

Understanding Designers' Use of Paper in Early Design and its Implication for Informal Tools

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ABSTRACT

While informal tools can benefit early design, their use requires that a designer give up the richer affordances of physical tools such as paper. To better understand the importance of physical tools for early design, we conducted contextual interviews with twelve designers from diverse domains. We found that paper is an integral part of the early design process and argue that informal tools will not realize their full potential unless they provide benefits similar to those of paper. We recommend that informal tools provide a mechanism to connect the use of physical tools to complement their electronic interface. We discuss several such mechanisms for an existing informal tool.

Keywords

Design Practice, Digital Pen Interface, Early Design, Informal Tools, Paper.

INTRODUCTION

In early interactive systems design, the use of computer tools can provide designers with immense benefits such as remote collaboration [6], design history [12], and execution of a design [4], leading to more effective solutions [24]. However, designers typically forego the use of computer tools in favor of using physical tools such as paper, overlays, and sticky notes [5]. Two reasons for this are that existing computer tools use *formal* representations, while designers use *informal* representations in early design practice [22], and that physical tools provide richer affordances than computer tools such as spatial flexibility, tailorability, and sociability [9].

To allow designers to leverage informal representations in a computer tool, researchers have developed informal tools based around intelligent sketching and pen-based input [4, 15, 16]. These tools enable more effective communication of the design than physical tools while impeding the design

process less than existing computer tools [3]. Informal tools, however, require that a designer sketch in an *electronic* medium and give up the richer affordances of physical tools. This calls into serious question whether continued enhancement of the electronic interfaces of informal tools can adequately address the full range of designer needs in practice.

To better understand the importance of physical tools in early design, we conducted contextual interviews with twelve designers from diverse domains. While prior work has argued for the richer affordances of physical tools [13], and has investigated design representation and process [5, 22, 26], our study investigated how and *why* designers utilize physical tools, especially paper, to meet their needs in early interactive systems design and to recommend how informal tools could better meet those same needs.

Consistent with similar studies in other domains [9, 17, 23], we found that paper is an integral part of the early design process. Designers use paper for brainstorming, annotation, and communication, and *choose* to use paper because it is quicker and easier to use, more portable, and more useful for face-to-face collaboration than computer tools.

From our study, we conclude that informal tools should provide a mechanism to connect the use of physical tools to complement their electronic interfaces. Several such mechanisms are discussed for informal tools, a sketch & scan interface, a tangible interface, and a digital pen interface. We describe a scenario illustrating how the digital pen interface could complement the electronic interface of our informal tool DEMAIS [4]. The scenario shows how the representation of a design can be intelligently mapped between a paper and electronic medium, how a designer can now select the interface best suited for a particular task, and how the benefits of computer tools can be accessed in early design without losing the affordances of physical tools.

RELATED WORK

In this section we discuss how our work differs from prior studies of the use of paper and studies of design practice, how our work impacts research in informal tools, and how it builds on research on physical interfaces.

Studies of Paper and Design Practice

Studies of paper in work practice show that paper continues to be widely used for many reasons including its spatial flexibility (it can be quickly arranged in physical space), tailorability (it can be easily annotated), and sociability (it facilitates face-to-face communication) [9].

While studies of design practice have noted the common use of paper in early design, these studies have focused on the *process* of creating informal representations, but not on *why* paper was so often selected as the medium of design representation [5]. For example, in [22], the authors found that web designers use paper to rapidly explore many design possibilities, but their study did not focus on why paper was selected the medium of representation.

In our study, we focused specifically on how and why designers utilize paper as the representation medium in the early design process. Our study provides practical evidence that shows that informal tools need a connection to physical tools to meet the full range of designer needs.

Informal Tools for Interactive Design

Informed by studies of design practice, researchers have developed several intelligent sketching or “informal” tools including SILK [15], DENIM [16], and DEMAIS [4]. An informal tool supports the use of pen-based input for sketching an informal representation of a design and enables execution of that design. These tools support more effective communication than physical tools while impeding the design process less than existing computer tools [3].

