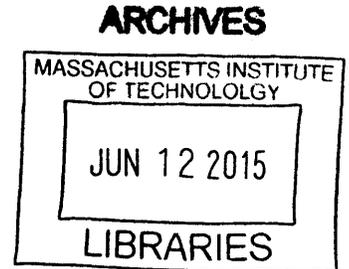


**Beyond the Boundaries of Paper:
A Gesture-sensing Pen for Interfacing Physical Content
with Digitally-augmented Surfaces**

by
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Submitted to the

Program in Media Arts and Sciences,
School of Architecture and Planning,
in partial fulfillment of the requirements of the degree of

Doctor of Philosophy
at the
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

June 2015

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Abstract

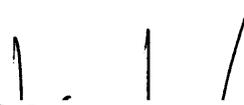
Humans are inherently creative and we have the desire to express and communicate. Pen and paper have been effective means of creation, expression, and communication for centuries. Today, technology increasingly permeates our environment but the spread of digital displays makes us more susceptible to passive viewership. What if we could combine the benefits of technology and pen and paper to empower people to become more active creators? This thesis explores new affordances for pens that become an interface to transcend the boundaries of paper through a series of gesture interactions that a) transfer content from the surface of creation (i.e., paper) onto surface of attention (i.e., intended surfaces in the immediate or remote locations); b) enable dynamic interactions across time by allowing users to create and transform static drawings on paper into an animated expression; c) maintain privacy for content creation while allowing users to selectively share only chosen content in real-time; d) explore the impact of gesture embodiment on audience engagement and shift their perspectives from being passive viewers to active creators. A series of usability studies were designed and conducted to evaluate the platforms and to explore how people may expand physical content beyond the boundaries of paper with the system. Beyond laboratory development, this thesis also presents the real-world deployment of the gesture-sensing pen as an interactive installation in a museum exhibition. Potential applications range from collaborative workspaces to participatory art experiences. Issues relating to creative process, sharing and privacy, and usability are examined in light of the interactive nature of the system.

Thesis Supervisor: Kent Larson

Title: Principal Research Scientist, MIT Media Lab

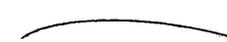
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Chapter 1

Introduction

1.1 Motivation

Since our ancestors, humans have recognized the importance of using drawings to communicate ideas and express feelings. Leveraging surrounding physical spaces, they created visual artifacts on various surfaces such as cave walls, ceilings, and stone tables. The origin of using cave surfaces for drawings can date back to around 40,000 years ago, in both Asia and Europe.

We no longer live in caves, but we continue to use drawings to communicate and express ourselves. As early as 4000 BCE, the Egyptians used pens to produce hieroglyphics on papyrus scrolls. Since the invention of paper and the development of modern fountain pens, these tools have served as two of our most important media in communication. In the US market alone, over \$4 billion of pens are sold and about 100 million tons of papers are produced and consumed per year.¹ Today, pens and paper still remain major instruments of creativity and communication despite the ubiquity of computers.

1.1.1 Transcending the boundaries of paper

The action of drawing and creativity is not static but is vigorous. The process consists of developments on two-dimensional surfaces over a period of time. However, paper has boundaries. Content created on paper is static, still, and inactive once the creation is completed. What if a static drawing could be presented in a dynamic way that reflects the action and vigor of creativity?

In order to do that, this thesis focuses on transcending the time, location, and physical-digital boundaries with pen and paper. We must also consider the interactions in terms of creator-audience engagement and their interactivity.

¹ Data source: Writing Instrument Manufacturers Association
(<http://www.wima.org/Home/tabid/57/Default.aspx>)

From the surface of creation to the surface of attention

Sketching is an act of representing our ideas in visual forms. Although pens and paper are widely accessible, the content created with them stays within the physical borders of paper. The purpose of making such physical representation of our thoughts is to allow the ideas to be expressed and seen by others. People have thought of distributing the physical representation in different ways, such as by making large prints for public viewing, making multiple physical or digital copies of the drawings to reach remote audiences, and using post-it notes to assign visual cues situated in the environment.

Moreover, sometimes we may skip the use of paper and directly annotate physically on the surface of objects. For example, children paint on the walls; constructors note measurements on the furniture; event planners draw signs on the floor. This happens when the physical objects, rather than the paper itself, are the center of the attention.

The surface of attention, however, can be more than one surface and can be switched dynamic among one another, depending on the communication interfaces in use. For example, in face-to-face group communication, each participant may grab a piece of paper to sketch out ideas individually, while the whiteboard is the space for shared visual representation. Our focus can move back and forth between the whiteboard and our own piece of paper, or between each other's paper within physical proximity.

The surface of attention may not be the paper itself anymore once the drawing is completed. Surrounding physical objects are powerful tools to mediate communication. For example, everyday objects become topics of conversation, and designers use foam models or Lego bricks to communicate their designs. Thus the surfaces of such physical objects become surfaces of attention. What if, when an object becomes the center of the attention, the content we draw could take off from physical paper and land on the surface of the object we are looking at?

In addition, it is important to maintain privacy during the creative process. The surface of attention is for representation of the visual creation. It is a public, shared space that can be openly seen by others. On the other hand, the surface of creation should support the process of creation that can be highly personalized and private. Would users wish to share the full content created privately? This thesis introduces the concept of crossing the private surface of creation and the public surface of attention thus to move the creation across in real-time.

Pen and paper is the vehicle, through which our thoughts can be transmitted, expressed, and seen by both others and ourselves. This thesis considers the modalities of a pen to enable our thoughts to travel from one surface to another, i.e., from the surface of creation to the surface of attention. With regard to surfaces of creation, this thesis focuses on the use of paper, although the methodologies and the interactions created here can also be applied to drawing surfaces other than paper.

Crossing the boundaries of physicality

We are entering a world where we will be increasingly surrounded by screens and digital surfaces. The most up-to-date information on the screens catches the attention of each and every one of us. While pen and paper remain one of the most important tools to create and communicate, they are segregated in their own physical world. What if we could take the best of both worlds – taking advantage of the increasing ubiquity of digital displays, and leveraging the power of pen and paper – to pass the drawing beyond the boundaries of paper?

Considering the above, the surface of attention in this thesis focuses on the digital surfaces around us, such as projections and digital screens. This thesis explores how to cross intuitively transfer the content from the surface of creation (paper) to the surface of attention (digital displays) in real-time. We consider designing intuitive interactions using a pen to cross the digital and physical realms.

As we consider crossing the boundaries of physicality, we must also consider the need in bridging the gaps across spaces. As knowledge work increasingly becomes distributed and mobile, there is a growing need in supporting remote communication. Besides interacting with the immediate environment, new modalities and interfaces to address the needs situated in remote environments have yet to be created.

Crossing the boundaries of time

Imagine being able to see every step in your favorite artist's process, weeks, months, even years after the final piece is created as if they were drawing it in front of you. Would that open up new opportunities to interpret the work differently than seeing just static drawings? While we cannot go back in time and watch past artists creating their drawings, we can design new media to present static content in dynamic ways.

This thesis considers the representation of time on the physical page. As we design interactions in a temporal context, what if we could dynamically transform still artwork on paper into animated forms? Would that animation reflect the process of creativity as a function of time, as if we could revisit the way the drawing was composed on paper? What modalities of a pen can effectively and intuitively enable such interactions across time? How may these interactions impact audience engagement? Would the interactions impact how people create both individually and collaboratively in the real world?

In summary, this thesis explores the opportunities that leverage the benefits of pen and paper to transcend the boundaries of paper, enabling our thoughts to travel from the *surface of creation* to the *surface of attention*. To do this, we consider how to intuitively transfer content created on paper to the digital surfaces while the user's attention shifts. Furthermore, it is important to consider how to harness the creative

power of pen and paper to seamlessly transfer content across platforms and across time, and to represent the static content with its dynamic nature. In doing so, we must also consider new opportunities these new media can offer to support interactivity, and the impact on audience engagement and interactions.

1.1.2 From passive observer to active creator

Digital technologies increasingly permeate our environment and we are more aware of their significance to our lives. In parallel, the spread of digital displays cause a shift in our activities -- as the monitors grow bigger, the display resolution goes higher, and computation speed gets faster, they become the primary interfaces for information. However, the content on these screens is usually predefined. The information on these displays is usually generated by service providers or unknown third parties. This makes us more susceptible to passive information receiving. Are we really interested in being passive observers?

As humans, we have the desire to express ourselves. From hand-carved patterns in tree bark to graffiti in public space, humans leverage the environment as an interface to create visual cues that they use to express feelings and communicate ideas. Each of us has something to express and we want our creations to be seen.

Surrounded by digital screens, I started to explore new ways for people to become active creators and express their ideas, rather than

being passive observers. Given the benefits that digital technology and pen and paper can provide, I wanted to expand the physical affordances of a pen, and thus empower users not only to create but also to interact with their creation.

This leads to new interaction designs, which may switch the users' perceptions between being passive observers and active contributors. Furthermore, can this also change the way people create and share? Can this open up new opportunities for creators of a work to interact with viewers?

1.1.3 Audience engagement and interaction

The creator-viewer relationship is evolving especially in the context of art. Traditionally, museum art is created by professional artists and, according to artist Nick Zangwill, "audiences are ignored because many see the primacy of meaning and pleasure in the artwork as residing in a supposed unmediated understanding of the specific work or in the artist's intention" (Zangwill 1999). However, according to Allan Kaprow, a pioneer in developing the performance and installation art theories of "Environment" and "Happening," institutionalized "artlike art" is distinguished from "lifelike art". "Artlike art" is segregated from reality, as opposed to "life-like art", which is inseparable from real life. He emphasizes its nature of communication: "Lifelike art's message is sent on a feedback loop: from artist to us and around again to the artist..."

‘conversation’ is the very means of lifelike art, which is always changing” (Kaprow 2003). Such conversation opens up new opportunities for artists to interact with audiences.

I believe technology can be transformed into a way for the audience to put themselves in perspective of artists and for the artists to revisit their thought process from a viewer’s perspective. Similarly but as a contrary, I was interested in expanding technology and the artwork created upon to empower my audience to become an active creator rather than a passive viewer.

Until recently, much of the emphasis on technology indicates digital innovations such as ubiquitous computing and augmented reality that will help us face the pressing challenges of communication. However, at the core of a more integrated, life-centered understanding of communication is the fluid relationship between the audience and the creator. In the context of art, this interaction occurs between viewers and artists. Technology, pen and paper, and the new platforms presented in the following chapters of this thesis, again are the vehicles of creation. Artists and viewers converse through them. How would this change the audience engagement and interaction?

As opposed to still painting on the wall, I was interested in the interactivity between the artwork and the audience, as well as in that between the audience and the artist mediated through the artwork. This thesis introduces new affordances for pens that become an interface to

not only transcend the boundaries of paper but also to explore the impact on audience engagement and on the shift of their perspectives from being passive viewers to active creators. With suitable interfaces provided, would audiences perceive a piece of drawing from the artist's perspective? This cross-boundary experience invites both the artists and audiences to reveal the process of creation. This new interactivity can inspire both artists and audiences to have a conversation mediated by the artwork and offer a new channel to engage. This thesis offers opportunities to sustain audience interest and engagement as they become aware that creative expressionists can be made through dynamic interactions.

1.2 Scope of the Research

This thesis explores opportunities to leverage the benefits that pens and paper can provide, and to expand their affordances for creators and audiences alike, enabling them to create, share, and interact with their work beyond the boundaries of paper. New issues arise concerning how the pen mediates interactions across the surface of creation and the surface of attention. We must consider how to intuitively transfer content from paper to intended digital surfaces across time, location, and physical-digital boundaries. This thesis contributes to the design and development of new media leveraging the power of physical pen and paper to cross the physical and digital realms without switching devices. With this in mind, when content on private surface of creation transfers to the public surface of attention, we must also consider crossing the

private-social realms by allowing only specific portions to be shared while the interactions remain with the same device. Furthermore, this thesis serves a medium that empowers passive viewers to become active creators, and engage artists and audiences. To address these issues, this research explores the following:

Designing interactions that cross the physical and digital realms, using a pen: This thesis presents the design and implementation of interactions that exploit the affordance of pens and portability of paper to a) support physical content creation and b) transfer it to intended surfaces at the time of the user's choosing. In addition to interactions with digital surfaces in the immediate environment, this thesis also considers applications in remote interactions using pen and paper, allowing physical content creation and sharing at a distance without switching devices.

Dynamic interaction across time: This research considers the representation of time on the physical page. It presents new ways to cross the boundaries of time by transforming static drawings on paper into animated facsimiles. This thesis explores new gesture interactions with the goal of effectively and intuitively enabling such animations to reflect the process of creativity as a function of time. Furthermore, the dynamic interaction across time creates new opportunities for asynchronous communication.

Selective Sharing: How can the use of a pen be leveraged to share only specific content while hiding the private notes on the same piece of

paper? How can static written content be presented in a dynamic order? This research presents a strategy to selectively share paper content through gestures, while maintaining privacy during the creative process.

