlike the plans created using SolTree, artifacts created on the whiteboard were not often displayed at the larger meetings, perhaps because of their transient, informal content. As a result, informal presentation of this information was done directly on the MERBoard for small groups of collaborators, and did not migrate onto the projection screens. As described in the SolTree section, the need for the whiteboard arose again during the transitional phase of planning when the group still needed to collaborate synchronously on Sol planning, but no longer needed the tight scaffolding of the SolTree tool.

Lack of use for routinized tasks: In contrast to how the scientists used the whiteboard, the engineers we spoke to made almost no use of it for collaboration. In contrast to the science activities, the engineering activities were more structured and proceduralized in large part because they bore significant similarity to activities from previous missions. The sequencing team, whose job was to create very precise, low-level sequences of instructions to transmit to the rovers, had tools with which they were already familiar that had been designed for the purposes of creating sequences. A lead tactical engineer on the mission spoke of the importance of tools that explicitly supported his tasks, stating that he dealt with "very specific bits of hex code going to very specific places" and that a freeform tool like the MERBoard whiteboard simply would not offer the level of detail that he required. Although he and his team worked collaboratively on sequencing tasks, their procedures and tools were well-defined, and the whiteboard's freeform support offered no benefit to their collaboration.

The unexpected value of passive image display: While most scientists claim to have interacted little with the whiteboard, many were positive and enthusiastic towards it because one team member frequently used it to display images taken from Mars orbiters, maps, and panorama cameras, with graphical overlays or line drawings that he had created on his laptop (Figure 3). Often, these images were displayed for days at a time, attracting interest and prompting discussion, or even retrieved later in the mission for reference.

The scientist liked that he could "release" information into the environment, rather than displaying it from his personal machine. The large display naturally drew people's attention; the size and dynamic nature of the board made it "easy to notice changes" when new material was present. The scientist regarded the information sharing as a type of "asynchronous collaboration"; for him it was a way of keeping others informed of his activities, prompting new ideas, and letting his images and ideas "enter the public consciousness" with no effort on anyone else's part. He saw MERBoard as an "easily changed posterboard" through which he could convey ideas and be guaranteed that they would receive attention.

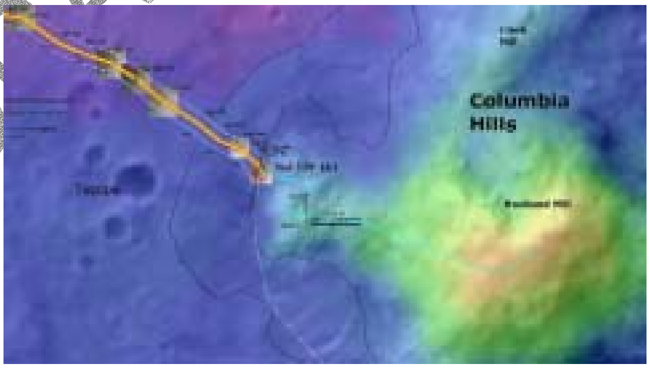

Figure 3. An image created by a scientist and displayed on the whiteboard

Other scientists who wanted to share information preferred to use projectors, not because they felt that MERBoard was inferior for viewing ambient information, but because it was easier to plug a laptop into a projector than post content to the MERBoard. For this reason, projectors were also used to display images in the environment that might otherwise have been displayed on MERBoard.

Although actual paper printouts of terrain data were also used during the mission, printing images was expensive and few had access to use the poster printer. One scientist said that the use of some paper images was eventually "superceded" by the annotated maps that had been posted on the MERBoard.

Although the images were admired and drew interest, scientists stated that there was no conflict or awkwardness about appropriating a MERBoard that was currently showing an image. The author of the images said that people understood that the images were "like screensavers" – non-urgent and displayed as objects of interest, and that it was thus acceptable to hide the image using the whiteboard tabbing functionality in order to use the board for other purposes. There was a "sense that it was public space" and that anything left there was "fair game," as opposed to owned content.

5.3 The Mars Clock

Decreasing interaction leads to ambient information display: The Mars clock was a particularly interesting example because of how the ambient display use of MERBoard emerged as the mission tasks and collaboration styles changed. As the mission progressed, the Mars clock became the single most dominant use of the MERBoards used by the scientists. One scientist described the phenomenon as: "When people stopped using the MERBoard, the clock became a useful thing to have up." This statement suggests that it may not have been the case that the clock was perceived a crucial functionality of the MERBoard, but rather that as the other functionalities of MERBoard ceased to be as applicable in everyday work activities, the clock was useful default content for the tool.

While scientists generally described the Mars clock as extremely useful, many of them felt the need to "admit" this appreciation of the clock, as they were aware it was not the use that took the fullest technological advantage of a sophisticated and expensive system. Even so, they expressed a preference for keeping the clock ambient in the environment; clocks on their personal machines would take up valuable personal workspace and would be likely to be covered up by other more pressing applications.