The use of informal tools, however, requires that a designer sketch in an electronic medium, losing many of the richer affordances of physical tools. Our study investigates the importance of physical tools for early interactive systems design and provides compelling evidence that informal tools should include a mechanism to connect the use of physical tools to complement their electronic interface.

Physical Interfaces to Computer Tools

A physical interface provides a mechanism for connecting physical and computer tools. Paper PDA, for example, enables users to integrate paper and electronic representations of calendar, email, and task information [11]. Paper-to-computer integration is achieved by having users write on paper and use stickers that contain radial markers. When a computer system later analyzes the paper, the radial markers cause specific actions to be invoked in the system. Computer-to-paper integration is achieved by printing the electronic data to paper pre-printed with the markers. Other physical interfaces include [2, 10, 18, 25].

Physical interfaces often provide users with devices similar to the physical tools with which they are already familiar. For example, Anoto’s digital pen system [1] enables users to write on paper with a pen that records and saves its stroke information. When the pen is cradled, the stroke information is uploaded to a computer tool, which can then apply its own analysis to the information. Digital pen

technology is commercially available and provides development kits for building physical interfaces. In [10], researchers have used digital ink to better support paper-based annotation of electronic documents.

Tangible interfaces enable users to directly interact with digital information and computation using physical objects [7, 13]. For example, Rasa [20] uses physical maps, post-its, and markers to maintain situation awareness in a military command post, yet supports remote collaboration and intelligent assistance. Designer’s Outpost [14] enables a distributed design team to explore information architecture for web design by linking physical post-it notes to an electronic representation shared among remote designers.

Our study draws upon this area of research in concluding that an informal tool should provide a physical interface to complement its electronic interface. We discuss several physical interfaces that could provide such a mechanism in context of our existing informal tool DEMAIS.

USE OF PAPER IN EARLY DESIGN

Because the use of informal tools requires that a designer give up the richer affordances of physical tools, the purpose of our study was to understand the importance of those affordances for early design and the implications for informal tools. Our study consisted of twelve contextual interviews with designers from diverse domains. Of the twelve designers, four were web designers, each with at least three years experience; three were video game designers, each with at least five years experience; three were digital artists, each with at least two years of experience; one was an architectural designer and one was an industrial designer, each with one year of experience. These designers used both paper and computer tools such as Authorware, Photoshop, and Dreamweaver for design.

Contextual Interviews

For the interviews, we traveled to the workplace of the designer to make the designer feel more comfortable, to make sure they had access to their design tools and artifacts, and to gain a better understanding of their design environment. In an interview, we asked a designer to talk us through the early design of a recent or ongoing project.

Although the interviews were structured around a specific project, the projects varied widely among the designers, ranging from individual work on a website to large design groups working together on an interactive 3D game. While discussing a project, we focused on a designer’s use of paper, asking questions about what paper was used for and why it was selected in favor of computer tools.

We asked a designer to show us related design artifacts that were available, whether electronic or physical. We asked for copies of artifacts, and when permitted, we took the artifacts with us for later review. An interview lasted about one hour and was audio recorded for later analysis.