Impacts on audience engagement and the shifts from passive viewers to active creators: This thesis presents a new interactive medium that leverages pen and paper through a series of gesture interactions. Furthermore, it presents the real-world deployment of this work beyond laboratory development. In order to explore how creators interact with their own work and with the viewers through their creations, this thesis takes a particular interest in artistic creation and expression. By deploying the work as an interactive art exhibition in a contemporary art museum, this thesis adds a new scope to the gesture interactions in the real world and explores its impact on how people do creative work. Would the gesture embodiment engage artists and audiences alike to revisit the creation process of an artwork? Would the new time-based interactions allow the audience to take the artist's perspective and vice versa? Would these new interactions that transcend the boundaries of paper empower people to shift from being passive viewers to active creators? Further issues related to how artistic expression and participatory experience are investigated.

This research explores the potential of embedding computation and communications technology in a wide variety of applications—from collaborative workspace to participatory art experiences. In light of the

interactive nature of the systems, this research investigates issues related to creative process and usability, as well as maintaining privacy during the creation process.

1.3 Structure of the Dissertation

The dissertation is structured as follows. Chapter 1 introduces the motivation of the work, followed by the scope of the research. It outlines the four primary issues in exploring the design philosophy of interest. Chapter 2 reviews the literature, and its subsections cover the related issues. It summarizes existing systems that are closely relevant to these areas and presents the challenges of the design space.

Chapter 3, Chapter 4, and Chapter 5 cover the core design space of interest, the technical implementation and potential applications. Chapter 3 presents the new interactions using a pen to cross the physical and digital realms. It discusses the design considerations that lead to the design and implementation of the gesture-sensing pen, entitled FlickInk. The design metaphors, iterations, challenges, technical solutions and prototype implementation process are illustrated. In addition, this chapter describes the limitation and potential applications in interacting with surfaces on surrounding objects and in remote interactions.

Chapter 4 shifts the focus into interactions across time. It covers the scope of dynamic interactions that are typically unavailable with pen and paper. This chapter presents MoveInk, a system and platform that

enable a user's static drawing on paper to become an animated digital creation. The design of interactions, implementation, challenges and applications are illuminated.

The previous two chapters serve as a foundation for the design of “*Selective Sharing*” functionality. *Selective Sharing* is another core element in this research that explores the privacy considerations in content creation and sharing. Chapter 5 provides in-depth illustrations of the motivations, the interaction design, and the system implementation for *Selective Sharing*.

Chapter 6 describes the evaluation of the above systems. It covers the designs of the usability study in three sessions and the procedure of the study. The questionnaires for each of the sessions in the design of the usability study and the approval from the Committee on the Use of Humans as Experimental Subjects (COUHES) are included in the Appendices. The findings from the evaluation study are presented in chapter 7. Issues relating to creative process, sharing privacy, and usability are discussed based on the results from the usability study. Chapter 8 presents the real-world deployment of MoveInk in a contemporary art museum. It describes the process of designing the museum exhibition and carrying it out in museum gallery oversea. The chapter describes how the exhibition brought the work from a laboratory setting into real-life interactions. This chapter further investigates the potential of the dynamic interactions using MoveInk pen and paper as a function of time

in artistic expression. It also opens a door to explore the relationship between the audience and the artists. Chapter 9 concludes this work and points to directions for potential application areas and future research opportunities.

Chapter 2

Background

2.1 Why Pen and Paper

Recent research has recognized the benefits that sketches with pen and paper provide: pen and paper are easy to use, they facilitate face-to-face communication, and they can be quickly arranged in physical space (Cook and Bailey 2005; Gladwell 2002; Sellen and Harper 2003). Traditional pen and paper continue to be widely used as one of the most

popular means to create because their the intuitive feedback embedded in our cognitive and muscle memories (Goel 1995). Recent studies also show that users have held on to pen and paper interfaces, despite powerful incentives to adopt electronic replacements (Mackay and Fayard 1999; Weibel et al. 2011).

Fundamentally different than our thought processes required in the digital world, sketching, especially with pen and paper, entails the quality of being ambiguous and amorphous. As a contrary, it is expected to be precise, rigid, discrete, and unambiguous in the digital world (Haller et al. 2010). The ambiguity that sketching provides encourages the designer to explore more ideas without being burdened by concern for making errors or being constrained by precision in details. Leaving a sketch at this ambiguous, amorphous stage and having it not interpreted is crucial to preserving such creativity in design (Hearst 1998).

Furthermore, researchers have observed and compared designers solving design problems by sketching on paper and by using a computer-based drawing program. The results showed that “when the designers generated a new idea in a freehand sketch, they quickly followed it with several variations. But those who used a drawing program tended to focus more on refining the initial design, without generating design variations” (Goel 1995). Comparing to using digital tools, sketching with pen and paper has unique advantages in our cognitive process to

create, which may impact on design thinking and engender new variations of creation (Gross and Do 1996; Haller et al. 2010).

Beyond individual design and creative tasks, researchers also identify the importance of pen and paper in collaboration-intensive work. Examples can be found in various situations, such as paper flight strips used in air traffic control (MacKay 1999); physical tickets in financial trading (Heath et al. 1994); medical record for primary health care (Heath and Luff 1996); and the documents in professional law offices (Suchman 1999). Despite the prevalence of digital technologies and the attempt to reform traditional work practice and procedure, pen and paper remains an irreplaceable feature of work and collaboration.

2.2 Systems Integrating Pen and Paper with the Digital World

There is a large body of research on systems that incorporate the use of pen and paper with the electronic world. The DigitalDesk is one of the earliest endeavors to integrate paper documents with digital interfaces (Wellner 1993). The system utilizes at least one overhead camera and a projector mounted above a desk. The camera tracks the positions of paper and the user's finger. The overhead projection superimposes computer-generated images onto paper documents. Through video-based finger tracking, the system allows users to copy printed content on paper and paste to the projected area. The system successfully integrates paper

content with the electronic interface using bare fingers. However, it does not support real-time content creation with a pen. In addition, it introduces new challenges with respect to user's behavior. One problem with such desk-based touch screens is that users tend to rest their hands on them and everything touched can be interpreted as input. In addition, a bare finger is too thick to indicate small objects. Further design considerations are discussed in section 3.2.

Various other interfaces have been proposed and developed to incorporate real-time input from pen and paper using a tabletop-based setting. For example, the Shared Design Space uses digital pen to allow participants to annotate both physical printout and digital data in a collaborative tabletop environment for brainstorming and meetings (Haller et al. 2006). The Nice Discussion Room extends the use of pen and paper from tabletop interfaces to whiteboards in the meeting room (Haller et al. 2010). VoodooSketch uses pens and conductive paper to create functions for tabletop interfaces, such as by drawing sliders or buttons on palettes and attaching them to existing applications (Block et al. 2008).

Paper interfaces have also been developed for speech and audio interactions such as VocieNotes (Stifelman and Arons 1993) and the audio notebook (Stifelman, Arons, and Schmandt 2001). Recent advances such as the NiCEBook which supports natural note-taking and audio recording using a digital pen (Brandl, Richter, and Haller 2010).

Besides tabletop interfaces or notebook interfaces, other researchers explore physical pen and paper platforms that are associated with physical objects in the environment, such as the use of sticky notes. For example, Quickies utilizes ink recognition technologies to digitize handwriting on sticky notes and provide timely information while making the sticky notes searchable (Mistry and Maes 2008). The above studies further indicate the importance of using analog pen and paper for content creation and the attempt to integrate it with the digital world.

The majority of these systems digitize the pen ink using the Aoto system.² The Aoto system combines a digital camera and an ordinary ink pen. The pen works by recognizing the dot patterns on Aoto special paper, hence these systems do not accommodate the use of regular paper (Signer 2005). The Aoto system is used for the commercial products such as Livescribe Smartpen.³ It consists of an embedded computing unit and a digital audio recorder. The Livescribe system records what the Smartpen writes on Aoto paper, and allows users to upload the digitized writing and audio recording to a computer later and to synchronize the digital notes with the audio data.

Various other commercial products have been made available such as APen,⁴ IRISNotes,⁵ and Inkling.⁶ These systems focus on capturing the handwriting and digitizing the analog strokes. Such position-based digital

^{2, 3, 4, 5, 6} For more information about these commercial products, please refer to their corporate websites.

pens use a receiver that attaches to paper. The sensor detects the location of the pen tip during writing. These commercially available digital pens can be applied in the systems discussed in this thesis.

2.3 Interaction across Space and Time

Among the interfaces developed that incorporate pen and paper for information sharing, the majority considers the interaction across physical and digital objects in a local space as mentioned in section 2.2. Recent studies have started to consider the interaction across spaces or across time.

Given the increasing demand in remote collaboration and communication, researchers propose various approaches to integrate pen and paper in remote interaction. Designer's Outpost enables a distributed design team to explore information architectures by linking physical post-it notes to a shared electronic representation with remote teams (Everitt et al. 2003; Klemmer et al. 2001). A front camera is used to digitize the handwriting on the post-it notes pasted on the Designer's Outpost board. A back camera tracks the position of the post-it notes. The digital representation of the notes and virtual lines indicating the relationship among them are displayed on the remote board. Other researchers focus on remote whiteboard interactions. Synchronized Distributed Sketching integrates pen and paper technologies within a whiteboard-based digital remote sketching tool (Guo, Zhang, and Cui 2007). Tele-Board

incorporates a digital whiteboard and sticky note software tool for remote collaboration on a whiteboard (Gumienny and Gericke 2013). PaperSketch focuses on digitizing handwriting or drawing in real time to allow remote users to sketch on paper simultaneously (Weibel et al. 2011). Their analysis on sketching activities in working environment are important to remote participation, which further highlights the requirement of natural pen and paper interactions to support synchronous and asynchronous communication in both remote and local settings.

Pen and paper-based interactions in the temporal context, however, has received relatively less attention comparing to that in the spatial context. The majority of research in this domain focuses on using sketch-based techniques for making computer animation. New interfaces incorporating pen and paper sketches are found to be valuable in defining and modify motion trajectories for computer animation (Baecker 1969; Davis, Colwell, and Landay 2008). Other researchers focus on using sketched trajectories as a pre-defined basis in editing visual properties (Santosa and Chevalier 2013). As opposed to sketch with physical pen and paper, other sketch-based interactions involve motion-based interactions. For example, I/O Brush picks up colors and textures of objects in the immediate environment and uses them as the ink to paint on digital surfaces. The digital drawings reflect the motion at the time when the Brush captures the features of the object (Ryokai, Marti, and Ishii 2004).

In addition, pen and paper interactions are explored to support collaboration and version control. For example, MemTable is an interactive tabletop system that captures information from co-located meeting and supports asynchronous search in order to review past meetings (Hunter et al. 2011). Incorporating other input mechanisms, such as integrating voice input with paper interfaces, VocieNotes and commercial product LiveScribe allow users to play back audio recordings as the pen points at corresponding notes (Stifelman et al. 2001; Stifelman and Arons 1993).

While this thesis research does not aim to focus on interfaces for producing computer animation or for version control, it shared the common ground with the above studies which demonstrated compelling interfaces that enable the creation of artistic expression or collaboration in the time domain.

2.4 Creation and Sharing Privacy

Content generated with pen and paper, whether it is for note taking or for creative activities, generally contains private content that users wish to keep within their notebook as well as sharable content that users are willing to show to others. Both kinds of content may exist in its own way on the same piece of paper. However, only the author knows what to share and what should be kept private. It has been identified to be an important but challenging problem to distinguish the public content

from the private one (Brandl et al. 2010; Hinckley and Ramos 2004; Liao et al. 2007). With traditional pen and paper interactions, it requires users to copy and extract pages or to reproduce the existing content in order to share it with others. Other approaches require the author to give viewers access to their pages, which affects the owner's privacy (Brandl et al. 2010). Similar privacy issues are discussed in systems such as Stitching (Hinckley and Ramos 2004).

Various approaches are proposed to address the need in creating with pen and paper while sharing the content without affecting privacy. PaperCP focuses on students' note-taking and sharing in collocated classroom settings (Liao et al. 2007). It predefines a "public" area and a "private" area on a student's Anoto-based paper. Only the notes written in the predefined public area on paper can be shared with other class members via a display screen. Such "spatial differentiation" strategy is also seen in SharedNotes (Greenberg, Boyle, and LaBerge 1999). However, later findings also show that such solution "prevents users from writing personal comments near pertinent information in the public area."

Furthermore, some researchers later pointed out that, with this approach, users must "determine *a priori* what to submit and what not to submit, which is not compatible with the typical user experience" (Liao 2009). The same *a priori* decision problem occurs with the "pen-switching" strategy, which requires users to switch between a private pen and a public pen. This approach, though provide a solution, is an unnatural

interaction since users can find it difficult to decide what to share and what to keep private at the stage when the content is not yet generated.