Although the use of the clock was entirely passive, the value of this ambient information as a group resource is clear. Even in the later phases of the mission when some of the MERBoards were being used almost solely to display the Mars time, the administrators of the system were flown in to fix them when they crashed.

Social difficulties stemming from uncertainty of use and ownership: Some scientists suggested that people might have wanted to use the MERBoard, but were hesitant to appropriate the board for fear of depriving other group members of the clock. The scientist who frequently posted images using the whiteboard believed that people were considerably more hesitant to hide the clock to interact with the MERBoard than they were to hide the images that he had displayed; once the clock was on the MERBoard, people were less likely to use it than if it had one of his images displayed on it. The scientists may have perceived the clock as being crucial to others' work and were hesitant to interact with the display for their own benefit if it meant inconveniencing the group at large. It also suggests that images were perceived as interesting but non-urgent and non-task-critical, whereas the clock was perceived as potentially in use at any time.

5.4 CIP and Other Schedules

Structured ambient information: Another use of the MERBoard frequently mentioned by mission scientists and engineers was for the passive display of schedule information. Some of the MERBoards in the science assessment area were used for schedule display nearly as much as they were for clock display. An individual's CIP (Collaborative Information Portal) schedule would be posted on the group's MERBoard and then displayed ambiently throughout the day for the entire group's use. These schedules kept group members aware of important events such as satellite passes and meeting times with very little effort. Interestingly, although this use of the MERBoard was as passive as the display of the Mars clock, the general attitude towards the display of the CIP schedule was somewhat more positive. The schedule information was more inherently group relevant, and therefore may have been perceived as supporting collaboration or coordination to a greater extent than the Mars clock, and therefore more in keeping with the original intent of the shared display.

Low-overhead authoring: The sequencing work done by engineers was highly collocated and required tight time coordination, which made awareness of the schedules crucial. The tactical uplink lead engineer used text on the whiteboard tool of MERBoard rather than the official CIP schedule to type schedules directly onto the MERBoard, including times, events, and primary milestones such as the activity plan approval and sequence walkthroughs. Schedules were generated daily, either created from scratch or modified from the previous day's schedule. Additionally, schedules were modified as necessary throughout the day by the tactical uplink lead engineer in the event that a particular activity "slipped."

The visibility of the MERBoard was extremely important for the display of the sequencing schedules not only because it provided the shared awareness, but also because the schedule did not reside elsewhere, either physically or virtually. The tactical uplink lead emphasized this point by saying that the version of the schedule on the MERBoard served as the "official memory of the activity." If anything needed to change, he would announce it verbally and make the change official by editing the text schedule the MERBoard; thus the MERBoard was the only persistent source of schedule information for this team.

The flexibility and low overhead of using this tool was what made it successful for schedule authoring, editing, and display. The tactical uplink lead admitted that the reason he chose to use the whiteboard for this purpose was because he had never bothered to figure out how to use the CIP schedules that the scientists used. He could not afford to spend "8 hours learning how to do a task." The straightforwardness of the whiteboard tool for text entry and display made it the fitting choice for this task throughout the mission.

6 Implications for Multi-Display Environment Design

In looking at the use of the NASA MERBoard over time, several patterns emerge across the various applications. These patterns demonstrate the evolving role of the system in the context of a dynamic work environment, and a complex ecology of displays. The evolution of the role of the MERBoard was clearly tied to several factors:

- *Changes in the collaboration style over time* – MERBoard's value for collaboration was that it supported synchronous sharing of artifacts; multiple users could engage in viewing, authoring and discussing material simultaneously. The fact that procedures became familiar and routinized meant that responsibilities could be divided up among workgroup members and tackled individually, thus reducing the need for a shared work surface for synchronous collaboration.
- *Changes in the tasks of the scientists over time* – MERBoard’s value for interaction was primarily as a ramp-up tool that allowed users to conduct exploratory work, especially when procedures or tasks were unfamiliar, and scientists benefited most from doing them together to see and learn how the problems should be addressed. As the mission progressed and mission goals became more focused, tasks required less exploratory work and less time and effort for decision making; groups ceased to need the support for shared exploration and discussion afforded by MERBoard.
- *Other displays and applications available in the environment* – MERBoards were one of many display technologies available to the scientists; the fact that they had other means of displaying information that also could be used for sharing, such as laptops and shared workstations for very small collaborations, and projection screens for large meetings, allowed tasks to migrate off of the MERBoard as necessary. Had MERBoard been the primary or only large display technology available to the scientists, the migration of tasks would have been different.