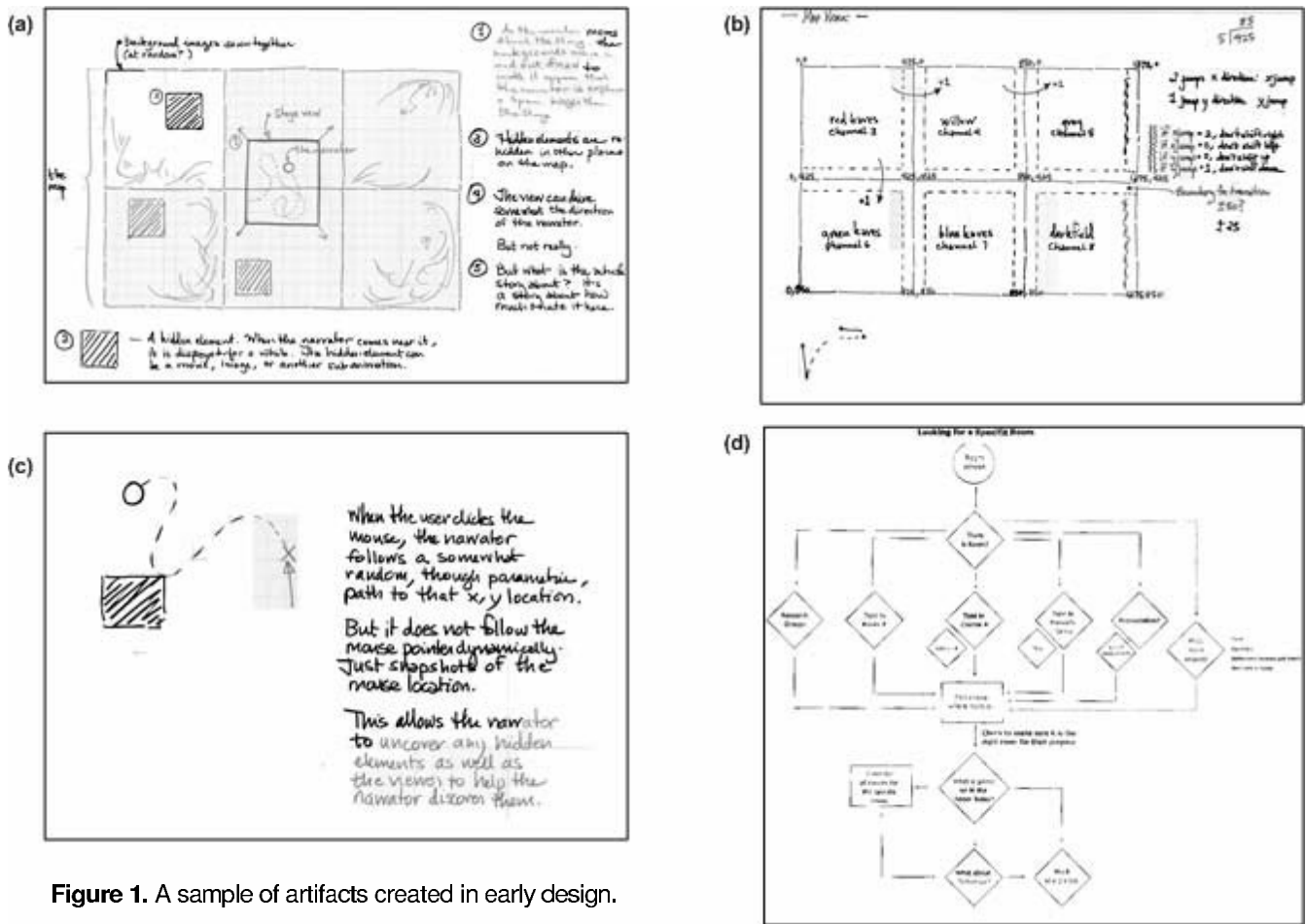


Figure 1. A sample of artifacts created in early design.

Design Tasks Better Supported by Paper

We discuss common - yet essential - design tasks for which the designers used paper and argue why these tasks would be more difficult to perform with computer tools.

Communicating Ideas

When a designer communicates an early design idea to a client, colleague, or end user, the designer typically talks through the idea spread across multiple sheets of paper. For example, Figure 1d shows a flowchart that was used to communicate how information was organized on a client's website. Other paper printouts were used to suggest alternative designs that would provide better organization. Designers choose to use paper to communicate ideas because it allows them to socially interact with the client as they are conveying design information. By gauging another person's understanding and reaction from their non-verbal cues, a designer can adapt their presentation to more effectively communicate the design.

Achieving the same communication bandwidth is difficult with a computer tool because computers are typically designed to be used by one person at a time. It is more difficult to allow multiple people to interact with a single computer system than with a single piece of paper because

only one person can control the computer system without changing seats or awkwardly leaning over each other. Additionally, because control can not be shared, the designer interacting with the computer typically spends much more time and attention dealing with the computer than communicating the design to the other person.