Different from the “spatial differentiation” strategy, CoScribe provides a button-based strategy (Steimle, Brdiczka, and Muhlhauser 2009). It differentiates private and public notes by consecutively tapping with the pen on the corresponding buttons and the note. This requires pre-printed buttons, which are implemented with Anoto paper but users cannot use any other paper. Besides, the tapping does not leave visible mark on paper for the users to know what content has been associated with which button. In terms of the interactions, the following section describes the use of pen gestures and compares the interactions with the use button clicks and other input mechanisms.

2.5 Sketching and Gesture Interactions

Sketching and gesturing with a pen are recognized as the two valuable major components for artistic and creative design tasks (Gross and Do 1996; Michael Moyle and Cockburn 2002). Gesturing and pointing are also known to improve communication and convey workspace awareness to support collaborative work (Gutwin and Greenberg 2002; Ishii 1990).

When it refers to pen gestures, some researchers mean movements performed directly on the surface of digital screens with a digital pen or with a stylus, while others mean wand interactions in three-dimensional

environments. Pen gesture input has been used for a wide range of applications such as air traffic control (Chatty and Lecoanet 1996) and interactive surfaces for editing graphics and diagrams (Frisch, Heydekorn, and Dachsel 2009). Recent studies expand pen gestures from digital surfaces to physical paper by using a digital pen to draw gesture marks on a physical printout. The gestural marks on paper are recorded, interpreted, and applied to the corresponding digital document (Liao 2009). Other researchers employ the pen gesture commands on paper and apply the interactions in different areas such as for interactive learning in classroom settings (Liao et al. 2007) and for field biologists to organize and collect notes on paper (Yeh et al. 2006).

With the increasing popularity and advanced technology of digital displays, many researchers recognized the advantages of multi-display environments including the use of projections, monitors, touchscreens, and mobile devices. A wide range of solutions has been proposed to transfer content across different devices. Researchers consider gesture interactions in multiple-display environments (Ballendat, Marquardt, and Greenberg 2010). Particular gestures such as tossing and rotating motions are explored to transfer content with one hand between mobile devices and large displays (Hassan et al. 2009). Besides gesturing with mobile devices, pen-based gestures have also been leveraged to facilitate the transfer of images across multiple displays. For example, *Stitching* uses stylus pens to span across adjacent mobile displays (Hinckley and Ramos

2004). Other gestures such as the use of a pen to initiate remote pointing have been used for device selection (Swindells et al. 2002). These approaches focus on gesture interactions that allow users to transfer content across digital displays.

Further studies compare pen gestures with other input mechanisms such as mouse input, button clicks, and keyboard shortcuts. The results show that using gestures can significantly reduce the time taken to perform simple commands (M Moyle and Cockburn 2002). A comprehensive evaluation that compares different input devices for a 3D environment including voice input, graphical and touch interfaces, and wand interface (Dang et al. 2009). The results further indicate that wand gestural interface supported better performance in terms of accuracy, effectiveness, and user experience among all the mechanisms.

Chapter 3

Pen-based Interactions that Cross the Physical and Digital Realms

3.1 Purpose

Drawing with pen and paper provides tangible feedback that is very different than drawing with a computer mouse or on digital pads. The inherent physical properties make it hard to replace traditional pen and paper with digital alternatives. Grasping a pen, feeling the tip hitting the paper as one's thoughts flow through their fingers creates cognitive feedback. Such feedback can be an integral part of the creative process.

Handwriting and hand-drawing not only provide an intuitive way to express ideas, they can often reveal information about the author's thought process at the moment of the creation.

In addition, creating with pen and paper is personalized: the style of hand drawing and handwriting is specific to each individual and can hardly be replaced by computer; the choice of notebooks, the texture of paper, and the preference of pen can influence an individual's creation. It is also widely accessible, portable, and much more low-cost than computers.

As graffiti artist Keith Haring pointed out, "Drawing is still basically the same as it has been since prehistoric times. It brings together man and the world. It lives through magic," However, we now live in a world that is very different than the ancient times. We are surrounded by more and more digital screens that make us more susceptible to passive viewership. What if we could take the best out of the two worlds, integrating the benefit of traditional pen and paper and the ubiquity of digital displays to enable us to create, express, and communicate?

This thesis explores new affordances for pens that become an interface to transcend the boundaries of paper. This chapter focuses on interfacing with the immediate physical spaces in real-time. The goal is to enable interactions that allow the users to share their content on paper as their attention shifts from the surface of creation to the surface of attention. The interactions and the system presented in this chapter were

designed in the way that addressed the design considerations in the following sections.

Section 3.2 presents the challenges and the design considerations towards intuitive interactions using pen and paper to create and interface with digital displays. Section 3.3 presents the design of the interactions that allow users to transfer content created on paper to an intended surface in the surrounding environment. Section 3.4 describes the system design and implementation. Section 3.5 discusses potential applications including augmenting the surfaces of physical objects and remote interactions.

3.2 Design Considerations

The majority of existing systems use overhead cameras and projectors to integrate pen and paper with digital interfaces. Other approaches involve special tabletop settings. Although these approaches successfully integrate the use of paper with computers, the most important thing to take into account is the user's behaviors.

While using pen and paper with these systems, a number of issues can arise. For the systems using a camera-based approach, touching or holding the paper can interfere with the computer system by generating unwanted shadows. Users normally rest their hands or arms on tables, which can also create false input. This is called Midas Effect (Wellner 1993). To avoid Midas effect in such systems, users are required to change

their habit in using pen and paper at a table. For example, they have to constantly avoid covering their fingers with paper or other body part, and avoid touching the table besides making a gesture. In this thesis, we set out to design an interface to not only intuitively enable new interactions to happen but also to incorporate users' original behavior at a table.

As discussed in Chapter 2, these systems allow users to use pen and paper only in special rooms that have particular setup of cameras, projectors, or tabletop equipment. However, one of the advantages of using pen and paper is its portability. The room-based or tabletop-based interactions provide benefit for group interactions, but they restrict the use of pen and paper within specific areas in such rooms, using particular equipment. In addition, since the interactions are constrained to be in specific local rooms, they do not support remote communication.

Besides, camera-based and tabletop projection-based platforms require specific lighting condition, which may conflict with the lighting required for using pen and paper. The shadows from users' hands and pens can also interfere with the system. To address these problems, we must consider how to design a camera-free, portable system to allow people to freely use pen and paper without being restricted.

Furthermore, given the variety of commercial products that focus on digitizing the pen input, the majority of the existing solutions use Anoto system that requires special patterned paper. However, the ideal interactions should accommodate the convenience and personalized

experience, i.e., to allow people to use any paper in hand or to choose their personal notebook rather than using specific paper. With regard to creating personalized and intuitive experience, the challenges in maintaining privacy during content creation and sharing are yet to be addressed as discussed in section 2.4.

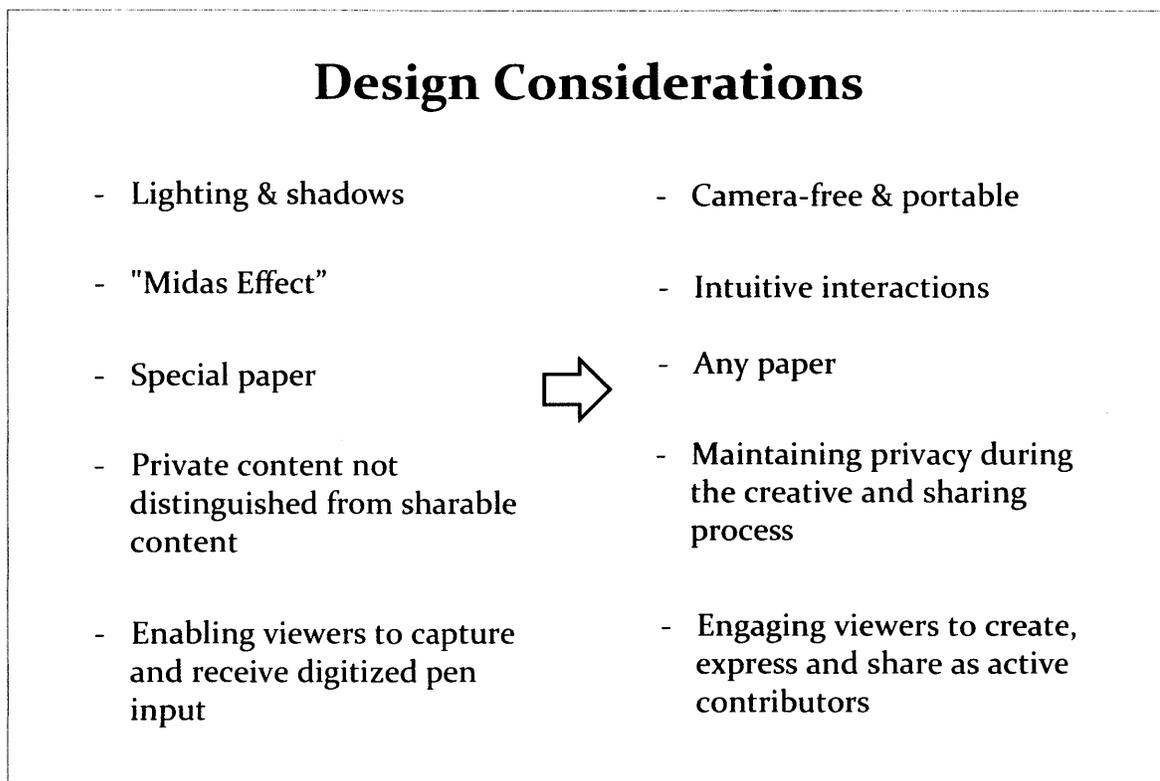


Figure 1. Design considerations for pen-based interactions that cross the physical and digital realms.

The primary design considerations are summarized in Figure 1. As we integrate the benefit of using pen and paper and the digital displays, we must consider what makes an intuitive interaction when crossing the physical and digital interfaces without having to switch devices. In addition, we must also consider how the interactions may mediate and

change interactions between the author and the audience. How can we effectively incorporate the use of pens, rather than interacting with computers, to shift our center of focus from the computers to the physical presence and to mediate communication? How can the system be designed to maintain the advantages of using pen and paper, such as its tactile feedback, the portability, and the ease of access? What interactions can smoothly expand the content to go beyond the boundary of paper, entering the surrounding environment? How to design a system that is functional, low cost, and easy to install? This thesis focuses on creating the interactions to engage people to create, express, and share as an active contributor, rather than digitizing the pen stroke for people to passively receive and capture information only. In designing intuitive interactions with a pen, this thesis addresses the above issues.

3.3 Interactions

This chapter explores new affordances for pens that they become an interface to transfer physical content onto desired surfaces. Existing digital sketching systems that allow input from paper usually require setups such as overhead cameras, particular tabletops or special patterned paper. To leverage the portability and ease of using pen and paper, the platforms presented in this section are compatible with any paper, from users' preferred notebooks to a piece of napkin in hand, and have no spatial restriction as there is no camera required in the system. We

developed the platform, FlickInk, a system that addresses the above issues through gesture interactions (Pao, Reben, and Larson 2012).

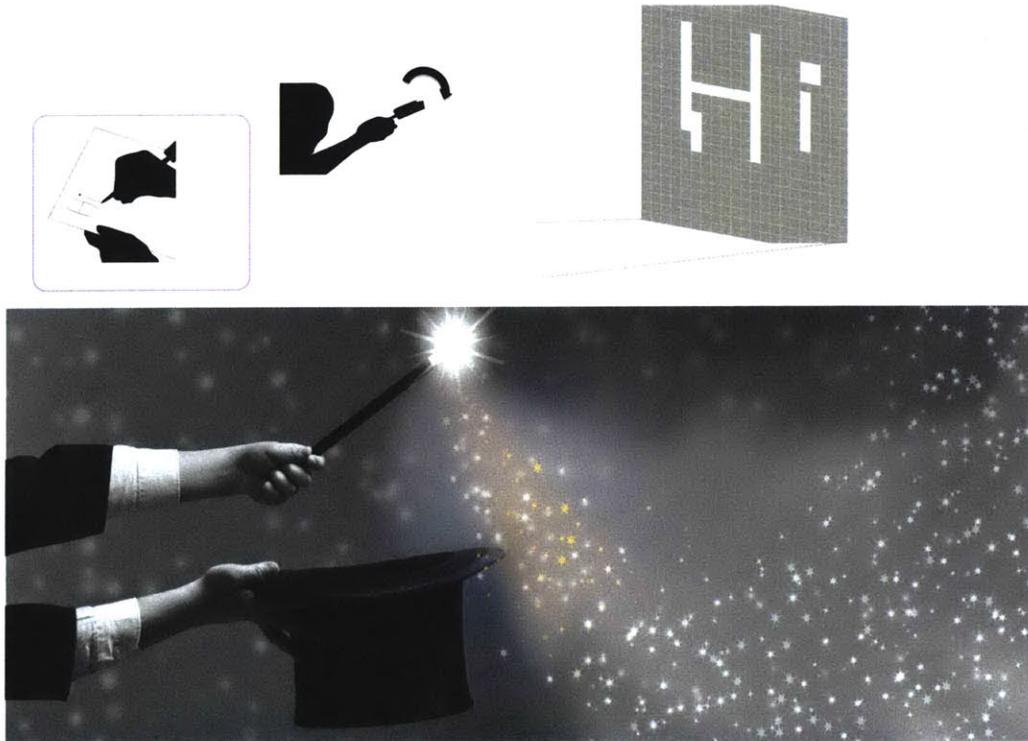


Figure 2. FlickInk interaction.

