

# Adapting paper prototyping for designing user interfaces for multiple display environments

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**Abstract** A multiple display environment (MDE) networks personal and shared devices to form a virtual workspace, and designers are just beginning to grapple with the challenges of developing interfaces tailored for these environments. To develop effective interfaces for MDEs, designers must employ methods that allow them to rapidly generate and test alternative designs early in the design process. Paper prototyping offers one promising method, but needs to be adapted to effectively simulate the use of multiple displays and allow testing with groups of users. In this paper, we share experiences from two projects in which paper prototyping was utilized to explore interfaces for MDEs. We identify problems encountered when applying the traditional method, describe how these problems were overcome, and distill our experiences into recommendations that others can draw upon. By following our recommendations, designers need only make minor modifications to the existing method to better realize benefits of paper prototyping for MDEs.

**Keywords** Multiple display environments · Paper prototyping · Rapid prototyping · User interface design

## 1 Introduction

A multiple display environment (MDE) networks personal devices such as laptops and shared devices such as large vertical displays to provide a virtual workspace [1]. Designers are just beginning to develop interfaces that leverage the unique affordances of these environments, e.g., interfaces that allow application windows to be opened across independent displays [2] or that allow task artifacts to be modified through personal devices and juxtaposed on shared displays [3].

When designing any interface, designers need to employ methods that allow them to rapidly generate and test alternative ideas [4], and this is especially true for MDEs as they represent a complex design space and there are few guidelines available. Paper prototyping offers one promising method, as it allows numerous ideas to be explored with minimal cost and has long been a staple of the design community [5]. However, as paper prototyping has evolved with the assumption that the interfaces being designed were for single user, single display applications; a challenge is to understand how to best adapt this method to explore interfaces for MDEs where there are *multiple* displays that are shared by *multiple* users.

For example, how should paper prototyping be adapted to simulate different numbers, sizes, and spatial configurations of displays, simulate the coordination of input and output among displays, allow facilitators to quickly manipulate artifacts among displays, and elicit feedback from groups of users in situ. Addressing these challenges is important for conducting an efficient evaluation and conveying a realistic interaction experience, which helps designers better identify usability issues and generate novel insights

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early in the design process [6]. This, in turn, can lead to more effective interface solutions. Any designer who employs the use of paper prototyping within MDEs would need to address similar challenges.

In this article, we share our experiences of having encountered and addressed many of these challenges within two research projects involving MDEs. One project investigated the design of interfaces for managing task artifacts across displays [7, 8] while the other investigated how to utilize multiple displays to better support collaborative design activities [9]. We provide relevant context of the projects to situate how these challenges materialized when applying the traditional paper prototyping method, illustrate how the challenges were addressed, and distill our overall experiences into practical recommendations that others can draw upon. By following our recommendations, designers need only make minor modifications to the existing method to better realize benefits of paper prototyping for MDEs.

## 2 Related work

We further describe MDEs and challenges of designing for these environments, review the traditional paper prototyping method, and situate paper prototyping within other commonly used tools and techniques for designing user interfaces.

### 2.1 Multiple display environments

A multiple display environment (MDE) networks personal/portable devices and shared/fixed displays within a physical or ad-hoc workspace [1]. Examples of MDEs include CoLab [10], Dolphin [11], iRoom [1], and Gaia [12]. The promise of these environments is to allow users to better create, share, and organize digital task artifacts for both individual and group activities, e.g., for design, brainstorming, urban planning, problem solving, and more.

As the systems needed to form MDEs have become available [13], we envision that will be increasingly facing the challenge of developing interfaces for applications that will execute in and leverage the unique affordances of these environments, e.g., see novel applications discussed in [2, 3, 11]. Developing interfaces for these environments requires designers to consider interaction designs that allow users to interact with task artifacts spread across multiple displays as well as to consider the coordination issues caused by multiple users attempting to interact with those artifacts at the same time [14]. As there are few guidelines

available for MDEs, it is imperative that designers have access to methods that allow them to effectively generate and test numerous alternatives early in the design cycle, as this is critical to developing an effective interface solution [4]. Paper prototyping offers one promising design method and our work seeks to understand how to adapt it to better explore interfaces for MDEs.