Soliciting Feedback

Designers argued that people are much more likely to give feedback when handed a paper design artifact than when sent a digital version of that same artifact. One designer described how when he sent around electronic versions of a design document, he got little or no feedback from the recipients, but when he printed out paper copies and directly handed them to people or even just placed the document on their desks, he received much more feedback. This small investment of effort to directly hand a collaborator a physical document, or even leave it on their desk results in much more feedback because the document is provided in a more direct, visible, and personal way. Computer tools filter out many of these social cues which are necessary for designers to generate the feedback essential to improving the design.

Annotating Designs

When analyzing a design, whether alone or in a group setting, a designer often makes notes on paper containing a copy of the design itself, either hand-drawn sketches or printouts of an electronic version. In Figure 1a, a designer wrote comments about the interactive behavior of the design to more clearly communicate it to a collaborator. During a discussion, designers also make short annotations within the spatial context of the design to better aid memory and reduce the amount of notes that must be written down. While most computer tools support annotation, there is always some interaction overhead, which can inhibit the amount or depth of annotation performed. With paper, there is no additional overhead for annotating a design.

Sharing at Meetings

Designers often find that bringing paper printouts to design meetings is useful for sharing information and that this is more useful than having an electronic design presentation (e.g. PowerPoint). For example, one designer talked about using paper artifacts in a meeting to enable each person to quickly refer to different parts of the artifacts and focus their ideas around those sections without disrupting the thoughts of others. They could also annotate the printouts to remind them of a comment they would like to make later or to give back as notes to the designer presenting the idea. To do this with a computer tool, each participant must bring their own computing device. In addition, there is much more effort required to make sure everyone has the most recent digital copies of design artifacts than to make sure everyone has a printout from a stack of papers. This is due to the lack of efficient sharing tools, differences in computer hardware or software, and the fact that people may not check for the electronic versions in time.

Rapid Sketching

Designers often make a quick sketch on a piece of paper when exploring alternative design ideas. This allows them to externalize their mental representations and the process of sketching helps them generate new ideas [21]. Many sketches take just a few seconds and are later discarded or set aside as no longer valuable. For example, Figure 1c shows a design idea that was rapidly sketched, but later discarded when a newer version of the design was created. Rapid sketching on a computer is certainly possible, but requires a stylus input device, supporting software, and sometimes the use of a specific room where these systems are available. Additionally, computer tools are restricted by an overpowering disadvantage: there is an extra layer of interpretation between the strokes that the designer makes and what the computer stores or displays on the screen. This extra layer requires a greater investment and more time for the designer to interact with it, thus taking away mental resources that could otherwise be used for creative design.

Ubiquitous Sketching

Designers were most emphatic about the use of paper when they discussed how they could use it ubiquitously. They

were adamant about the benefit of being able to sketch out ideas in a meeting or at a coffee shop. For example, a designer worked on Figures 1a and 1b both at home and the workplace due to her irregular schedule. Most importantly, however, the designer wanted to work on a design at different locations because she felt that it inspired her creativity - different ideas occurred to her when she was in different physical locations. To sketch design ideas using a computer tool in multiple locations, the designer must both transport the hardware with them and spend time setting up both the hardware and software before they can begin sketching in the computer tool.

Brainstorming

Paper is often used for brainstorming. For example, one designer discussed using “sticky notes” to design a video game storyline. The design team sketched events or characters that would be interacted with on separate sticky notes and then stuck them to the wall. While brainstorming, the designers moved the sticky notes around on the wall to iteratively refine the storyline. Most existing computer tools do not support free-form brainstorming techniques. At best, designers can use research tools such as [14], but these require special hardware such as large displays and video cameras. Using sticky notes on an available wall is cheaper and easier for face to face collaboration.

Refining Ideas

Designers use paper as a tool for refining complex design ideas quickly. This comes in the form of jotting down notes, making small sketches or diagrams, and marking relationships between them. For example, a designer sketched the idea shown in Figure 1a while brainstorming, then sketched the equations in Figure 1b to determine the mathematics necessary for the design to be implemented. While the results are incomprehensible to most, they made perfect sense to the designer and served as a recording of her thoughts before moving into a different medium where she could implement part of the design. Designers often choose paper for this task because they do not want to deal with the extra layer of interpretation of a computer tool before they are ready. This enables them to focus on creative design, not on using the computer tool.