To do so, we designed the following interactions: with a quick flick of the pen towards a desired destination, the user's creation was instantly transferred from paper onto the targeting physical object in the surrounding environment. The interactions allowed users to transfer pen-based physical content onto surrounding surfaces at the time of the user's choosing. Figure 2 illustrates the interactions. Figure 3 shows users using the FlickInk pen. An individual drew with the FlickInk pen on paper, which can be a personal notebook or any paper. A flicking gesture was achieved when a user grasped the pen and swung it. Users can flick the pen toward their selected surface, and thus transfer the written content

from the physical paper (Figure 3A) to the target surface (Figure 3C). This flick gesture was a metaphor of making desired content appear with a magic wand-like action, as a magic wand is commonly known to create instant visual surprise and the action is often directional.

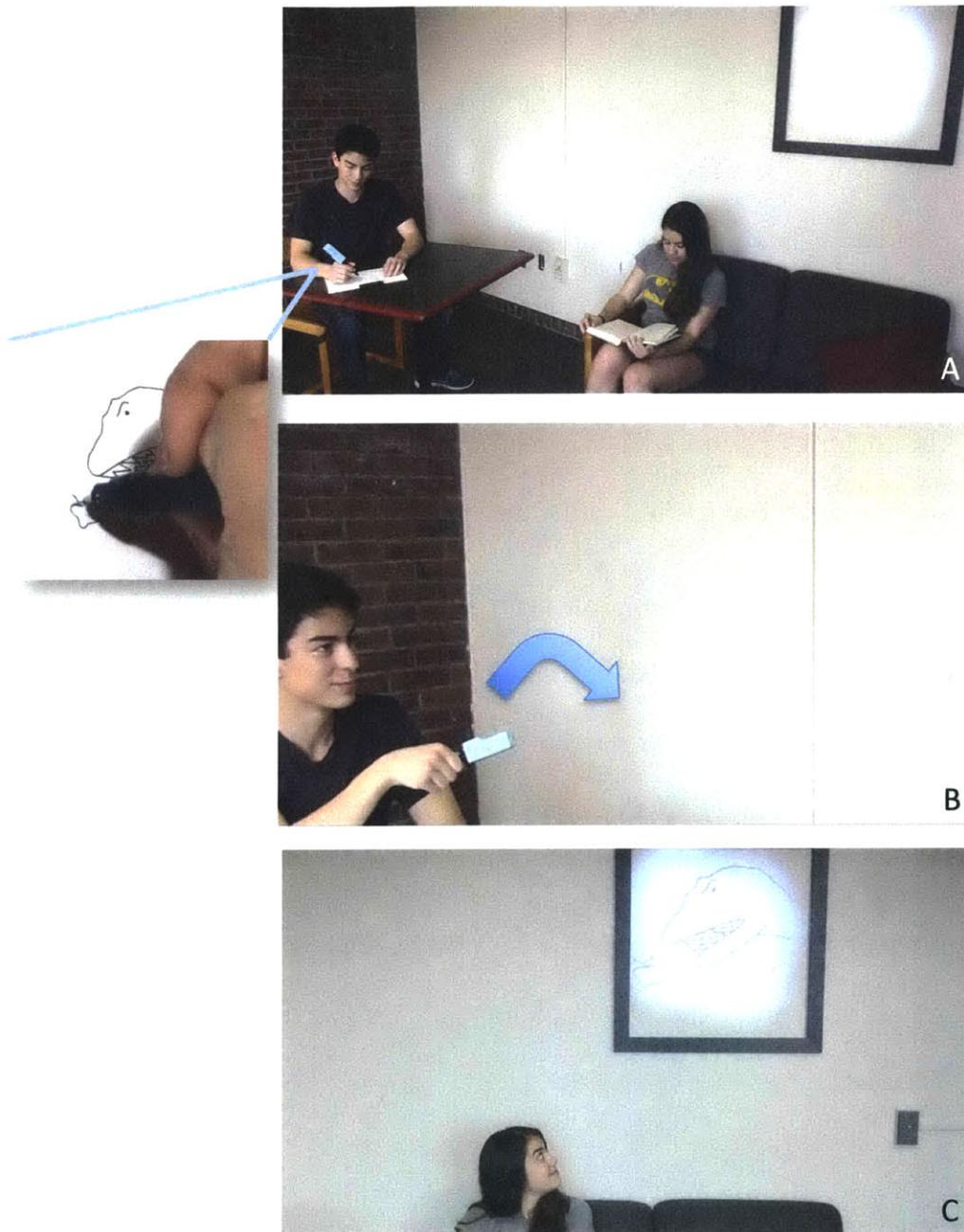


Figure 3. Using the FlickInk pen, user creates content on paper (Figure 3A). By flicking the pen towards the target surface, in this case, the canvas on the wall (Figure 3B), the drawing on paper is transferred onto the surface (Figure 3C).

3.4 System Design

Figure 4 demonstrates the proof of concept prototype.⁷ This initial prototype gave us insights about transforming a pen into an interactive interface. Flicking the pen instantly transferred analog ink to a surface in the physical environment. This first prototype was accomplished through wired connection to transfer data from the pen to the base station. Using the flicking gesture with the pen (Figure 4B), physical content on paper was instantly transferred to the target digital surface (Figure 4C).

The wires coming out from the pen served two primary purposes: first, they transmitted data from the pen to the base station. In addition, they distributed power to the gesture sensing components on the pen. Besides the wires, all the components in this prototype were mounted directly on the surface of the pen. However, the wires introduced unwanted constraint, which especially interfered with pen gesturing. To solve this problem, we implemented the next version, the wireless FlickInk.

⁷ This first prototype was developed under the collaboration with Cisco System Inc.

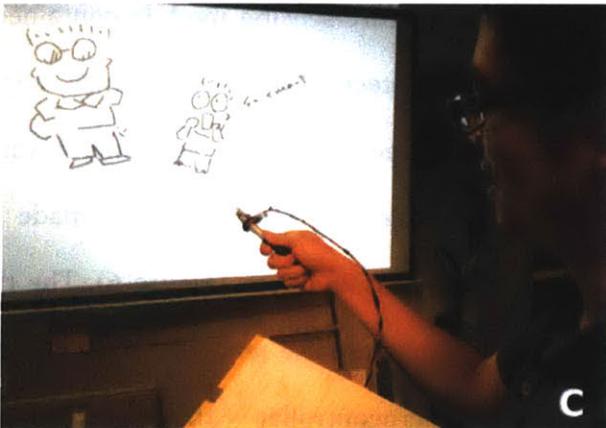
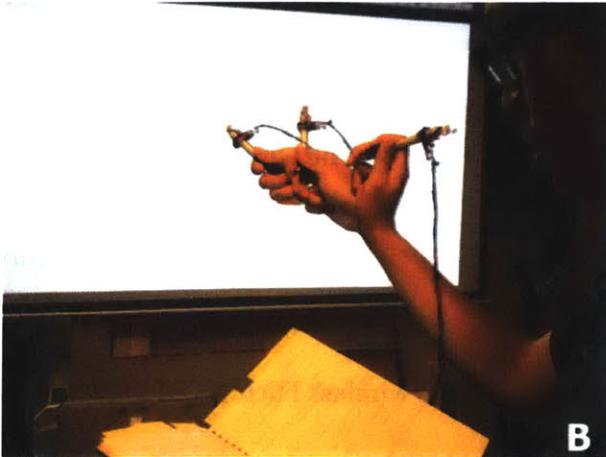
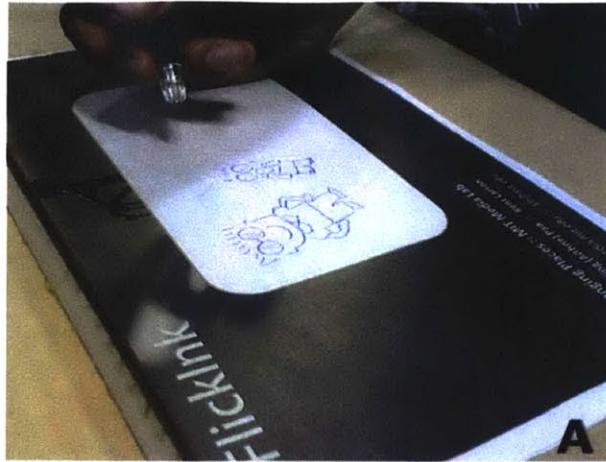


Figure 4. The first proof of concept prototype (with wired connection) allowed analog ink to be transferred to surrounding digital interfaces through a flicking gesture.

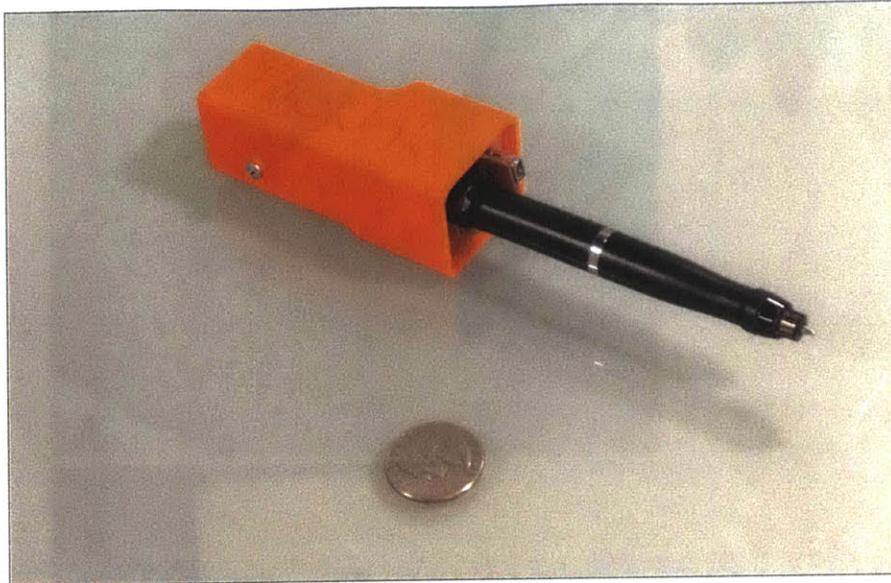


Figure 5. The wireless FlickInk prototype.

Evolving from the proof-of-concept prototype (Figure 4), I designed and developed the wireless FlickInk (Figure 5). The design and implementation of the wireless FlickInk addressed the above challenges.

The FlickInk gesture-sensing module contained all of the sensing and processing to detect the pen gestures, allowing for wireless communication and directional gesture sensing. It was designed and built as a module detachable from a pen, which made it compatible with various off the shelf encoding pens (Figure 6). The threshold was set in such a way as to eliminate false readings. If a flick or other gesture was detected, the microcontroller then modulated the wireless communication to send a unique ID along with gesture data to the base station sensor. Hence, the base stations identified which pen was pointed at them in line-of-sight. The tradeoff of removing all the wires that

connect the pen to the base station was to increase the number of components to be mounted on the pen. New components were required in order to achieve wireless data transmission, to supply power, and to enable the functions with the pen to operate on their own. Considering all these components increased the design complexity. Another challenge in this wireless FlickInk prototype was to consider the mechanisms of mounting all these components onto the pen given the limited surface area and the shape of pens.

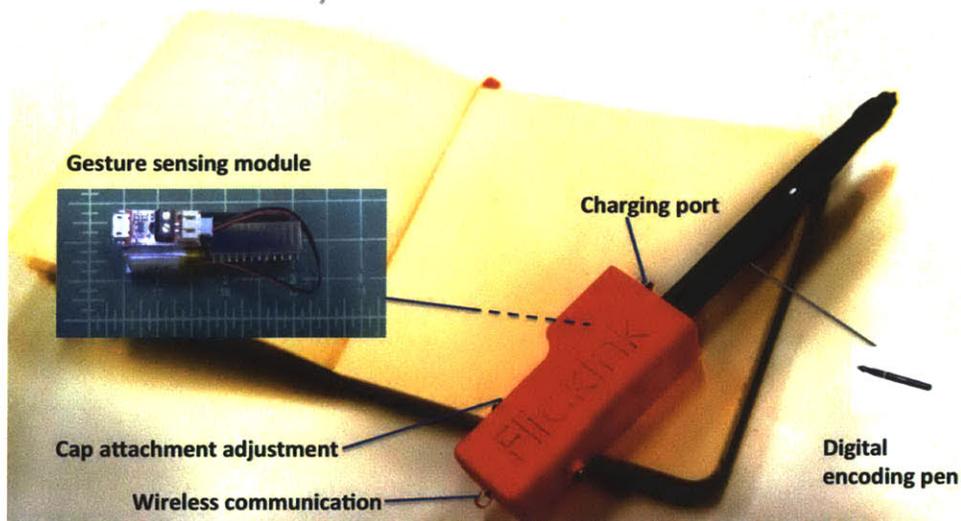


Figure 6. The wireless gesture sensing module that can be attached to a pen cap so as to be compatible with any generic digital encoding pen.

