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DESIGNERS' USE OF PAPER AND THE IMPLICATIONS FOR INFORMAL TOOLS

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ABSTRACT

While informal tools can benefit early design, their use requires that a designer surrender the richer affordances of physical tools. 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 argue that informal tools will not realize their full potential unless they provide similar benefits. We recommend that informal tools provide a mechanism to connect the use of physical tools to complement their electronic interfaces. We discuss several mechanisms and use lessons from our study to evaluate their relative strengths and weaknesses, concluding that a digital ink interface would be most effective. A realistic scenario involving a digital ink interface is evaluated. Results confirm our design rationale and suggest that a digital ink interface would benefit existing design practice.

KEYWORDS: *Informal Tools, Early Design, Digital Ink, Sketching.*

1. INTRODUCTION

In early interactive systems design, computer tools can provide immense benefits such as remote collaboration (Everitt, Klemmer, Lee & Landay, 2003), access to design history (Herbsleb & Kuwana, 2003), and execution of a design (Bailey, Konstan & Carlis, 2001a). However, designers typically forego the use of computer tools in favor of using physical tools such as paper, overlays, and sticky notes (Bailey, Konstan & Carlis, 2001b). Two reasons are that existing computer tools use *formal* representations, while *informal* representations are used in early design practice (Newman & Landay, 2000), and physical tools provide richer affordances such as spatial flexibility, tailorability, and sociability (Gladwell, 2002).

To leverage informal representations in a computer tool, researchers have developed informal design tools based on intelligent sketching and pen-based input (Bailey et al., 2001a; Landay & Myers, 1995; Lin, Newman, Hong & Landay, 2000). These tools enable more effective communication of early designs than physical tools while constraining the design process less than existing computer tools (Bailey & Konstan, 2003). However, informal tools require that designers sketch in an *electronic* medium and give up the richer affordances of physical tools. This calls into serious question whether continued enhancement of their electronic interfaces will 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 a wide range of domains. While prior work has argued for the richer affordances of physical tools (Ishii & Ullmer, 1997), and has investigated design representation and process (Bailey et al., 2001b; Newman & Landay, 2000; Wagner, 1990), our study investigated how and *why* designers utilize physical tools, especially paper, to meet their needs in early design practice and to provide recommendations on how informal tools could better meet those same needs.

Consistent with similar studies in other domains (Gladwell, 2002; Mackay, 1999; Sellen & Harper, 2001), 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 recommend that informal tools provide a mechanism that connects the use of physical tools to complement their electronic interfaces. We describe three such mechanisms; a sketch & scan interface, a tangible interface, and a digital ink interface, and use lessons from our study to evaluate their strengths and weaknesses, concluding that a digital ink interface would be most effective. We describe a realistic design scenario illustrating how a digital ink interface could complement the electronic interface of an existing informal tool DEMAIS (Bailey et al., 2001a). An evaluation of the scenario confirms our design rationale and suggests that the use of a digital ink interface would benefit existing design practice.

2. RELATED WORK

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

2.1. 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 is easily annotated), and sociability (it facilitates face-to-face communication) (Gladwell, 2002).

While studies of design practice have noted the common use of paper in early design, they have focused on the *process* of creating informal representations, but not on *why* paper was so often selected as the representation medium. For example, in Bailey et al. (2001b) and Newman & Landay (2000), the authors found that designers use paper to rapidly explore many design possibilities, but these studies did not focus on why paper was selected as the medium of representation.

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

2.2. Informal Tools for Interactive Design

Informed by studies of design practice, researchers have developed several informal tools including SILK (Landay & Myers, 1995), DENIM (Lin et al., 2000), and DEMAIS (Bailey et al., 2001a). 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 (Bailey & Konstan, 2003). However, the use of informal tools 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 design and provides evidence that informal tools must provide a mechanism to connect the use of physical tools.

2.3. Physical Interfaces to Computer Tools

A physical interface allows users to interact with a computer tool using physical objects. For example, paper PDA enables users to integrate paper and electronic representations of calendar, email, and task data (Heiner, Hudson & Tanaka, 1999). Paper-to-computer integration is achieved by having users write on paper that uses stickers with radial markers. When a computer system later analyzes the paper, the markers cause specific actions to be invoked. Computer-to-paper integration is achieved by printing the electronic data to paper pre-printed with the markers. Other physical interfaces include Arai (1997); Guimbretière, (2003); Mackay, Pothier, Letondal, Bøegh & Sørensen, (2002); Stifelman, Aarons & Schmandt, (2001).