### 2.2 Constructing and evaluating paper prototypes

Paper prototyping is a widely used and validated technique for exploring, communicating, and evaluating early interface designs [5]. Prototypes are typically constructed using combinations of stock paper to represent main interface screens, overlays and sticky notes to represent results from user interaction, colored pens and pencils to sketch content, etc.

Paper prototyping has many benefits during the design process. These benefits include allowing rapid externalization of design ideas with low investment, allowing numerous alternatives to be generated and tested early in the design cycle; designers can iterate on a design many times prior to committing to an implementation; evaluation tends to focus more on macro-level issues such as major interface screens and overall interaction metaphor, issues that need to be resolved as early as possible; and users and other designers are more willing to offer substantive critiques of the design since it appears rough and informal [15]. Our work seeks to adapt the paper prototyping method so that designers are able to realize these benefits when designing interfaces for MDEs, e.g., to effectively simulate the use of multiple displays and coordinate input from multiple users.

The primary limitation of constructing paper prototypes is the lack of complete realism in the resulting interaction, but this is generally a worthwhile tradeoff for the ability to explore numerous alternatives early in the design cycle [15].

A common technique for evaluating paper prototypes is user evaluation [4], where a user informally works through several controlled tasks and the design team tries to identify where the prototype did (and did not) meet user expectations. Our work has focused on adapting this particular evaluation technique to support input from a group of users during an evaluation, as this allows the design team to test coordination and other group issues with the prototype. However, future work should investigate how to adapt other evaluation techniques such as cognitive walkthroughs [16] and heuristic evaluations [17] for interfaces for MDEs.

### 2.3 Other prototyping tools and techniques

Though commonly used, paper prototyping is just one of many techniques for exploring user interfaces in the early stages of design. Other techniques include the use of high-fidelity tools, informal design tools, and Wizard of Oz studies.

High-fidelity tools such as Director, Flash, and Visual Basic allow designers to build high-fidelity representations by composing pre-defined components and scripting interaction. The advantage is that users can directly interact with the prototype while the disadvantage is the increased investment needed to create it.

Informal design tools also allow designers to construct functional prototypes, but provide a more natural interface representation typically based on the use of storyboards and sketching [18]. For example, CrossWeaver [19] is an informal design tool that allows a designer to sketch a series of interface screens, specify transitions between screens and across displays, generate a functional prototype, and execute it within an MDE. The disadvantage is that the range of interaction that can be specified with this and other informal tools is quite limited.

Using a Wizard of Oz technique [20], users are provided with an interface that appears to be functional, but in fact, only part of it has been implemented. When a user interacts with the interface, a facilitator changes the representation in the background causing the user to perceive that s/he is interacting with a fully functional application. This allows designers to evaluate the interface with a high degree of realism, but without the cost of implementing it. This technique is particularly useful for speech, audio, and video-based interfaces (e.g., see [21]).

Each of these techniques is more or less useful for different design problems and it is generally left up to the designer to select which one to use. In practice, however, designers often choose to use paper prototyping, especially when the design space is large or unexplored, as it is for MDEs. Our work seeks to ensure that the use of paper prototyping remains an effective choice when designing interfaces for MDEs.

### 3 Paper prototyping user interfaces for MDEs

We describe how paper prototyping was utilized to design interfaces for two research projects that involve the use of MDEs. One project investigates the design of world-in-miniature interfaces and related interactions for managing task artifacts across displays. The second project investigates how the use of tablet PCs

or similar devices networked to a large display can better support a shared information space for collaborative design. These are representative of many projects being pursued in MDEs (e.g., see [1, 10, 22–29]).