The base station consisted of a microcontroller connected to the wireless signal receiver. The microcontroller read the receiver and waited for incoming codes. When a code was received, it was processed and the information was sent through USB to the computer. The computer

identified the code with customized software, with which the threshold was set in such a way as to eliminate false readings.

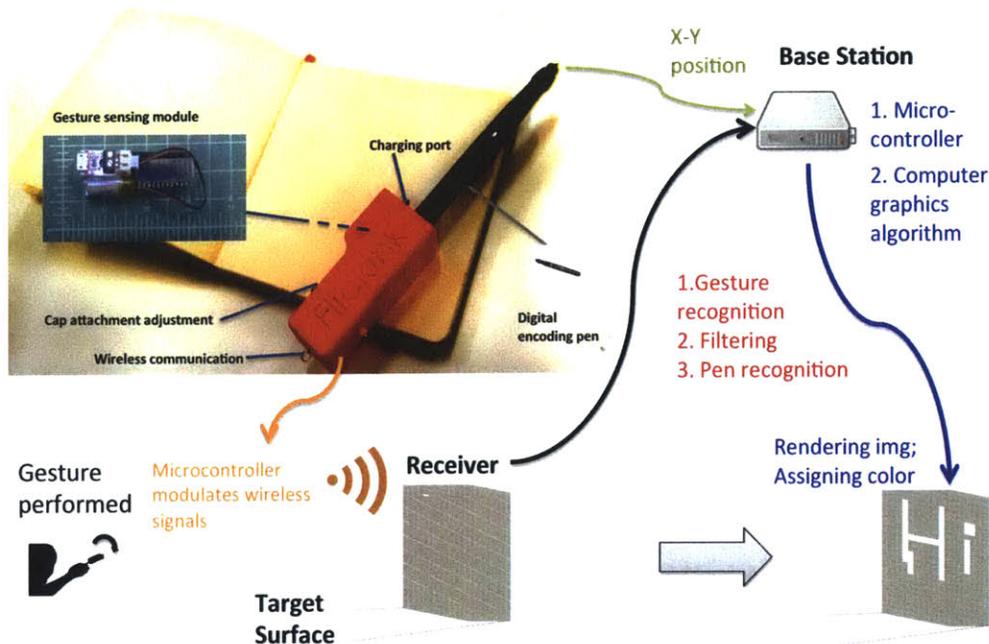


Figure 7. The FlickInk software components.

I designed and developed a graphic algorithm and software, which rendered the images created by the users on paper and projected them onto the corresponding surface. This was achieved through the costumed algorithm illustrated in Figure 7. Gesturing at surrounding environments with the pen enabled content to appear on the target digital display or to superimpose it onto the intended physical objects through projection. The detection of a gesture was through wireless IR signal that was encoded

with a unique ID. Each unique ID was specific to one FlickInk module. This allowed multiple users or multiple pens to interact at the same time.

Furthermore, not only because the flicking gesture itself was directional, but because the IR transmitter was implemented in the way that it was mounted on the tip of the gesture sensing module which would be pointing at the targeting surface when the gestures were performed, this allowed users to select the target surface to transfer their content to. As the IR receiver received the signal, the connected surface would display the content. The system allowed users to easily enable a selected display, such as a digital screen or projection area, to become a target surface for FlickInk by mounting the receiver near the target surface area. If multiple surfaces are available, the direction of the pen swing determines which screen the information is transferred to.

3.5 Applications

3.5.1 Augmenting remote surfaces

Using pen and paper, the content created on physical paper can be directly presented and expressed to its audience as long as they are collocated in the same physical environment. However, if the audience is remote, it can be cumbersome when it comes to sharing and presenting the work on physical paper.

Advances in technology have enabled us to instantly interact with each other across geographical boundaries in the digital domains. While

the majority of prior work focuses on improving the video and audio qualities for teleconferences, we developed a new platform, namely *augmented participatory design*, for remote communication using pen and paper to share and present visual content (Pao and Larson 2013).

Figure 8 illustrates the platform, with particular focus on integrating analog tools into a design activity. For example, when a local designer used this platform, she sketched out the ideas on paper using the FlickInk pen (Figure 8B). The local designer was communicating with her colleague via videoconference. They were working on a new design using Lego models. However, the Lego model was in the remote site and she did not have physical access to it. In this situation, she used the FlickInk pen to draw out her design on the printout of the screen. Once she was ready, she flicked the pen towards the screen and thus augmented the remote Lego model with her sketch (Figure 8C). Upon the flick, her sketch on paper instantly appeared on the remote Lego model, indicating the shape and position. Her collaborator saw her design showing on the surface of the Lego model, which allowed him to quickly understand the ideas and modify the physical objects accordingly and remotely (Figure 8D).

The *augmented participatory design* platform can be applied in all kinds of remote collaboration situations especially when visual representation of ideas is beneficial to effective communication. FlickInk enables users to augment inaccessible remote objects with their own

creation to provide a wealth of digital information and communication capabilities for distant collaborators.

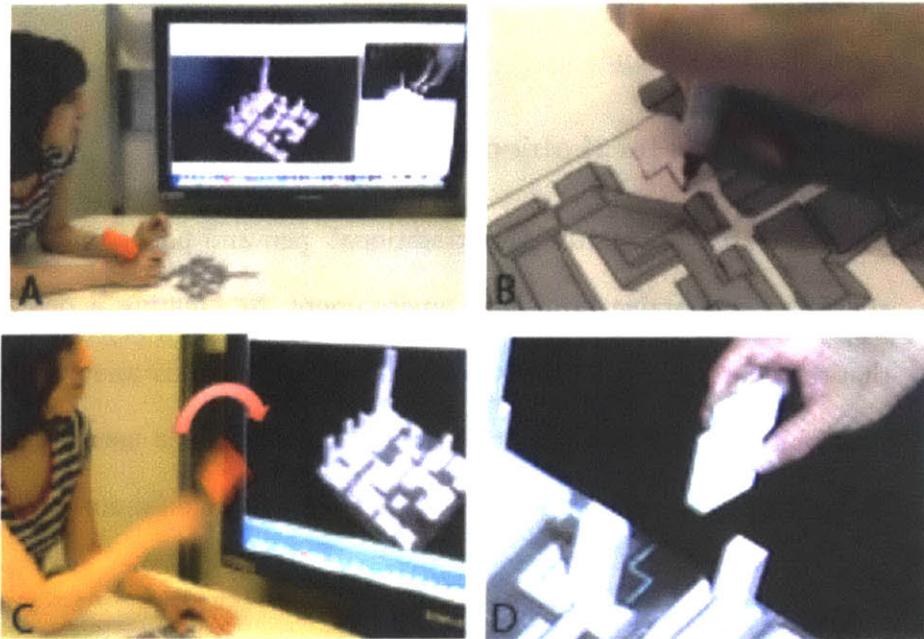


Figure 8. *Augmented remote reality.* (A) Local designer uses FlickInk pen to collaborate with her colleague on Lego model, via videoconference. (B) FlickInk system captures her gestures and sketches on paper. (C) Flicking pen instantly transfers paper sketch to remote model. (D) Remote collaborator creates new physical prototypes accordingly.

This platform leverages videos and cameras in a teleconference to register remote real-world objects and precisely match the corresponding real-time content generated with pen and paper. In the current prototype, a printout of the screen view of the physical prototype was used for the local designer to sketch on. This offered the convenience to directly register and match the position between the sketch and the remote object. The limitation included the following: recalibration or reposition was

required if the camera view of the remote physical object in the videoconference was different from the paper view. In this case, users may incorporate the use of a mouse to reposition the sketches on the teleconference screen.

3.5.2 Augmenting local objects

FlickInk integrates the traditional pen-and-paper interface to enable an interactive expressive environment, by creating a perception that the content is instantly transferred from the familiar analog world of paper into the physical object. Figure 9 demonstrates a user annotate a design prototype without permanently leaving a mark on them.

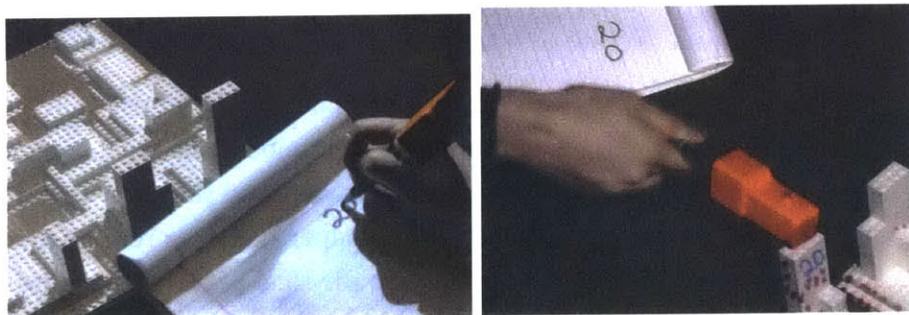


Figure 9. Tapping the pen on co-located physical objects allows for augmented annotation of the physical model with real-time written content.

This was accomplished through the FlickInk system with its recent development in wireless sensing capability, augmented reality, MIT CityScope's parametric 3D computer models with projection on Lego models. We developed wireless sensing technologies and computer graphics algorithms, with the goal of augmenting objects, both in the

immediate environment and in remote locations, to provide a wealth of digital information and communication capabilities. The *augmented participatory design* platform may open a door to future augmented reality that integrates user-generated content creation (Pao and Larson 2013).

3.5.3 Limitations

FlickInk enables users to instantly transfer their drawings on paper to surrounding surfaces, including projections on whiteboards, at the time of their choosing. As a result, users can instantly create with pen and paper and share on a variety of digital surfaces, including projections, screens, and digital whiteboards, with a quick flick. However, in some situations, positioning the shared content on whiteboard is important. However, FlickInk is not intended to reposition this visual content that emerges from these gestures to a designated spot on the selected surface. Rather, it is for individual users to quickly transfer content from paper to a desired surface in the space.

Working with Cisco WebEx initially inspired me to look at the use of whiteboards for interactions and collaboration. To allow users to position the shared content on the whiteboard, I developed another project, Point and Share, with Gonglue Jiang, Misha Sra and Austin Lee as one of our class projects in the Tangible Media class, initiated and developed a few months after my collaboration with Cisco on FlickInk. Although this class project, Point and Share, also involved the use of pen and paper, it is distinct from FlickInk in its purpose and methodologies.

Point and Share is designed specifically for whiteboard interaction. Acting as a pointer, Point and Share involves pressing a button we mounted on the pen and pointing the pen at the desired spot on the whiteboard. This interaction positions paper content on whiteboards. Holding the button allows users to move the content to a desired position on a whiteboard. Sliding another button controls the zoom, changing the size of the shared content as the position is adjusted. Since the interaction and purposes are different than FlickInk, the implementation is different and is independent from FlickInk. Point and Share uses two Wiimotes as sensors to identify pointing location. The computer codes were modified from an open source project developed by Johny Lee.⁸ FlickInk does not use a Wiimote and its hardware and software systems are implemented and developed from scratch. These two projects, though designed independently using different technologies, may have the potential to be combined in the future.

⁸ Wiimote Whiteboard: <http://johnnylee.net/projects/wii/>

Chapter 4

Dynamic Interaction across Time

4.1 Purpose

Drawing is often used to express ideas and explain thoughts. The process of forming a drawing is rich of temporal information. It is full of thoughts, actions, and decisions. In situations such as brainstorming, storytelling, or design activities, with a group or as an individual, drawings facilitate communication because it is happening in real-time.

However, upon the completion of a drawing, it immediately becomes static, still, and inactive. What if there was a way to past present

and future, and allow us to experience the stories imbedded in the drawings ourselves and through others? Most of communication channels have been created to cross the barriers of space. This chapter in the thesis presents the new interactions with the ability to cross the barriers of time.

4.2 Interactions

With the goal to create intuitive interactions for the representation of time on the physical page, this section describes the platform, MoveInk, which addressed the design considerations to transform static drawing into dynamic interaction in the temporal context.