To summarize, while specific research tools may support some of these tasks better than paper, the use of paper supports *all* of these tasks well. Most importantly, the tasks that designers use paper for - sharing, brainstorming, communicating, annotating, soliciting feedback, etc. - are absolutely essential for designing high-quality interactive systems [24]. If designers are restricted by the tools they use, they will likely produce lower quality systems or will produce systems of the same quality, but at a higher cost.

LESSONS LEARNED

From our study, we learned that the underlying reasons that designers choose paper for many design tasks include:

- *Paper is quicker and easier to use than a computer tool.* Designers emphasized this point from many different perspectives in the interviews. One designer pointed out stencil tools around his desk that he preferred to any computer tool for drawing a curve. Similarly, several designers noted that drawing lines and curves is much easier from certain angles and is therefore more easily accomplished by turning a sheet of paper than turning one's body. Paper also provides much higher-resolution than computer tools. Another designer discussed how computer tools are created for a "default user" which does not reflect his own style and preferences. Finally, designers often asserted that paper is quicker and easier to use because it doesn't require the use of menus or buttons. As one designer stated "[With paper] you don't have to go through all the menus, you just start drawing."
- *Paper does not require the extra layer of interpretation that a computer tool does.* In addition to extra modes, menus, and buttons, if a designer makes a stroke in a computer tool, the stroke that shows up on the screen is usually not an exact replication of the stroke that the designer intended. As a result, a designer must take care when interacting with the tool or risk having to redraw or modify the stroke. This slows the capture of design ideas, just when it needs to be rapid and causes a designer to waste effort predicting how the computer will interpret their input. Computer tools also require a designer to conform to the default style that the system was developed to support, thus restricting their own personal style. Conversely, paper provides a more direct representation of the stroke. One designer summed this up by saying "[With paper] there's nothing inhibiting me from doing what I want."
- *Paper is more portable than a computer tool.* Designers frequently use paper in places where a computer is not readily accessible such as in meetings or at a coffee shop. They find it beneficial to exchange paper design artifacts among clients, colleagues, and end users. Some designers pointed out the usefulness of taking handwritten notes back to their workspace to integrate with the rest of the design, while others pointed out the ubiquitous nature of paper. As one designer stated "The nice thing about paper is that I can take it pretty much anywhere, and it's usually available wherever there's a flat surface handy. When I get an idea, I can just reach over, grab a sheet, and sketch it out. Then I just fold it up and carry it with me."
- *Paper is more useful for face-to-face collaboration than a computer tool.* Communication through paper enables more effective interaction with other people. Designers referred to handing paper design artifacts back and forth between collaborators, annotating each other's printouts, and sharing paper copies of early

design ideas with clients. One designer called paper "friendly". Another discussed how people are more likely to review a paper design artifact that you hand to them than an electronic version of that artifact that you email to them. Still another pointed out how multiple people can easily manipulate the same paper-based design artifact, which would be much more difficult with an electronic version of that artifact because only one person can control the computer. As one designer said "A computer is very one-person centered...one person is driving. You can't have four people working the computer at once."

- *Paper supports transient information better than a computer tool.* When designers work with an artifact that needs to be available for an extended time, they typically create it using a computer tool. However, if designers only need the artifact long enough to work through an idea, receive feedback, or to use it as a reminder, they are more likely to use paper. The paper artifacts are usually not retained by designers because the information is transient and no longer useful after some time. In fact, one designer in our study went so far as to give us all her paper artifacts because she felt they no longer held any value for her. This choice to use paper for transient data is due to the lower effort required to create the related artifacts, enabling them to be easily discarded or ignored later. As one designer said "[Paper] is completely throw-away."