Physical interfaces often provide users with devices similar to the physical tools with which they are already familiar. For example, Anoto's digital ink system (Anoto, 2004) enables users to write on paper with a pen that records its own stroke information. When the pen is cradled, the information is uploaded to a computer tool which analyzes the information. In Guimbretière (2003), researchers have shown how the use of a digital ink system can better support paper-based annotation of electronic documents.

Tangible interfaces enable users to directly interact with digital information and computation using physical objects (Fitzmaurice, Ishii & Buxton, 1995; Ishii & Ullmer, 1997). For example, Rasa (Mcgee & Cohen, 2001) 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 (Klemmer, Newman, Farrell, Bilezikjian & Landay, 2001) enables a distributed design team to explore information architectures by linking physical post-it notes to a shared electronic representation.

Our study draws upon this research in recommending that an informal tool provide a connection between its electronic interface and the physical tools that designers often use. We discuss several mechanisms to make this connection and use the lessons from our study to evaluate their strengths and weaknesses.

3. 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 contextual interviews with twelve designers from a wide range of 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.

For an interview, we travelled to the workplace of a designer to make them more comfortable, to make sure they had access to their tools and artifacts, and to gain a better sense 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 tasks paper was used for and why it was selected in favour of computer tools. We asked each designer to show us related design artifacts that were available, both electronic and 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 review.

3.1. 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.

3.1.1. Communicating ideas

When a designer communicates an early design to a client, colleague, or end user, the designer typically talks through the idea, which is represented 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. In this case, designers chose paper because it allowed them to socially interact with the client while conveying design information. By gauging another person's understanding and reaction from non-verbal cues, a designer can adapt a presentation to more effectively communicate the design.

Achieving the same communication bandwidth with a computer tool is difficult because only one person can control it without changing seats or awkwardly leaning over one another. Also, designers must allocate part of their attention to interacting with the computer tool rather than communicating the design.

3.1.2. 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 via email. 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 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 can be vital to the generation of feedback and thus to design improvements.