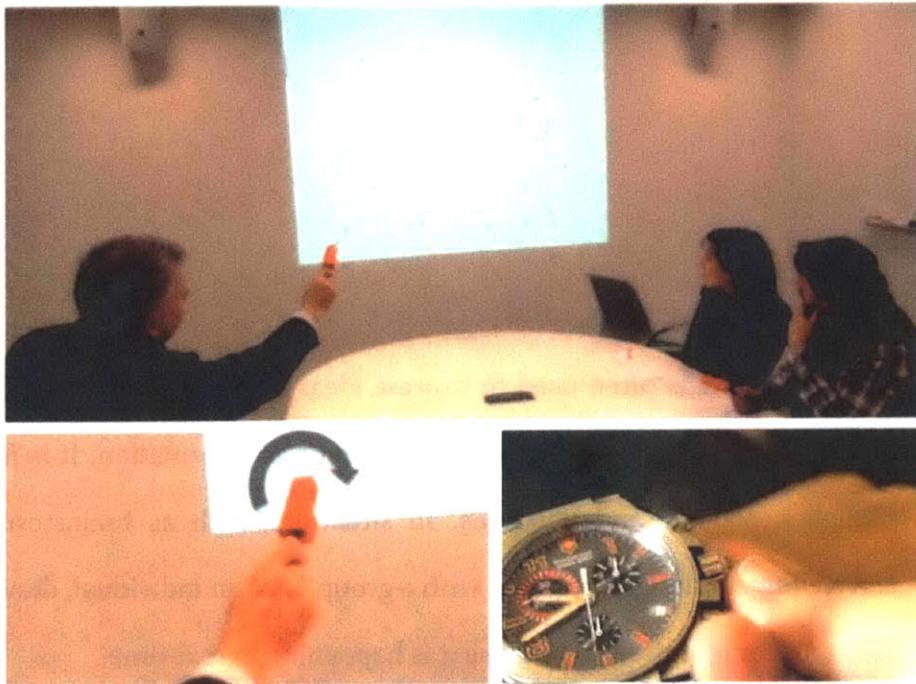


Figure 10. Twisting the pen as turning a knob, a metaphor of time moving, triggers the animation to play. Twisting clockwise or counterclockwise directs the animation to play in forward or rewind mode.

The MoveInk gestures included the following: Twisting the pen clockwise triggered the animation to start (Figure 10). This gesture represented design metaphor of turning a knob, moving the clock forward. The animation reflected the trajectory and speed of the analog ink as it migrated over the paper back in time. Similarly, twisting the pen counterclockwise rewound the trajectory animation. As the animation was played backwards, it removed the lines from the time point when the gesture was performed. This can serve as a function to erase the projected lines as well as to dynamically interact with the trajectory animation by reversing its direction.

The twisting gestures were designed in the way that they were directional and deliberate – users lift the pen and point the back tip of the pen towards the intended screen with two consecutive twists, either clockwise or counterclockwise. The directional double twists differentiated the gestures from potential movements during the regular use of the pen when writing or drawing. Using pen and paper, MoveInk acted simultaneously in physical and virtual realms, transforming a pen into a gestural wand that converted a user’s static drawing on paper to an animated digital creation.

4.3 Implementation

Although MoveInk and FlickInk shared the same mechanical design in terms of their shape and appearance, MoveInk used different

hardware components than FlickInk with new sensors including a new microcontroller and a 3-axis accelerometer in order to capture the MoveInk gestures. The wireless transmission components stayed the same as in FlickInk, by mounting an IR LED on the top of the gesture-sensing module to send signals wirelessly to the IR receiver mounted on an intended digital display. However, new IR signals were defined to associate them with MoveInk gestures. The hardware layout in MoveInk were rearranged to fit the new microcontroller, sensors, batteries, charging station, and power switch, into the sensing module in order to keep the size as small as FlickInk.

In addition, new software components were developed to implement the interactions. The custom software captured the pen stroke and recorded them as x-y coordinates as the pen touches the paper. The software running on the base station not only structured the x-y coordinates data received from the pen in real-time, it also denoted the time. Another piece of custom software in the MoveInk system kept track of the gestures, while at the same time filtering out false positives. When a clockwise twisting gesture was picked up by the base station, the computer graphics algorithm then rendered the animation based on the x-y coordinates, the time point of each pen stroke, and the time point of the gestures performed.

Some challenges occurred when implementing the counterclockwise gesture. First, the system could easily misinterpret a

counterclockwise twisting gesture to be a clockwise twisting gesture. It was because right after a twisting gesture was performed, the user's wrists have the tendency to rotate back to the original position. This led to the redesign of the gestures from single twist to double twists. Twisting the pen twice consecutively made it a deliberate gesture for the system to differentiate clockwise twists from counterclockwise ones.

Another challenge was to implement the reverse animation in real-time because the trajectory animation was rendered at the time when the gestures were performed. All the gesture interactions and content created with the pen were interactive in real-time, so the reverse animation playback also needed to be rendered in real time rather than simply rewind the animation as a pre-rendered video clip. At the same time while users performed the gestures and while the animation was rendered and displayed, they may continue to draw and to gesture more to dynamically change the animation on the fly. How could the animation be reversed at the time of the counterclockwise gesture was received, while users continue to change the drawing? Our solution to this was by creating an array which tracked the positions of the pixels to be "reversed." Upon detecting the counterclockwise gesture, for each of the pixels, we created a new animation but in the background color. This created the perceptions that the lines was erased from the point when counterclockwise gesture was detected, i.e., the animation was played backwards.

Furthermore, when multiple pens were used at the same time, the MoveInk algorithms differentiated signals from different users by assigning each pen input with a unique identification code. Each pen was represented with a specific color. A single user could also draw in different colors with different pens. When lines from different pens crossed each other, there would be more than one color overlapping in the same position. Since the system recorded the time point of each of the pens, when a clockwise twisting gesture was performed, the sequence of corresponding colors can be displayed in the animation. Technical challenges included the following: how to represent the most up-to-date pen stroke when the counterclockwise gesture was detected in the past? In particular, when multiple lines crossed, how to correctly “erase” and “reverse” the animation to show the correct line and color in reverse sequence without corrupting the rest of the lines? While the animation was reversed, new pen strokes from users may continued to be generated at the same time. When there was only one pen was in use, the counterclockwise twisting was implemented by filling the pixels with the background color. When there were multiple pens, the MoveInk algorithms kept track of the sequences and fill the erased pixels with the previous pen color instead of the background color, which allowed the system to precisely animate the trajectories from multiple pens with the combination of gestures at the same time.

4.4 Applications

4.4.1 Interactive visual expression

Though traditionally, the visual arts have not had much of an interactive esthetics, designing the interactive experience can add an entire dimension to the aesthetic endeavor. Unlike having a traditional canvas, MoveInk can offer an interactive visual experience. It does so by offering real-time feedback at any chosen moment after the artwork is initially created.

The real-time animation and interactivity presented in this chapter can take both authors and viewers back to the past when the drawing was created. The authors can revisit their thought processes and receive feedback on their own creativity. The viewers can maneuver back into the creative trajectory of the artists.

Both the viewers and the creators of an artwork have full control of the pen to create, to animate and to interact across time. This control gives users (as both an audience and an artist) the flexibility, spontaneity, and divergent thinking which can impact the creation process. Further discussion of MoveInk as an interactive museum exhibition is presented in Chapter 8.

4.4.2 Participatory experience and social engagement

MoveInk allows users to maneuver either their own content creation or interact with each other's work. The gesture interactions offer a participatory experience that engages the audience in a process of interacting with the work as if they traveled back in time to see the work while the author created it. It also invites the author to revisit his or her creation process. Therefore, through paper sketches and gestures, MoveInk allows animated content to be easily created in a playful and intuitive way without prior experience in producing computer graphics and animation.

Chapter 5

Sharing and Privacy

5.1 Purpose

Using traditional interfaces such as whiteboards or overhead projectors with a transparency, an individual develops text or sketches as other participants of a session observe the process. False starts and errors are visible to all. To remove this kind of pressure, using traditional interfaces such as notebook offers a way to protect content in a private space. As users generate input on their private notebook and share content in real-time, designing interactions for privacy control becomes an important consideration. When users are ready to share a final creation,

they either present the notebook to others nearby or to scan or copy the content to send to a remote person, so their viewers can view it. However, this requires users to share everything on the page even though they may want to keep certain portion private. Alternatively, users have to engage in a process to recreate the content in a public domain when they are ready to share. Switching devices and recreating the content is a time consuming process, which may often introduce interruptions. *Selective Sharing* is developed to protect user's needs of intuitively sharing when ready and maintaining privacy as they create.

5.2 Interactions

The *Selective Sharing* gestures are illustrated in Figure 11. By writing with a pen, any content made on paper was by default private. Holding down the pen for two seconds turned on the ability to draw a selection circle around the content that users wish to share. Flicking the pen shared only the selected content at the time of users choosing. The rest of the content was kept private (Figure 11). The hold-down gesture was designed as a metaphor for users to pause and think twice before selecting what to share. This provided an opportunity for users to review the content before sharing it. If they decided not to share, users can release the pen before closing the loop to retain content privacy.

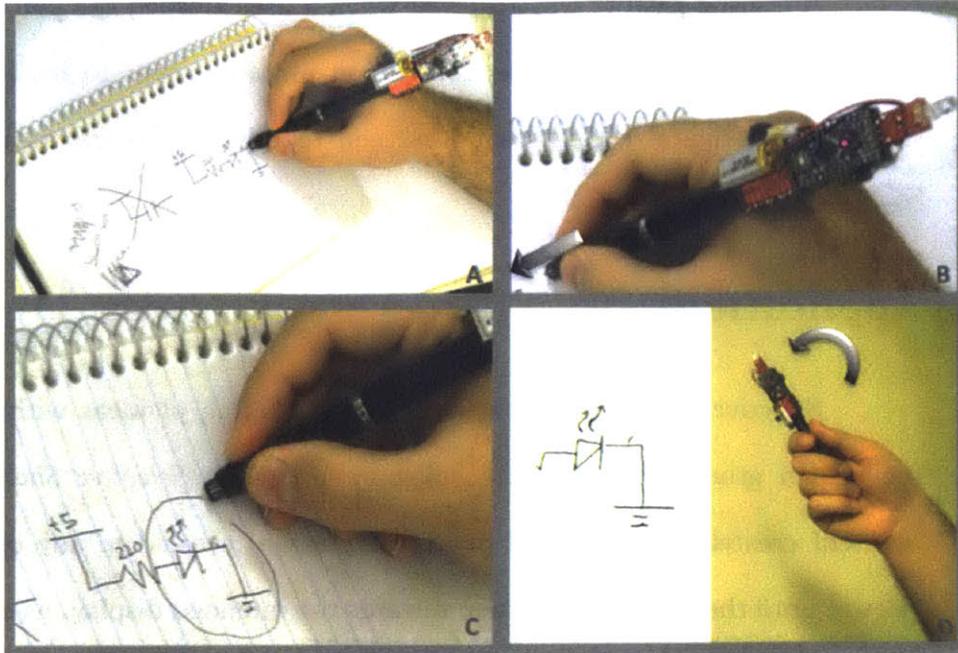


Figure 11. *Selective Sharing*: (A) Any content made on paper is by default private; (B) Holding down the pen for two seconds to initiate selection; (C) Making a selection circle around content ready to be shared; (D) Flicking the pen at a desired display shares the content exclusively within the selection circle, while the rest of the content remains private on paper (comparing to A).

5.3 Implementation

To decide whether a stroke should be interpreted as a command or data input, we designed and implemented the algorithm, which differentiated a selection circle from a drawn circle that was part of the content on the same paper. The selection circle was initiated with a deliberate gesture by holding down the pen on paper for a couple of seconds prior to making the circle (Figure 11B and Figure 11C). The circle could be in any shape, as long as it was a closed loop.

A sharing gesture was achieved when a user grasped the pen and swung, which triggered written content on physical paper to instantly appear on a digital surface that was seen to other collaborators in a session (Figure 11D).

5.4 Applications

Selective Sharing may be used for the sharing of ideas within a collocated group or for remote collaboration. With *Selective Sharing*, content created with pen and paper will not be revealed to any other viewer until the user flicks the pen towards the intended display. As each user flicks their content to the screen, it is color-coded. In this way, each author can see what the other have contributed and can see who added what.

Users obtain control over their sharing privacy with the freedom to generate personal creation within a public realm through *Selective Sharing*. An individual gets to select what on the notebook to share and what to keep as private at any moment after the content is created. The methodology and interactions allow users to quickly share certain content without incorporating cameras or switching devices.

In addition to maintaining creation privacy as described above, *Selective Sharing* can be used creatively to support communication. Users can select certain content specific to the topic of interest and share it at the right time as the conversation goes. In situations such as

brainstorming, meetings, or classroom discussions, users may also select content they created in the past, and share them on the shared surface at the time of their choosing.

Chapter 6

Evaluation

6.1 Usability Study Design

We designed a series of usability study to evaluate the interactions and systems presented in Chapter 3, Chapter 4, and Chapter 5. The purpose of this study was to evaluate the MoveInk system, with particular emphasis on usability and participation experience. The primary goal was to observe how users use the system in order to evaluate the functionality and design of the system. The secondary goal was to explore new interaction patterns that users might come up with. The study allowed us

to collect data through observation and questionnaires. The series of usability studies are described in the following sessions.

6.1.1 Free content creation and sharing

The first session in this study was a free exploration session to evaluate the gesture usability in content creation and sharing. The goal of this session was to evaluate the usability of MoveInk pen to create, share, and animate content through the following gestures: (1) using the flicking gesture to instantly transfer analog content on paper to the intended digital surface in the immediate environment; (2) using the clockwise twisting to transform paper sketches created by users into a dynamic animated form on the selected digital screen; and (3) using the counterclockwise twisting to reverse the animation playback.