Both of these projects posed significant interface design challenges for at least two reasons. First, we needed to provide users with the ability to access, share, and organize task artifacts across displays, where the displays could be of various sizes and could be both local to as well as distant from the users. Since there are few, if any accepted techniques for performing these types of interactions, the design space is still relatively unconstrained. Second, since the configuration of a workspace can affect the usability of an interface [7, 30], the interface needs to be designed for and tested with various configurations; e.g., with different numbers of displays, displays of various sizes, and displays in myriad spatial configurations.

Since we needed to design and evaluate interfaces situated within this complex design space, we felt it was imperative to be able to rapidly explore it and not be prematurely constrained by existing design templates or interaction metaphors. We also felt that a thorough exploration of the design space would help spur our own creative thinking, leading to a more usable solution [31]. We thus turned to the use of paper prototyping during the early stages of design in both projects. In total, we created more than a hundred design artifacts, conducted half a dozen evaluations, and worked with over thirty users, both individually and in groups.

In the next sections, we first review the basic method employed for building and evaluating the paper prototypes. We then provide further details about the projects, identify major problems encountered when applying the basic prototyping method, and describe how these problems were overcome.

#### 3.1 Paper prototyping method

We initially approached the paper prototyping process from the perspective of currently accepted practices [4, 5]. Prototypes were constructed by using physical tools such as stock paper, transparent overlays, colored pens and pencils, etc. Once constructed, prototypes were evaluated with representative users.

During an evaluation, a user would informally work through several controlled tasks with the prototype and would be encouraged to “think aloud” in order for the design team to better understand how she was reasoning about interacting with the interface. As a user interacted with the prototype, one researcher (the “computer”) would manipulate the paper artifacts to

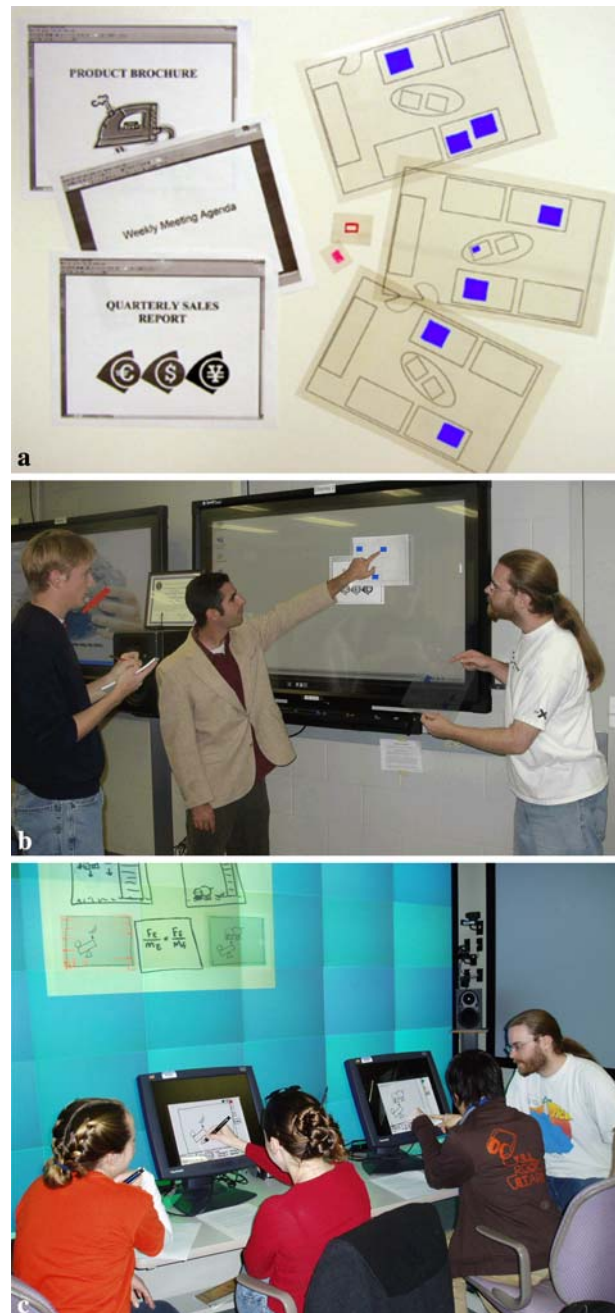
simulate responses to user input; another researcher (the “facilitator”) would guide the overall session, asking and answering questions and prompting the user to continue talking aloud; and a third researcher (the “note taker”) would document usability issues and user comments about the prototype [4]. Figure 1a shows a sample of design artifacts from one of our early paper prototypes while Fig. 1b and c show evaluations of different prototypes in progress.