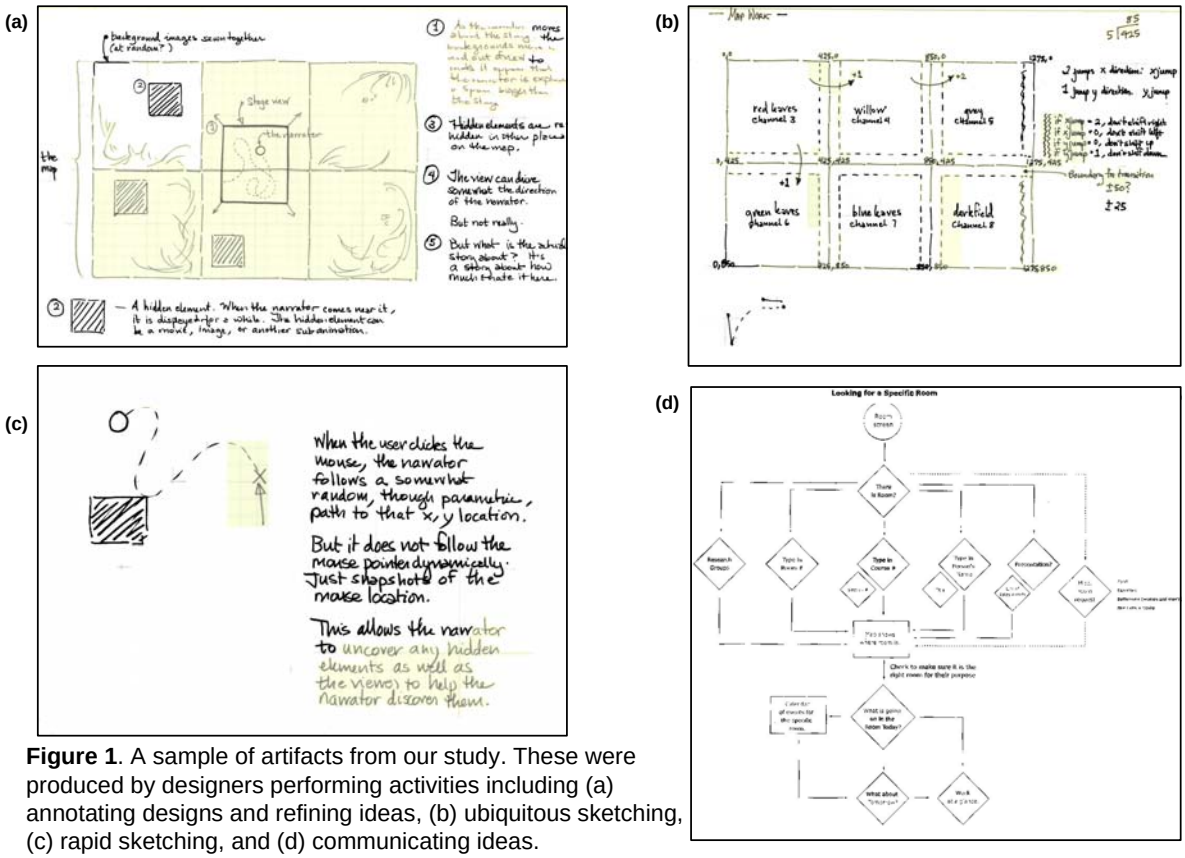

Figure 1. A sample of artifacts from our study. These were produced by designers performing activities including (a) annotating designs and refining ideas, (b) ubiquitous sketching, (c) rapid sketching, and (d) communicating ideas.

3.1.3. Annotating designs

When analysing a design, whether alone or in a group setting, a designer often makes notes on a paper copy of the design. In Figure 1a, a designer wrote comments about the interactive behaviour of the design to more clearly communicate it to a collaborator. During discussion, designers 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. With paper, there is no additional overhead.

3.1.4. Sharing at meetings

Designers often find that bringing printouts to design meetings is more useful for sharing information than an electronic presentation (e.g., PowerPoint). For example, one designer discussed how the use of paper in a meeting enables each person to quickly refer to different parts without disrupting the thoughts of others. Designers can also annotate the printouts to remind themselves of a comment or to give back as notes. To perform these tasks with a computer tool, each person must bring their own computing device and acquire the most recent version of the documents. Ensuring that everyone has the most recent version requires more effort than just passing out paper copies at the meetings. This is due to the lack of efficient sharing tools, differences in hardware or software, and that people may not check for the digital versions in time.

3.1.5. Rapid sketching

Designers often make a quick sketch on a piece of paper when exploring alternative design ideas. The process of sketching allows them to externalize their mental representations and helps them generate new ideas (Nagai & Noguchi, 2002). 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 the design was refined elsewhere. Rapid sketching on a computer is 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 impose an extra layer of interpretation between the strokes that

the designer makes and what the computer stores or displays on the screen. Interacting through this extra layer requires allocation of attentional resources, resources that could have otherwise been used for design.

3.1.6. 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, she wanted to work on a design at different locations because she felt that it inspired her creativity – different ideas occurred to her in different locations. To sketch design ideas using a computer tool in multiple locations, a designer must transport the hardware and spend time setting up both the hardware and software before they can begin sketching.

3.1.7. 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 Klemmer et al. (2001), 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.

3.1.8. 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 to implement the design. While the results are not comprehensible to most, they made perfect sense to the designer and served as a recording of her thoughts before implementation. 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 their attention 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 essential for designing high-quality interactive systems (Shneiderman, 1997). 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.

3.2. Reasons Designers Cited for Choosing Paper

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

- *Paper is quicker and easier to use than a computer tool*. One designer pointed out stencil tools around his desk that he preferred to any computer tool for drawing a curve. Similarly, designers noted that drawing lines and curves is much easier from certain angles and is more easily accomplished by turning a sheet of paper than turning one’s body. Paper also provides a much higher-resolution drawing surface 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 impose the extra layer of interpretation that a computer tool does*. For many early tasks, designers do not require immediate access to the functionality and feedback offered by computer tools, causing their extra modes, buttons, and menus to represent unnecessary overhead. Even when using a computer tool only to sketch, the strokes displayed may not match the strokes intended, causing a designer to redraw the strokes or invoke commands to modify them. This slows the capture of ideas, just when it needs to be rapid, and causes a designer to waste attentional resources interacting with the tool

rather than focusing on creative design. 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. 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 where computers are not readily accessible such as in meetings or at a coffee shop. They find it beneficial to exchange paper 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 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 the electronic version that you e-mail 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 because only one person can control the computer. As one designer said “A computer is very one-person centred...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 create it using a computer tool. But, 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 design process. But, all the designers in our study recognized and desired access to the benefits that computer tools can provide, e.g., execution of a design, access to design history, and remote collaboration. It is simply that designers are not willing to give up the richer affordances of paper – as supported by our study – to gain access to the benefits of informal or other tools. For informal tools to realize their full potential and be widely adopted in practice, we recommend that they provide a mechanism that connects the use of physical tools to complement their electronic interfaces.