In this session of the study, we measured the following

(1) Usability: Were participants able to figure out how to use the above gestures after receiving the instruction? Did they find the gesture interactions intuitive? Did they find the gestures easy or difficult? Comparing to a regular pen, was it easy to create content using the MoveInk pen?

(2) Accuracy: How many mistakes or errors happened with the system when participants intended to use certain gestures to achieve corresponding goals?

(3) Stickiness: How much time does a user spend on using MoveInk before getting bored?

(4) Emotional response: When their paper sketches were transferred from paper to the intended surface in the environment, how did the users feel about it? Did the user look confident or stressed?

(5) Other: Did users come up with other ways to use the system?

This session began with an instruction video demonstrating the functions of the MoveInk pen, including writing or sketching on paper using the pen, flicking the pen towards the digital screen, and twisting the pen clockwise and counterclockwise. After participants watched the instruction video, the researchers gave them verbal instruction as follows:

“In this session, you have five minutes to explore the pen and sketch anything you want. You may use the following three gestures: flicking, twisting clockwise, and twisting counterclockwise or may freely use the pen in any way you want. No one will judge the content of your work. If you have questions, please ask.”

Participants were each given five minutes to freely use the pen. There was no other task required. During the entire duration of this session, a single participant was in a room to participate in the study. The researchers might enter the room to answer any questions or to maintain the cameras when necessary. After the five-minute free exploration period,

the participants filled out a questionnaire (Appendix A). The entire duration of this session was 10 minutes.

6.1.2 Group interactions

In this session of the study, participants were paired up into groups of two in order to study the group interactions and collaborative creation using the MoveInk pen. Each group was taken into a room described in 6.3. They were asked to collaboratively create a drawing with their partner.

In order to compare the use of the MoveInk pen with a regular pen, this session was divided into two phases. In phase 1, all the functions on MoveInk pen were disabled. Participants used the MoveInk pens as regular pens to sketch and draw. They were provided with one sheet of blank paper. Each of the participants in the pair was given one pen. The researcher read the following instruction to them:

“In this session, you will be using regular pens to collaborate on a sketch. You have three minutes to work together and sketch anything you want. You may talk with your partner and may use the pen in any way you would like. We will not judge the content of your work. If you have questions, please ask.”

In the end of this phase, each participant filled out a questionnaire independently. The questions are listed in appendix B. After they filled

out the questionnaire, participants returned to the room. They stayed with the same partners and were each given the same MoveInk pens.

In this phase, the MoveInk functions were enabled. First, their collaborative drawing from the previous phase was presented to them on the same sheet of paper. Next, the researcher read the following instruction to them:

“In this session, you can use the following three gestures: flicking, twisting clockwise, and twisting counterclockwise. You have three minutes to work together and sketch anything you want. You may talk with your partner and may freely use the pens to interact with your work on the screen. We will not judge the content of your work. If you have questions, please ask.”

They were asked to use the MoveInk pens to flick the collaborative work from the previous phase onto the screen, and twist the pens to animate their work. This allowed them to review their process of the collaborative work that they created in the previous phase. They were free to use the pens to interact with this work further or to continue drawing at any time in this phase.

In the end of this phase, another questionnaire (Appendix C) was given to each participant in a group to collect their feedback on the group interactions regarding the use of gestures, participatory experiences, and perceptions of the work comparing the static paper form and in the

animated form. The total length of this session, including the two phases, was 15 to 20 minutes. In this study we observed how participants used MoveInk comparing to regular pens. How would they interact with each other? Would they pay attention to their partners or do they focus only on their own work? Would viewing the collaboration process impact on their own creation process or on their creativity? Would these gestures, i.e., flicking, twisting, and *Selective Sharing*, engage their partners during the process or not? We gathered data from this session to evaluate the system and explore how the gesture interactions mediate communication and expression.

6.1.3 Remote interaction using Selective Sharing

This session focuses on the evaluation of *Selective Sharing* being used in remote interactions. *Selective Sharing* was designed to allow users to create content in their private workspace, i.e., notebook, rather than in a shared public workspace such as shared screen or whiteboards, and allow them to share only selected portion with the audience at the time of their choosing without having to switch devices.

We designed a remote meeting scenario in which the participants had to produce content under pressure while their boss and clients were watching. In addition, this scenario created the need for the participants to take written notes, to make changes in the iterations of their drawings, to communicate with the boss and clients but to not share unwanted content such as their work-in-progress doodles or mistakes.

In this session, we observed what participants did in order to deliver only the best final version when the boss requested to review the work and to present the end product to the clients.

Regular pens and paper are tools people commonly use in meetings. This session was divided into two phases in order to compare the use of *Selective Sharing* with the use of regular pens and paper.

In phase 1, the participants were given a regular pen and paper. By the end of this phase, participants were unaware of *Selective Sharing*. In phase 2, participants used the MoveInk pen instead. They may use *Selective Sharing* whenever they wanted to. In between these two phases, there was a 5-minute break. During this break, the researchers introduced the *Selective Sharing* function to the participants for them to learn about the gestures and to play with the *Selective Sharing* function.

Throughout the whole session, one participant participated in the study at a time. The participants were asked to play the role as a watch designer working for a company. One of the researchers was connected to the videoconference as their boss from a remote location. Through the videoconference, the participant and the boss could see and hear each other.

The design of these two phases is described as follows. In phase one, the researcher read the following at the beginning of this phase:

“You are a designer, and you are particularly good at designing watches. You have an emergency videoconference with your boss. You are given a pen and one sheet of paper to bring to the meeting.”

They were pointed to the seat in front of the videoconference screen that was connected to the boss. They may use the table if they needed to sketch or write on the paper. The participants may talk to the boss during the meeting or may start to use the pen at any time. After the boss and the participant greeted each other, the boss said the following:

“Hi, I’m on the phone with one of our clients, and they just told me that they need a new watch design. I’m going to tell you the requirements they want. Please take notes on this and begin sketching your ideas while I’m talking. Here are the requirements:

Include the company’s name: “Chronarchington” (spells out name);

Have a rectangular face;

Must be an analog watch;

Uses roman numerals.

Actually, the company name does not need to be included on the watch. Let me double check to make sure if there’s anything else they need. In the meantime, please keep sketching. (Pause for 5 seconds.) Okay, sorry, the client actually wants a circular face for the watch instead. Feel free to make as many sketches and be as creative as you want, but, in two

minutes, I'll be inviting the client to this call. When they come on, please present only the best design you come up with to impress them. Thanks so much."

The boss left the teleconference for two minutes. During this time, we observed how the participants reacted to the boss and how they used the pen and paper to support the activity. After two minutes, the boss came back to the videoconference and said:

"Hi again, could you please show me your final design for the watch before I invite the client?"

We observed how participants showed their work on paper to the boss. The boss may instruct the participant to show only the best final work and not display the mistakes or doodles they might have made on the paper. After that, the boss said:

"Thanks, I'm sharing my screen with the clients now. Please show us your design. (Pause.) Thank you, I'll be discussing the design with the client momentarily; I'll be right back."

The boss left the teleconference again. This was the end of phase 1. The researchers entered the room and introduced *Selective Sharing* to the participants. Participants played with the MoveInk pens and used the *Selective Sharing* function during this time. They may ask questions before the researchers left the room.

In phase 2, the participants were given the MoveInk pen with the *Selective Sharing* function enabled. They were given a new sheet of paper for this phase of the study. The researchers read this instruction:

“For the rest of the meeting, you’ll be using MoveInk pen. The pen has the same functions that you have previously seen on MoveInk, and it also has a *Selective Sharing* option. *Selective Sharing* lets you circle specific things that you want to share, so that each time when you flick your pen, only the content within the circled area shows up on the screen.”

The researchers left the room and the boss connected back to the videoconference. The participant may freely have a conversation with the boss or may use the MoveInk pen during the entire session. The boss said the following:

“Hi. The clients want a second watch. I’m going to tell you the new requirements so please take notes again and begin sketching your ideas as I talk. These are the requirements:

Have an oval face;

Must be digital;

Must have three buttons.

Let me double check to make sure if there’s anything else they need. In the meantime, please keep sketching. (Pauses for 5 seconds.) Okay, so the client actually wants a triangular face for the watch instead.

Feel free to make as many sketches and be as creative as you want, but, in two minutes, the client will be invited back to the call. When they come on, please present only the best design you come up with to impress them. Thanks so much.”

The boss stepped away from the teleconference for two minutes. The participants used this period of time to create with the MoveInk pen. After two minutes, the boss continued the conversation by saying:

“Hi again, could you please share with me your final design on our shared videoconference screen using *Selective Sharing*? I’m also sharing my screen with the clients now.”

Participants showed design idea to boss using *Selective Sharing* and flicking gestures. The boss continued to say

“Thank you, I’ll be discussing the design with the client and let you know how it goes.”

The boss left the teleconference. This was the end of phase 2, followed by a questionnaire (Appendix D). Participants were aware that this was a role-playing scenario regarding *Selective Sharing* in a remote meeting. The primary goal of this session was to evaluate the *Selective Sharing* interactions (phase 2) and compare that with the alternative tool, i.e. regular pen and paper (phase 1), to selectively share and present content they created: Which would they prefer? As users create content on private workspace, would they be able to effectively transfer only

specific content onto the screen in real-time using MoveInk? Would they find the *Selective Sharing* gestures intuitive or difficult? Would they look confident or frustrated? This session took about 15 minutes.

6.2 Subject Recruitment

Subjects who were qualified for the experiment had to meet the following criteria: they were over 18 years old and are capable of using a pen to write and draw on paper. There was no inclusion or exclusion criteria based on age, gender, or race/ethnic origin. Subjects in this study were recruited through Emails or Internet postings via social media. A subject recruiting email is attached in Appendix H. Their participation in this study was completely voluntary and they were free to choose whether to be in it or not. If they choose to be in this study, they may subsequently withdraw from it at any time without penalty or consequences of any kind. Each subject was given a \$10 gift card upon the completion of their study if they would like it.

6.3 Study Procedure

The study was conducted in MIT Media Lab. The study procedure was designed and carried out as the following:

The researchers in the study introduced the purpose of the study to the subjects and provided the consent (Appendix G). Once the

participants read and signed the consent form, each participant was taken into a room as illustrated in Figure 12.

The study was divided into four sessions, which were carried out in the following sequence.

Usability Study Session 1: Free content creation and sharing, as described in section 6.1.1.

The runtime of this session was 10 minutes, including the instruction and the 5-minute free exploration session, followed by a questionnaire to evaluate the gesture interactions and usability of the system.

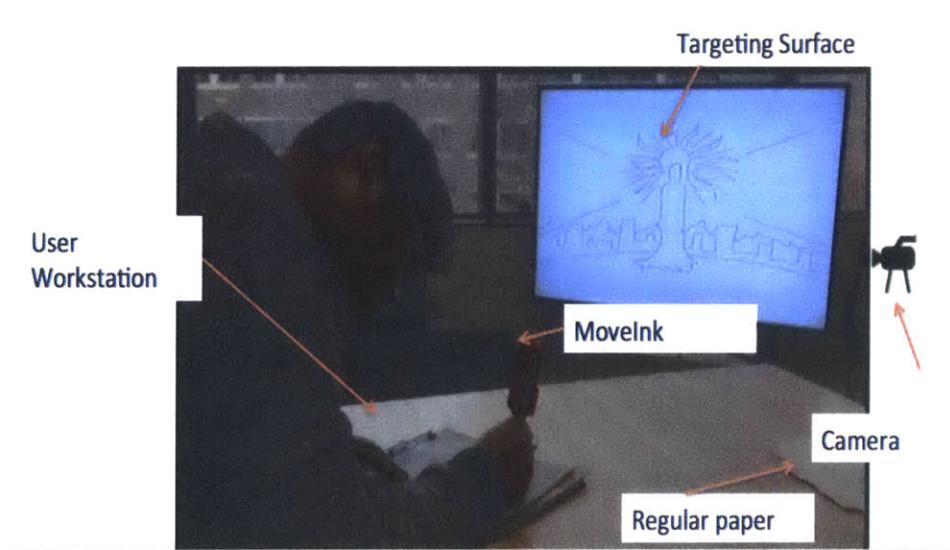


Figure 12. The setup for the usability study session 1.

Figure 12 shows the setting for the usability study. The room was equipped with at least one table for the participant to draw on, a screen for them to transfer paper sketches onto through gestures, a couple of chairs for them to use, and a camera to document the study. The room had transparent glass walls for the researchers to observe their actions, responses, and facial expressions, and to provide assistance if necessary. A MoveInk pen and a deck of blank paper were provided on the table. The computer system was underneath the table.

Usability Study Session 2: Group interaction, as described in section 6.1.2.



Figure 13. The setup for the usability study session 2.

This session was divided into two phases. In phase 1, participants used a regular pen and paper to collaborate on a drawing. In phase 2, they used MoveInk pen. Each phase was three minutes. In the end of each

phase participants filled out a questionnaire (Appendix B and C). The total runtime of this session was 15-20 minutes. They were taken in the same room as above where each participant was provided with one MoveInk pen, as shown in Figure 13.