Major design issues were identified by observing parts of the interface that were particularly problematic for users when performing the tasks, by analyzing verbal protocols to determine when expectations did not match the allowable controls [32], and by analyzing user feedback from open-ended discussions. Lessons from each evaluation guided subsequent iterations on the design. The transition from paper to functional prototype was made once we felt most of the major usability issues were reasonably resolved. Overall, the use of paper prototyping allowed us to rapidly generate and test alternative ideas, uncovering usability issues that may not otherwise have been identified had we started with a high-fidelity prototype.

### 3.2 Prototyping interfaces for managing digital artifacts

In this project, we have been exploring the use of world-in-miniature interfaces and related interaction techniques for managing task artifacts in an MDE [7, 8]. A initial task analysis showed that our interface should include the ability to relocate artifacts (applications) from a personal device to a shared display, from one shared display to another, from a shared display back to the personal device, etc.; and users should be able to redirect their input either as part of or separate from the relocation of applications. To explore interfaces supporting these and other tasks, we constructed several paper prototypes and evaluated the effectiveness of the prototypes by having users attempt to perform these tasks with them. The user evaluations followed the basic methodology previously described.

In preparing to evaluate our interface prototype, the first problem that had to be addressed was finding an effective method for simulating a particular physical configuration of displays in an MDE, as this would likely affect the design of our interface. For this project, the target MDE was assumed to have about one to three personal devices and about one to three large displays. One possible method was to arrange design artifacts onto separate regions of a large horizontal table, with each region representing a different display. However, we felt that this method would not ade-



**Fig. 1** a A sample of artifacts used in one of our paper prototypes. In b, a user is interacting with a prototype of our world-in-miniature interface while one researcher takes notes and another prepares to show the interaction results with a transparent overlay. In c, two users are interacting with a paper prototype of our interface for collaborative design. A researcher works with each user to manipulate the paper design artifacts that are associated with each user’s interface

quately depict the actual size, distance, and spatial configuration of displays in the target MDE.

After exploring this and other alternatives, our selected solution was to use the existing devices available in our lab as *physical props*. During an evaluation, we

placed design artifacts directly on the surface of each display (the devices were turned off). Using the devices as props provided an increased amount of realism, better conveying the physical configuration and function of displays in the MDE.

Following recommended practice [4], we created most of the prototype artifacts of the size of standard paper (21.6 cm × 27.9 cm). Artifacts of this particular size were effective when the user was interacting with a tablet PC or display of similar size, but when artifacts representing application windows were moved to a large display, they now reflected an inaccurate scaling of the content. This made it difficult to view the content from a distance and suggested an inappropriate resolution of the large display (see Fig. 2). We addressed this problem by creating additional versions of each artifact appropriately sized for each display. This provided increased realism and better-matched users' expectations.

Finally, in our evaluations, the single “computer” had to walk quickly among represented displays in order to update them based on the user's interaction. This created two additional problems. One was an overly slow response time, which hindered our ability to simulate realistic interaction between displays. The other problem was that the physical act of moving around the workspace implicitly informed the user of where to next direct their visual attention. This was particularly problematic when we were trying to determine how well users could detect an application's new location based solely on information provided through the interface prototype (see Fig. 3). We addressed these two issues by having multiple “computers” available in the workspace, one per display. This setup resulted in faster response times and reduced the



**Fig. 2** In this figure, a paper design artifact of standard size is appropriate for a display the size of a tablet PC, but is inappropriate for a larger display



**Fig. 3** A user is waiting for the researcher to move an “application window” from one display to another in response to his input. With only one researcher acting as the “computer,” updating multiple displays can be time-consuming and may implicitly direct the user's visual attention

overt physical acts of having to physically walk to the displays to place design artifacts.