Because paper supports many essential tasks in the early design process better than computer tools, paper is an integral, if not irreplaceable, part of the early design process. This does not mean, however, that designers cannot benefit from the use of computer tools in the early design process. All of the designers in our study recognized and desired access to the unique benefits that computer tools can provide, e.g., execution of a design to better communicate behavior, access to design history, and remote collaboration. It's just that designers will not typically give up the affordances of paper - as supported by our study - to gain access to the unique benefits of computer tools, informal or otherwise. We thus conclude that for informal tools to realize their full potential and be widely adopted in practice, they must provide a mechanism that connects to physical tools and complements their electronic interface.

CONNECTING PHYSICAL AND INFORMAL TOOLS

From our study, we conclude that an informal tool must provide a mechanism that connects to physical tools and that complements its electronic interface. With the addition of such a mechanism, a designer could use the interface - paper or electronic - best suited for the particular design task. For example, if implemented, a designer could use connected physical tools to quickly annotate an artifact or solicit feedback, but use the electronic interface to better

explore behavior, quickly share a design with others via email, or collaborate with remote colleagues or clients.

In this section, we discuss three mechanisms that could connect physical tools to an informal tool and complement its electronic interface; a sketch & scan interface, a tangible interface, and a digital pen interface. For each mechanism, we discuss advantages and disadvantages and characterize when it would be most appropriate to implement. From our study, we argue that a digital pen interface would be most appropriate for interactive systems design and provide a scenario showing how such an interface could complement the electronic interface of an existing informal tool.

Sketch & Scan Interface

A sketch & scan interface to an informal tool would enable a designer to scan storyboards sketched on paper directly into the tool. The informal tool would store the electronic storyboards as bitmaps and could provide some content analysis to extract shape and other information.

The advantage of this mechanism is that a designer transfers the design from a paper artifact to the tool using commonly available hardware and a simple process. Once scanned, the designer can use the electronic interface to share the design with local and remote designers and to define simple behavior such as navigation. The disadvantages are that scanning becomes more tedious as the size of the design increases and that extracting semantics from the sketch is difficult because the strokes and their drawing order are not preserved. A later transition to using only the electronic interface would require that the design be redrawn to access all the features of the tool.

This mechanism would be most useful for smaller designs with less interaction, if interactions are simple or have a shared understanding, or when effective extraction could be achieved due to the use of a limited visual vocabulary.

Tangible Interface

A tangible interface could consist of an over-the-desk vision system, a digitizing pad, multiple styli, and an electronic display. The vision system would track paper design artifacts using attached visual markers, as in [11]. By placing a sheet of paper on a digitizing pad as large as the paper and writing on it, a designer leaves a physical ink stroke on the paper while the digitizing pad generates a corresponding electronic stroke and sends it to the tool. A different stylus could be used to sketch content, behavior, and annotations. The electronic display would be used to view feedback and visualize design context.

Beyond the sketch & scan interface, the advantages of this mechanism are real-time capture and analysis of strokes and the ability to link electronic artifacts based on the spatial or temporal arrangement of their corresponding physical artifacts. The disadvantages are that the instrumentation required is not portable and imposes structure on how a designer interacts with the artifacts, e.g. the designer must

always sketch with the paper on the digitizing pad and must ensure that the markers are visible and correctly interpreted.

This mechanism is most appropriate when a designer works mostly in a single physical space, works with very large designs where context is important, or wants the content sketched on paper to be immediately visible in the tool.

Digital Pen Interface

A designer could use a digital pen, such as Anoto's [1], to sketch on paper and have the stroke information stored in the pen itself. Once placed in its cradle, the pen uploads the stroke and paper identifying information to the informal tool. The tool interprets the strokes in context of the template defined for the paper. For example, a mark made in a "color button" area informs the tool that all subsequent strokes should be in that color. Because strokes are interpreted in batch mode according to a template, a digital pen interface can also intelligently map the representation of a design between the physical and electronic medium.

The advantages of this mechanism are portability and preservation of stroke information when it is uploaded to the tool. Disadvantages include the need for special printed paper and the lack of real-time interpretation of strokes. The impact of the latter is that changes in state are not immediately visible, design context is unavailable, and behavioral information can not be immediately interpreted.