4. CONNECTING PHYSICAL AND INFORMAL TOOLS

In this section, we analyze three candidate mechanisms for connecting physical tools to informal tools – a sketch & scan interface, a tangible interface, and a digital ink interface. These three mechanisms were selected for analysis because they are representative of those in the research literature that use paper as part of the interface, e.g. Guimbretière (2003); Heiner et al., (1999); Wagner (1990).

After describing these mechanisms, we use lessons from our study to evaluate their relative strengths and weaknesses and argue that a digital ink interface would be most effective for interactive systems design. We provide a key use scenario showing how a digital ink interface can complement the electronic interface of an existing informal tool, enabling access to the benefits of informal tools without losing the affordances of physical tools. Results from an evaluation of the scenario are also presented.

4.1. Sketch & Scan Interface

A sketch & scan interface would enable a designer to scan paper storyboards directly into an informal tool. The tool would store them as bitmaps and provide some content analysis to extract shape and other information. The strengths of this interface come from allowing a designer to use paper in the same ways identified in our study and, once scanned, use the electronic interface to sketch some behaviour, execute the design, and share it with remote stakeholders. The weaknesses are that scanning becomes more tedious

as the size of the design increases and extracting semantics from the sketch is difficult because the strokes and their drawing order are not preserved. A later transition to only the electronic interface would require that the strokes be redrawn in order for the design to be effectively edited, analysed, and executed. This interface would be most useful for smaller designs, designs with simple, or well understood interaction, or when effective extraction could be achieved due to the use of a limited sketching vocabulary.

4.2. Tangible Interface

To address weaknesses of a sketch & scan interface while retaining benefits of paper, a representative tangible interface would consist of integrated components such as an over-the-desk vision system, a digitizing pad, multiple styli, and an electronic display. The vision system would track paper artifacts using attached visual markers, similar to Heiner et al. (1999). By writing on paper placed on the digitizing pad, a designer leaves a physical ink stroke on the paper while the digitizing pad sends a corresponding electronic stroke to the informal tool. A different stylus (or mode) could be used to sketch content and interaction. The electronic display would be used to view feedback and visualize the design context.

Beyond the sketch & scan interface, the strengths 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 weaknesses are that the instrumentation required is not portable and that the interface would impose specific structure on how a designer interacts with paper artifacts, e.g. designers must sketch with the paper on the digitizing pad and ensure that the system is in the right mode.

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

4.3. Digital Ink Interface

To retain the portability of a sketch & scan interface and the stroke information captured by a tangible interface, designers could use a digital pen, such as Anoto's (Anoto, 2004), to sketch on paper and have the stroke information stored in the pen itself. Once placed in its cradle, the stroke and paper identifying information would be uploaded 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 relative to a template, the tool could map the design representation between the physical and electronic medium.

Strengths of this interface include complete portability, preservation of stroke data, and access to all the functionality of an informal tool once uploaded. Weaknesses include the need for specially printed paper and the lack of real-time analysis of strokes. The impact of the latter is that changes in state are not immediately visible and that designs cannot be immediately executed or shared with others.

Each interface fits with lessons from our study by keeping paper itself as part of the interface. However, our lessons, supported by lessons from prior studies, strongly suggest that the digital ink interface would be the most effective for connecting physical tools to an informal tool for interactive systems design.

In interactive design, designers need to explore interactions beyond what a sketch & scan interface would allow (e.g. see interactions discussed in Bailey et al. (2001b)). Also, accessing the full benefit of the informal tool requires the entire design to be redrawn, a process which scales poorly with the size of the design. While a tangible interface enables immediate access to the functionality of an informal tool in an instrumented environment, our study indicates that designers would much rather have the ability to sketch designs in *any* location. Also, designers prefer paper because it does not impose an extra layer of interpretation and structure, both of which would be heavily imposed by a tangible interface. To illustrate a digital ink interface and how it fits with lessons from our study, we provide an example scenario.

4.4. Example Scenario

In this section, we describe a key use scenario exemplifying how a digital ink interface could complement the electronic interface of an informal tool DEMAIS (Bailey et al., 2001b), as shown in Figure 2. The digital ink interface relies on paper preprinted with a template understood by the tool. For this scenario, the template divides a sheet of paper into four sections; identifier, content, behavior, and mode sections.