Overall, with these changes in place, the prototyping process was able to yield valuable usability lessons early in the design process, when it was easiest to address them. For example, we learned that different interfaces caused different amounts of physical movement within the workspace and that users were very sensitive to this issue. A second lesson learned was that the interface itself needed to better represent the physical workspace, e.g., by showing salient features such as the door and table, in order to facilitate an efficient mapping between the interface representation and the physical workspace. A third lesson was that users wanted to see visual feedback of their ongoing interaction on the physical screens as they moved an application window across their representations in the local interface. These lessons would likely not have been discovered in the early design process had we not evaluated the prototypes in a manner that realistically simulated the size and physical configuration of displays. Details of these and other lessons from the prototyping process and our resulting interface can be found in [7, 33].

### 3.3 Prototyping interfaces for collaborative design activities

In this project, we have been leveraging design and creativity theory to guide development of computational tools that better facilitate the process of creative thinking among groups of co-located designers [9]. Our approach is to enable personal devices such as tablet

PCs to network to a machine driving any large display to provide a shared visual workspace. The interface is being designed to support several tasks, including sketching design ideas from local devices; configuring designs to be private, public, or shared; organizing and comparing designs on the shared visual workspace; accessing designs created by other designers, and manipulating remote designs from local devices. Several paper prototypes were created to understand how to best support these and other tasks.

Building on lessons from the other project, we began with an environment configured with physical devices used as props, appropriately sized paper artifacts, and multiple “computers”. However, this project also posed new challenges for the paper prototyping process because groups of users (as opposed to individuals) were now involved in the evaluations, the large display being simulated was a high-resolution wall-size display (3.7 m wide by 2.5 m tall), and the use of the large display was tightly integrated within the interaction design of the interface; e.g., each instance of the application showed an interactive spatial map of the designs on the shared display and users could choose to sketch separate designs independently or different parts of the same design simultaneously.

As with the previous project, we found that overlaying standard size artifacts on a large display was ineffective. However, even having the appropriate sized artifacts still caused problems as the “computer” could not reach many regions of the display wall and his physical presence often blocked portions of the display. To address these problems, our solution was to scan the artifacts and show the electronic versions on the display wall (this device was now turned on) in the MDE. This allowed us to more realistically move the artifacts on the display wall in response to user interaction on the local device and position the artifacts in locations that were otherwise impossible or difficult to reach. Having the electronic versions of the sketches also allowed the “computers” to more easily synchronize the information being presented among the displays in the workspace.

Another issue was how to tap into a group’s reasoning processes as they were engaged in interacting with a prototype. This is valuable for eliciting when and why an interface does meet expectations and deriving novel design insights that can close these gaps [4]. When evaluating a prototype with a single user, a common technique is to have the user “think aloud” as she interacts with the prototype [34]. However, this technique is obviously problematic for groups as asking all of the users to talk aloud at the same time would be disruptive.

During an evaluation session, our goal was not only to tap into each user’s ongoing reasoning about interacting with the prototype, but also to enable users to build off each other’s comments. For example, studies on brainstorming show that groups are able to produce more insights when users are able to re-interpret each other’s ideas [35]. Our solution was to provide each user with a paper notebook and have them write down notes as they interacted with the prototype (e.g., after completing a task or subtask). At pre-defined points, we would engage the group in a brief discussion about the interface so far, inviting users to leverage their notes to recall specific issues for discussion and build off each other’s ideas.

Since the interface was being designed for collaborative use, we felt it would also be important to facilitate a reasonable degree of workspace awareness [36], e.g., to help users understand whose interactions were causing changes to the content on the shared display. Our solution was to have users sit close together; closer than they might otherwise be in actual work settings, allowing them to easily glance at each other’s interface screens and coordinate and understand each other’s actions.