These three factors together shaped the use of the MERBoard during the mission and the pre-mission training. Taking these factors into account in evaluating the ebb and flow of MERBoard use during the mission and pre-mission, we identified some implications for display ecologies and large interactive displays for supporting group work:

- *The transition from interactive use to ambient display* – Designers of large displays should expect that the interactive use of large displays may not be constant over time, but that users may continue to find value in the ambient display capabilities of the systems. For this reason, applications and functionalities should not be designed only with interactive use in mind; attention should also be paid to how applications might be designed for passive use, what kinds of content might provide value while the displays are not being used interactively, and how that content can be easily shown on the display. In the case of the MERBoard, ambient use of the whiteboard for image display was valued, but not many users chose to post content. Low-overhead methods of information display might have helped to encourage this use, thus making the tool more valuable to the group. The Mars clock and schedule were both valuable to the group as ambient information; designers might also consider what other types of passive information would be of value for presentation in the environment.

- *The dynamic use of multi-display environments* – Large interactive displays in multi-display environments are by nature group-owned and flexibly appropriable; constant, steady use need not be a goal that determines the success of such systems. Rather their value should be considered in terms of the ease and level of support for task and collaborations that benefit from the use of a shared interactive surface. Multi-display environments should therefore be designed to be flexible and dynamic, perhaps allowing them to be easily reconfigurable, and designing for the fluid easy migration of tasks among the various display surfaces.
- *Support for undefined tasks and proceduralization* – Systems such as MERBoard support exploratory tasks and tasks that do not have a set procedure, becoming less necessary when work becomes streamlined and routinized over time. Designing for continuity by making data products easily accessible and movable between the various displays will help make transitions in work processes smoother, and help ensure that artifacts continue to be valuable as work progresses.

7 Implications for the Evaluation of Large Displays

From our in-depth study of the MERBoard within the context of a display ecology, we garnered several important lessons about evaluating the use of such systems. First, the “success” of a large interactive display within a display ecology cannot be measured by whether a steady state of use is reached. Because people appropriate these tools as necessary when tasks and collaborations require them, there may be a natural ebb and flow of use that does not correspond to success or failure, but rather to the dynamic nature of collaborative work processes. Success is therefore better evaluated by examining the ease and extent of support that such displays provide when tasks call for a shared visual display or interactive work surface.

Similarly, the notion of a “killer application” is one that needs to be reconceived in the context of shared displays in these environments. In the case of the MERBoard, because of changing tasks and collaboration styles, no application was used constantly throughout the mission. However, the SolTree clearly was a tool that got people to use the system, and functioned as a killer app in the sense that it was crucial to their work tasks for a period of time. During much of the time that the scientists were using SolTree for planning, planning methods such as the building of individual trees using PowerPoint would not have been sufficient because they needed the shared visual surface, as well as the shared exploration and decision making process. For these types of systems, killer apps may be better conceived as applications that support a particular task well enough to allow users to understand the value of the tool for the task.

Another important lesson regarding the value of large displays in work environments came from our observation of the interplay between interactive use and ambient information display. In the realm of large interactive display research, a decrease in interactivity is often viewed as a failure of the system to support workgroup practices. We observed a migration from interactive use to ambient information display, and through our interviews discovered how valuable this ambient information was. We therefore believe that success should be evaluated by looking both at interactivity as well as the value of the display in passive uses.

Finally, in the greater context of a display ecology, it is misleading to evaluate the isolated use of a single system; the existence of other displays in the environment means that it is important to understand how the ecology functions as a whole, not just how individual displays are used. Our findings lead us to suggest that the ebb and flow of use of a large display groupware system may not be an indication of problematic design or failure of the system to support collaboration sufficiently, but rather an indication that the need for such technologies in collaboration are dynamic rather than static. Just as researchers working together to write a paper may initially spend many hours brainstorming together using a whiteboard, the fact that they may later spend more time writing sections individually at their personal machines should not be regarded as a failing of the whiteboard to maintain collaboration; instead the nature of the collaboration changes, making other technologies more appropriate for the time being. In evaluating displays in such multi-display environments, we believe it is better to examine how well and fluidly the ecology as a whole supports the work tasks than to assume that disuse of a tool is a failure of the technology to support the task.

8 Conclusions

Evaluated within the context of a display ecology over an extended period of time, the NASA MERBoard can be considered somewhat successful in how it supported those tasks for which a shared work surface and shared visual display offered benefit. Its interactive and passive uses were important, and even crucial to the users at different points in the mission. The fact that it was used less for interactive purposes over time reflects the changing tasks and collaboration styles of the workgroup more than flawed design. MERBoard still presented several challenges to its users that decreased the overall flexibility and effectiveness of the display ecology as a whole. Users could not migrate content easily from SolTree into a form usable with a projector, creating additional overhead. Similarly, the work required to migrate content from a laptop onto the MERBoard may have decreased the use of MERBoard as an ambient display tool for sharing ideas and artifacts. The findings of our study and our design recommendations are currently being incorporated into new iterations of MERBoard's design that will be deployed at other NASA sites or to support future NASA missions.

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