Even with these disadvantages, however, we argue that this mechanism would be most appropriate to connect physical tools to an informal tool for interactive systems design. Our study indicates that designers would not want to always have to recreate their design as they move from physical tools to an informal tool, which a sketch & scan interface would require, and designers need artifacts to be more portable than a tangible interface would allow. To illustrate a digital pen interface, we provide an example scenario in context of an existing informal tool DEMAIS.

Example Scenario

In this section, we describe a design scenario exemplifying how a digital pen interface could complement the electronic interface of our informal tool DEMAIS [5]. The digital pen interface relies on paper preprinted with a template understood by the tool. In this example, the template divides a sheet of paper into four sections; identifier, content, behavior, and mode sections.

The artifacts developed in the scenario are shown in Figure 2. Two designers, Mike and Sarah, are working together to design an interactive experience of the U.S. expedition led by Lewis & Clark in the 1800s. Mike begins by selecting a sheet of paper and writing a '1' in the identifier section. In the content section, he sketches part of an initial design idea, which includes a map in the lower left, a placeholder for a video in the lower right, and text to indicate buttons.

Mike thinks that he would want the video to begin playing when a user selects the "Begin" text. He labels the text 'A'

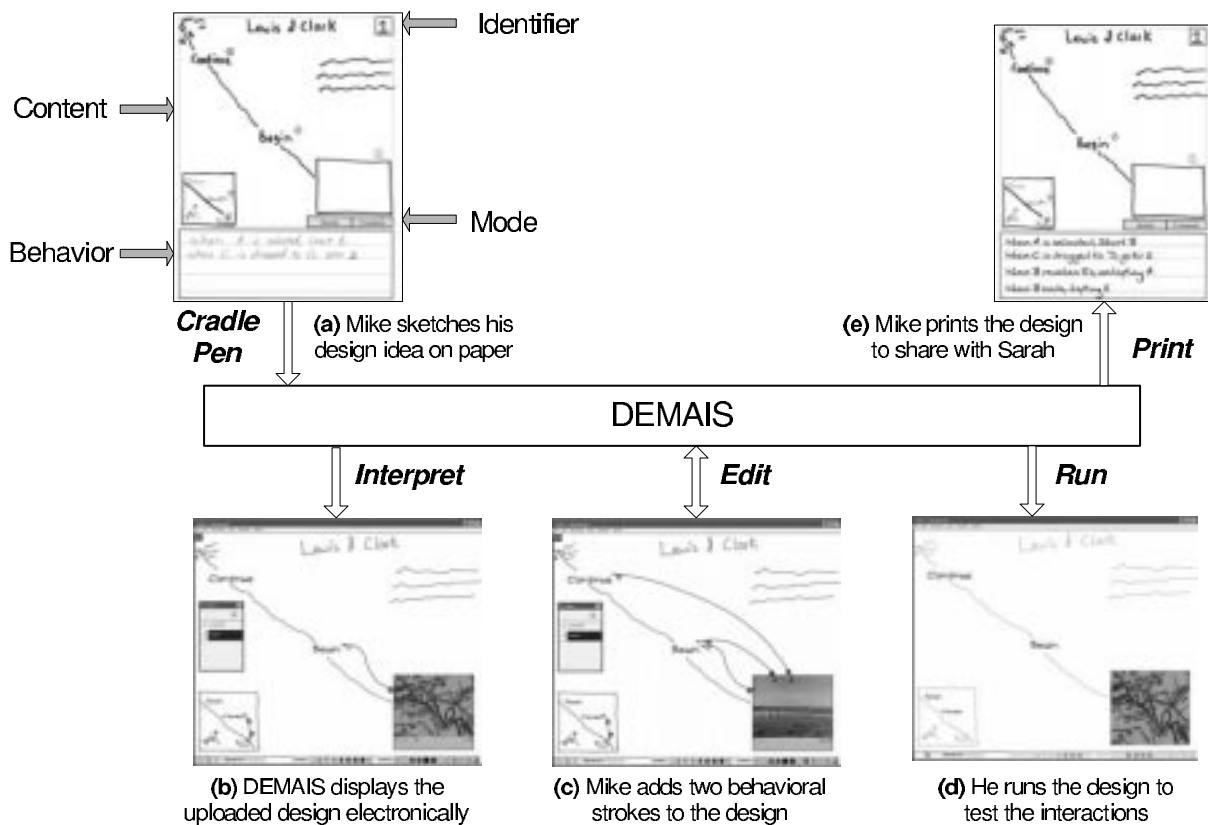


Figure 2. This scenario shows how a digital pen interface could complement the electronic interface of DEMAIS. With time shown as a progression from left to right, Mike refines a design using both a physical (top) and electronic (bottom) interface. The design representation is intelligently mapped between those two mediums so that he can choose which medium is most appropriate for his tasks.

and the video placeholder ‘B’. In the behavior section, he writes a sentence describing the behavior, using the labels to refer to the content involved in that behavior. Mike then thinks of a drag and drop interaction for the map, labels the appropriate content, and writes a sentence describing the interaction. The sketch is shown in Figure 2a. Mike now wants to run a prototype to see how well his ideas work.

To upload his design into DEMAIS, he places the pen into its cradle. The stroke information is uploaded and DEMAIS interprets the strokes based on the known template of the paper. DEMAIS creates a storyboard, names the storyboard from the name in the identifier section, creates strokes that match those in the content section, groups strokes based on their temporal and spatial properties, e.g., the strokes that form ‘Begin’ are grouped because they are proximate in both space and time, ties the identifiers to the nearest stroke or group of strokes, and translates the sentences in the behavior section into behavioral strokes. Note that DEMAIS supports each of these features today, including a grammar to infer behavior from textual annotations [4].