With these additional changes in place, the prototyping process again yielded important usability issues early in the design process. For example, we learned that when information was placed on the shared display, users expected it to initially appear on their side of the display; that a user’s interactions with shared information needed to be fed through to other users’ local interface; and that users expected not only to be able to share information on the large display, but also be able to control whether other users could interact with it. These and other usability lessons, along with our resulting interface, can be found in [9].

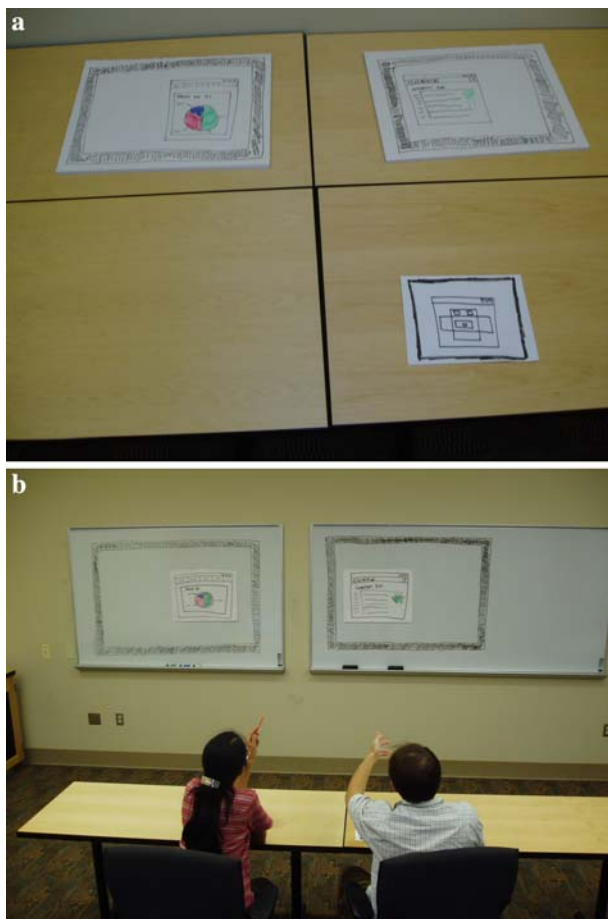
#### 4 Recommendations

Based on our experience from these projects, we recommend the following modifications to the traditional paper prototyping process to effectively represent and evaluate user interfaces for MDEs or similar environments:

- *Simulate the size and configuration of displays as realistically as possible.* The size and spatial configuration of displays in an MDE impacts both the interaction design of an interface as well as users’ perceptions of how those displays function together [33]. Therefore, simulating these characteristics is important when evaluating paper prototypes. In our projects, we physically positioned representative

displays (they were tuned off) and used them as props to reflect the expected configuration of the MDE. During an evaluation, the “computer” would move around the workspace and place the design artifacts directly on the surface of the displays. In situations where real devices are not available, e.g., you are designing for a client’s workspace; the use of other physical props, such as white boards or poster board appropriately sized and positioned, could serve a similar function, e.g., see Fig. 4 and work in [37].

- *Explain the functional relationship among the (simulated) displays.* At the onset of our evaluations, we quickly learned that many users struggled to understand how the paper prototype would “function” across displays, i.e., how and when input on one design artifact would cause changes to artifacts



**Fig. 4** The size and spatial configuration of displays in a workspace can affect a user’s perception of how the displays function together. On the *top*, we show how artifacts could be placed into separate regions on a table to represent multiple displays, but this does not reflect their true size and position. On the *bottom*, we show how a more realistic setup could be created by using two whiteboards to simulate the size and expected configuration of two large displays in a workspace

on other displays. This is likely due to years of interacting with the desktop where application I/O is tied to a single device. Though the application and relevant context should always be explained as part of pre-evaluation instructions, we recommend taking a few extra minutes to thoroughly explain and demonstrate how the prototype is divided and is intended to function across the displays (assuming that testing these relationships is not the focus of the evaluation). This can reduce confusion and misunderstandings during the evaluation.