Two designers, Mike and Sarah, are collaborating to design an interactive experience of a historical exploration of the Western U.S. To quickly externalize his rough ideas, Mike selects a sheet of paper and, in the content section, sketches a navigational map in the lower left, a placeholder for a video in the lower right, and text to represent buttons. Mike also writes a '1' in the identifier section to name this storyboard.

Mike envisions that the video will begin playing when a user selects the "Begin" text. He creates an identifier for the video placeholder by writing and circling a letter near it and adds another for the text. In the behaviour section, he describes the interaction, using identifiers to refer to the content. To represent a drag and drop interaction for the map, Mike creates identifiers for the related content, and describes the interaction. The design is shown in Figure 2a. Mike now wants to execute a prototype to test his ideas.

To upload his design into DEMAIS, he places the pen into its cradle. The stroke information is uploaded and interpreted based on the defined template. DEMAIS creates a storyboard, names it based on 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 space and time), ties the content identifiers to the nearest stroke or group of strokes, and translates the sentences in the behaviour section into behavioural strokes. DEMAIS supports each of these features today, including a grammar to infer behaviour from annotations (Bailey et al., 2001a).

If there are ambiguities, such as an identifier being close to more than one group of strokes, the tool requests clarification from the user. Once complete, DEMAIS displays an electronic version of the design, as in Figure 2b. Using the electronic interface, Mike sketches additional behaviour using the visual sketching language (Figure 2c) and executes the design to interact with a functional prototype (Figure 2d).

Satisfied with his idea, Mike prints the design on paper to give to Sarah. DEMAIS intelligently maps the

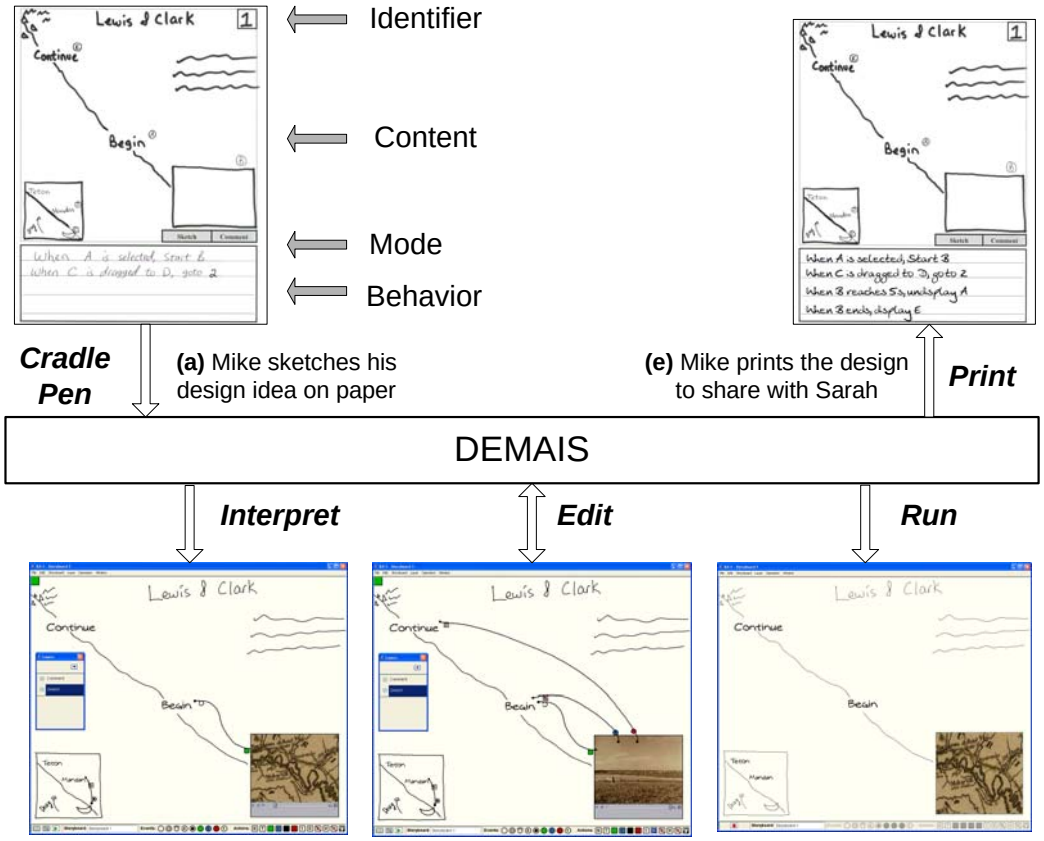

Figure 2. This scenario shows how a digital ink interface could complement the electronic interface of an informal tool. With time progressing from left to right, Mike creates and refines a design using both the physical and electronic interface, selecting the one most appropriate for each task.

design to the known paper template. For example, all of the behavioural strokes, including those sketched electronically, are translated into textual descriptions and placed in the behaviour section (Figure 2e). This is advantageous because designers tend to represent behaviour on paper using annotations (Bailey et al., 2001b), whereas informal tools represent behaviour using a visual language (Bailey et al., 2001a).