If there are ambiguities, such as an identifier being close to more than one group of strokes, DEMAIS requests clarification from the user. Once the process is complete,

DEMAIS displays an electronic version of the design, as shown in Figure 2b. Using the electronic interface of DEMAIS, Mike quickly sketches two more behavioral strokes (Figure 2c) and then runs the design to interact with a functional prototype of that design (Figure 2d).

Satisfied with his rough idea, Mike prints the design on paper to show to Sarah. DEMAIS intelligently maps the design to the known paper template. For example, the behavioral strokes created using the electronic interface are translated into sentences and placed in the appropriate location (Figure 2e). The mapping is necessary because designers typically represent behavior on paper through textual annotations [5], whereas informal tools represent behavior using a visual sketching language [4].

Once Sarah has the printout, she can annotate the artifact by touching the pen to the “Comment” box before annotating. She can also modify the design by touching the pen to the “Sketch” box and then sketching desired changes. When the design is later uploaded, the annotations and sketched content will appear in the appropriate layers in DEMAIS.

This scenario illustrates several benefits enabled by the digital pen interface; (i) the representation of a design can be intelligently mapped between a paper and electronic

medium to better support design practice, (ii) design iterations can now cross physical and electronic mediums, (iii) the eventual transition to computer tools is eased because stroke information is preserved, and (iv) a designer can use the interface best suited for the particular task. For example, a designer can quickly annotate a design and solicit feedback using paper, while he can use the electronic interface to further explore behavior, run the design, and share it with remote designers, clients, or end users.

A robust implementation, however, will require effective handwriting recognition, intelligent spatial reasoning [8], and effective mediation strategies to resolve ambiguity [19].

CONCLUSION AND FUTURE WORK

While the use of informal tools can dramatically improve the early design process, their use requires that a designer sketch in an *electronic* medium and give up many of the richer affordances of physical tools such as paper. To better understand the importance of physical tools for early design, we conducted contextual interviews with twelve designers. We found that paper is an integral part of the early design process and recommend that informal tools provide a mechanism to connect the use of physical tools to complement their electronic interface. We described three such mechanisms and discuss why a digital pen interface is most appropriate for interactive systems design. A design scenario illustrated how a digital pen interface could complement our informal tool DEMAIS. The scenario showed how the interface can better support design practice by intelligently mapping the representation of a design between a physical and electronic medium. Our future work is to implement and evaluate this interface for DEMAIS.

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