- *Size design artifacts relative to the size of the corresponding device.* Using paper design artifacts of standard size (21.6 cm × 27.9 cm) on a large display (or prop) results in an unrealistic visual scaling of the artifact. For example, in an early evaluation of our interface for collaborative design, we created artifacts out of standard size paper. This worked fine when using the artifacts to simulate local interactions on a tablet display. But, when the artifacts were manipulated on the large display to simulate changes to the shared context, users were unable to effectively view the interface representations. We recommend creating multiple versions of the artifacts, one for each size of device that they will be shown on. Alternatively, artifacts could be scanned and then placed and sized on working devices during the evaluation using a simple software tool.
- *Station an experimenter at each display to decrease interaction response times.* In an MDE, having only one “computer” manipulate the design artifacts in response to user interaction can cause unacceptably slow response times as the experimenter must physically move to the devices. In addition, this practice can inadvertently lead a user’s visual attention to a particular device. We recommend assigning one experimenter to each device in the MDE, which, assuming effective coordination, can reduce interaction response times and mitigate leading the user’s attention. An alternative would be to scan the artifacts and show them on working devices as needed using a simple tool.
- *Use physical movement as an additional metric by which to evaluate the usability of interfaces for MDEs.* From evaluating paper prototypes of our iconic interface, we observed that different interaction designs caused users to have to physically move around the workspace in different amounts and that they were sensitive to this issue. Because MDEs are intended for daily work, this ergonomic impact needs to be considered during the design process. Thus, physical movement such as the

number of footsteps and head turns should be considered when evaluating paper prototypes of interfaces for MDEs.

- *Elicit a group's ongoing reasoning using two-stage feedback.* Tapping into a user's thought processes when interacting with a prototype can provide valuable design insight and, for single user interfaces, is typically achieved by having the user think aloud during the evaluation session [34]. However, when groups are involved, e.g., for a collaborative interface, it would be distracting for all of them to be talking aloud at the same time. To address this issue, we recommend enabling and encouraging each user to write down short notes while interacting with the interface. At pre-defined moments, lead a short group discussion, prompting users to share issues in their notes. The notes could also be collected for later analysis or to help provide supporting rationale for a particular design decision. It may also be helpful to create multiple sets of artifacts; one set per user, with artifacts from each set having a different color around their borders or other user-identifying mark. This could help further facilitate awareness of each user's interactions.

We have and continue to apply these recommendations in our own ongoing work. Our experience is that following these recommendations can enable evaluations to be performed more efficiently and lead to more informative results. Though our recommendations impose a small amount of additional work for a design team, we believe that this is outweighed by the increased likelihood of identifying important usability issues early in the design process and should not negate the fundamental value of paper prototyping relative to other techniques. However, future work is needed to empirically compare the results of using paper prototyping with and without our recommendations for exploring interfaces for MDEs.

Applying our recommendations requires only minor modifications to existing practices and can thus be broadly applied in other projects. This set of recommendations should not be considered exhaustive. We expect that further experience with paper prototyping of interfaces for MDEs and similar computing environments will continue to produce additional useful lessons.

## 5 Conclusion

As devices become more pervasive and inter-connected, designers will be increasingly grappling with the challenge of developing interfaces that utilize

multiple displays and that support multiple users. It is thus imperative to understand how existing design methods such as paper prototyping need to be adapted to meet the challenges in this emerging design domain.

This paper has made two important contributions in this direction. First, we have provided a set of experience-based recommendations for how to adapt the traditional paper prototyping method for MDEs. Designers can draw upon these recommendations to better generate and test alternative designs for their own interfaces for MDEs, facilitating more effective design solutions. Second, this article has contributed to raising needed awareness of some of the challenges of designing interfaces for MDEs, and should help facilitate further research on developing more effective methods and tools for this emerging design domain.

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