Sarah takes the printout to her office. Touching the pen to the "Comment" box, she annotates the design. She then modifies the design by touching the pen to the "Sketch" box and sketching changes. When the design is uploaded, the annotations and sketched content will appear in the appropriate layers in DEMAIS.

This scenario shows how a digital ink interface nicely fits with lessons from our study. For example, the designers created the design on paper without being restricted to any physical location. To solicit informal feedback, paper copies of the design were produced and in a format consistent with design practice. The designers sketched the design freely on paper without the extra layer of interpretation imposed by an electronic interface. At any time, the designer could upload the sketched design and access the full benefits of an informal tool, e.g. executing the design. Thus, the digital ink interface enabled the designers to maintain the affordances of physical tools while retaining the benefits of informal tools.

The other mechanisms would not have allowed this scenario. For example, a tangible interface would not have allowed the designers to work in different locations while a sketch & scan interface would not have allowed effective electronic editing or execution of the complete design.

4.5. Evaluating the Scenario

To evaluate our scenario and learn lessons that could help guide a future implementation of a digital ink interface, we walked four designers (one from the interviews) through the scenario using mock-ups of the interfaces, similar to those in Figure 2. We then asked them to rate their agreement with several statements on a scale of 1-7 (1="strongly disagree", 7="strongly agree"), and provide any additional feedback.

Further supporting the premise of our work, designers wanted the ability to use paper (μ=5.5, SD=1.1) while maintaining the benefits of computer tools (μ=6.3, SD=.83). Stated benefits included the ability to run a design and remote collaboration. Our rationale for recommending a digital ink interface was also confirmed. Designers wanted the ability to work in different locations (μ=7.0, SD=0), which a tangible interface would not support. In contrast to a sketch & scan interface, they agreed that features requiring knowledge of strokes such as separating comments from content would be valuable (μ=6.8, SD=0.4). They liked the ability to transition from a paper to electronic medium without having to recreate a design (μ=6.8, SD=.4) and felt that the digital pen interface would be useful in early design (μ=6.5, SD=0.5).

Referring specifically to the scenario, designers strongly agreed that it was realistic (μ=6.5, SD=0.5) and that they would use a use tool that allowed them to realize a similar scenario in practice (μ=5.5, SD=1.1). Also, labelling parts of a design and writing sentences describing behaviour is consistent with existing techniques (μ=6.5, SD=.87) and they would be willing to use specially-formatted paper (μ=5.7, SD=1.3).

We also identified potential usability issues with the digital ink interface. There was concern that the necessary paper would not be readily available. Designers wanted the tool to work with paper found in everyday life such as napkins and the ability to customize the paper with user-defined regions. Another issue was that while existing sketching languages enable behaviour to be represented visually, several designers were concerned that translating behavioural annotations into a visual language may not be intuitive. Part of our future work is to investigate methods for improving this translation by providing alternative visualizations of a design's behaviour in an informal tool. Overall, we are very encouraged by how well the digital ink system was received by designers. As one designer stated, "this tool would be beneficial for the entire life of the project from early design to final product."

5. CONCLUSION AND FUTURE WORK

Informal tools seek to bring benefits of computer tools into the early design process, but require that designers give up the richer affordances of physical tools. To better understand the importance of physical tools for early design, we conducted contextual interviews with twelve designers. Results led to our recommendation that informal tools must provide a mechanism to connect with physical tools in order to meet the full range of designer needs in practice. We analysed several such mechanisms and concluded

that a digital ink interface would be the most effective. Others can draw upon our design rationale when considering similar systems. A realistic scenario showed how a digital ink interface could complement the electronic interface of an informal tool. An evaluation of the scenario confirmed our design rationale and identified important usability issues, outcomes that can now be drawn upon to justify and guide an actual implementation. Our future work is to develop, evaluate, and improve such a digital ink interface.

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