Usability Study Session 3: Remote interaction using *Selective Sharing*, as described in section 6.1.3.

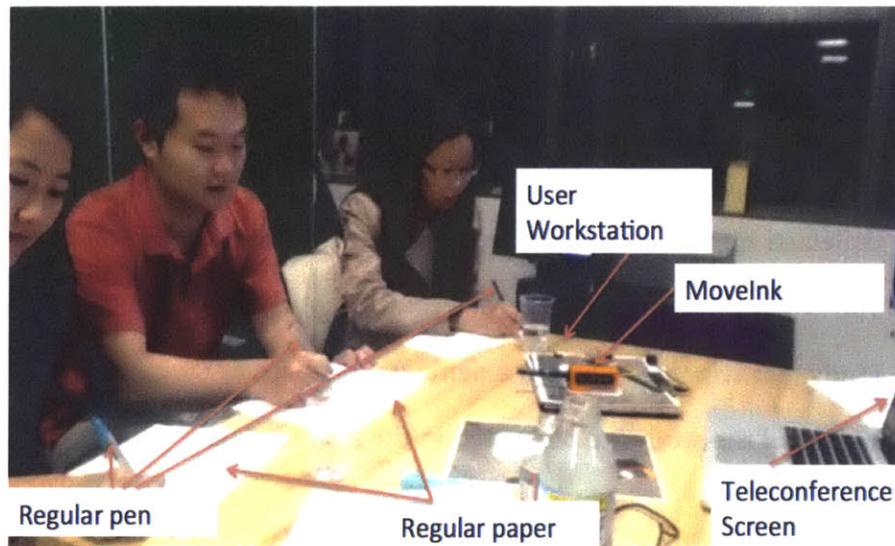


Figure 14. The setting for the usability study session 3.

This session was divided into two phases. In phase 1, participants used a regular pen and paper. In phase 2, participants used the MoveInk pen with which *Selective Sharing* was enabled. Each phase was five minutes. Between phase 1 and phase 2, the researchers introduced *Selective Sharing* to the participants. In the end phase 2, participants filled out a questionnaire (Appendix D). The total runtime of this session was 15 minutes.

Figure 14 presents the setting for the usability study. Different from the settings for the previous sessions, the participants were provided with a computer with camera and Internet connection in front of them. This computer connected them to a remote audience through a videoconference. They were asked to use their own regular pens in phase 1. If they did not have a preferred pen with them to use, they were provided with a regular pen and black sheets of paper. The rest of the setting in this usability study room remained the same as in the previous sessions.

The usability study session 3 was followed by a final questionnaire (Appendix E) regarding the overall experience using MoveInk and collected feedback on other feedback such as “Is there anything you wish you could do with MoveInk that you cannot do now?” In the end of this study, participants filled out a demographics survey (See Appendix F). The results of the study are presented in the next chapter.

Chapter 7

Results and Discussion

This chapter discusses the results of the usability study. We recruited 20 participants; 19 of them completed the study. Among the 19 participants, 11 of the participants were females and 8 were males between the age of 18 and 35. Of these participants, 17 were right-handed and 1 was left-handed. All of them were capable of using pens to write and sketch on paper and were familiar with using computers. The participation was voluntary and anonymous, with all participants completing all phases of the study. The data was collected at the time of the study. All data collected remained anonymous, though some of the videos and photos

may show participants' faces. The data gathered were non-sensitive and were used for research purposes only. The study took place at the MIT Media Lab.

7.1 Gesture Usability

This session describes the results of the free exploration session in the usability study to evaluate the gesture usability. The gestures evaluated in this session included the flicking gesture, the clockwise twisting gesture and the counterclockwise twisting gesture. In addition to each individual gesture, the accuracy of the system performance as a whole was also evaluated.

7.1.1 Flicking

The flicking gesture signaled to the system that a user wished to transfer their drawing or writing on paper to a selected display. As illustrated in Figure 15, all participants were able to successfully transfer their creation on paper to the display screen through a flick of the pen. All of them rated using the flicking gesture to share as intuitive (among which, 75% as “very intuitive”) and easy (62.5% as “very easy”).

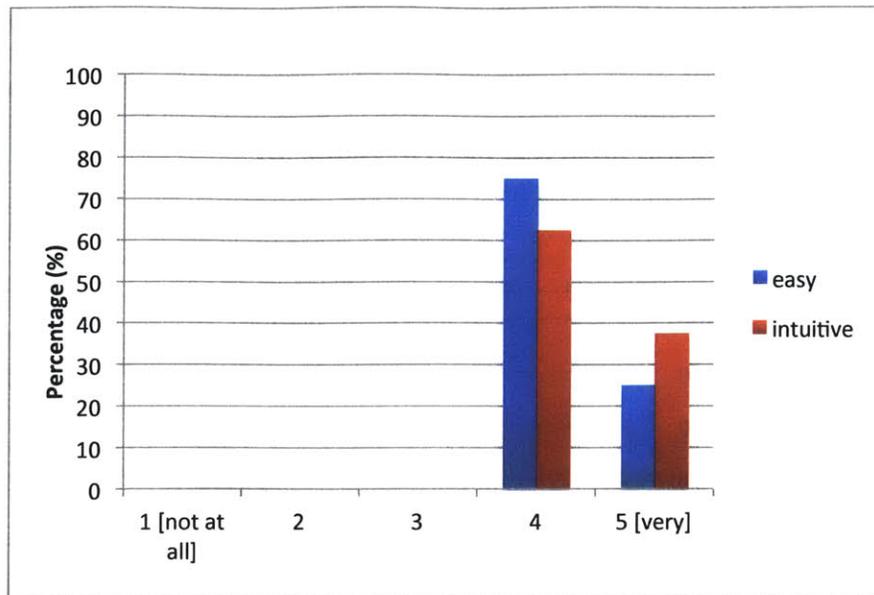


Figure 15. According to user ratings, transferring sketches on paper to the screen by flicking the pen is easy and intuitive.

We also observed their facial expression and emotional response; 87.5% of the participants expressed surprise and excitement. Some made the comment “wow!” when seeing their shared content appearing on the screen after the first flick.

7.1.2 Twisting

The twisting gestures involve clockwise twist and counterclockwise twist. All the participants were able to use MoveInk pen and twisted it clockwise to turn their still sketches into animations. 84.2 % of the participants reported that this clockwise twisting gesture intuitive (10.52% rated it as 5: extremely intuitive; 73.68% rated it 4:somewhate intuitive), and the rest reported this gesture 3 on a scale of 5. Twisting the pen counterclockwise reverse the animation playback direction. 94.75% of the

participants reported the counterclockwise twisting gesture intuitive (15.8% rated it as 5: extremely intuitive; 78.95% rated it 4:somewhate intuitive.) The rest rated it as neutral (Figure 16).

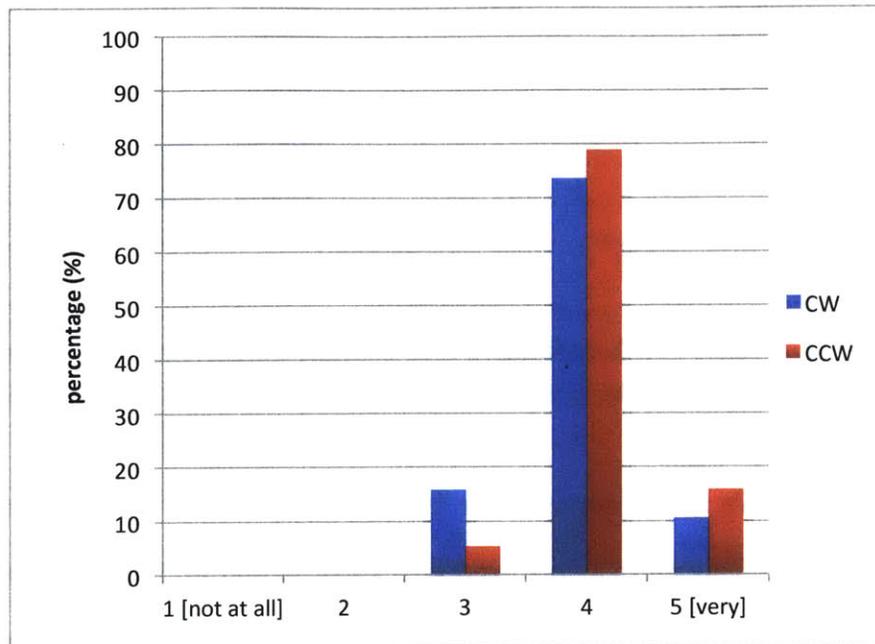


Figure 16. According to user ratings, it is intuitive using clockwise twisting (CW) and counterclockwise twisting (CCW) gestures to transform still sketches into animation.

As they used the twisting gestures to animate their sketches, all of the participants were drawn to the animation on the screen. None of them seem to be confused or frustrated, but all of the participants were smiling or surprised by the animation they flicked and animated on the screen through gestures. Towards the end of this session, 78.95% of the participants did not want this free drawing session to end. They asked for an extension of time to play with the pen more. Three participants

continued to draw for another two to five minutes as they were not willing to leave the even after the experimenters reminded them the time was up. The rest of the participants followed the instruction of the experimenter and proceeded to the next session.

7.1.3 Accuracy

Besides the gesture interactions, this study also measured the system performance. We analyzed the videos recorded during the usability study, with particular focus on the accuracy of the gesture responses to see if the system detected the flicking gesture, received the data, and responded to the gestures correctly. This study evaluated the false positive rate by observing if movements of the pen other than flicking gesture resulted in transferring their drawings to the display screen. From the videos, we observed that each participant had a particular way in using the pen to write or draw, which involved different movements of the pen. Some participants moved the pen very fast, while some participants moved the pens more gently. This caused different level of movements of the pen. Even while not writing or drawing, we observed participants playing with the pen by moving it in the air or rotating it. Also, a few participants dropped the pen to the floor accidentally. None of these movements caused false positive errors.

7.2 Collaboration, Social Interaction, and Self-reflection

7.2.1 Comparing using MoveInk with using a regular pen in a collaborative drawing

Comparing to using a the pen with and without MoveInk functions, 63.16% of the participants rated that they like the collaborative drawing using MoveInk more than using a regular pen.

High ratings

Those who preferred MoveInk to a regular pen for the following reasons:

First, people found it easy and intuitive:

“Moveink makes it easier show the process. It feels more interactive. Also, you can see the work as your collaborate, there was some story telling going on. You can see when the story turns into an interest sequence of event.”

Also, a lot of the participants mentioned the enjoyment. They enjoyed watching the process of each individual’s creation and the process of how the trajectory from each participant came along, interacted with or inspired each other to become a collaborative work:

“I enjoyed playing with the MoveInk and watching the process on the screen and seeing how both pens could work at the same time.”

“I enjoyed seeing the trajectory of both creators' drawings, especially when we saw how we compromised and inspired each other.”

“It captures the moment when drawing. Watching the drawing on the screen as a video gives a different type of enjoyment. It feels very different when I'm drawing v.s. viewing what I'm drawing.”

“I like how I can see my creative process and even see the drawing being undrawn. It makes my own creative process more visual.”

“because MoveInk can record the process of our ideas.”

“It's interesting watching the replay.”

In addition, some participants reported that using MoveInk gave them a feeling of achievement that using a regular pen did not provide:

“The pushing the drawing from paper to screen part is very interesting. It triggers the feeling of achievement.”

“... [I could] track my thoughts along the way. That might help me remembering what I was trying to achieve.”

Besides that, some participants found it easier to collaborate because it is easier to view the work on a big screen than on the paper:

“I can visually see the bigger image, which was more stimulating.”

Most interestingly, participants explored creative ways of using MoveInk pen to produce animated stories or an interactive game:

“You can create an animated storyline while collaboration.”

“I liked it with MoveInk more because my partner destroyed my tree [that I drew on paper] and I was able to resuscitate the tree using MoveInk. Animate it let us see the process and it was fun!”

Low ratings

15.79% was indifferent. 21.05% liked MoveInk less comparing to using it as a regular pen in this collaborative session. The reasons behind this include:

“The computer was being slow, so it was more distracting than anything else.”

“You can see instantly what and where the other person is drawing. With the MoveInk you need to wait for the other side to flick it.”

“I think both regular pen and MoveInk has its benefit. With a regular pen, I have more control of displaying different pressure on paper (light strokes and darker strokes and details).”

Despite the majority of the participants preferred using MoveInk much more than using a regular pen, the feedback from those who did not rated it high gave us insight to the improvement we could make on the project in the future. The computer needed to be upgraded in order to

have more memory and computing power to process the graphics and animation rendering in a timely manner. The digital pen used in the system was the most basic pen without pressure sensitivity. The MoveInk gesture-sensing module, however, can be attached to different digital pens and this will allow users to create and animate their work with fine details of different strength of the pen stroke.

7.2.2 Social cue and turn-taking

We observed that the flick gesture served an extra function, which was to visually show other participants that something was being shared and who was sharing it. The study revealed new social interaction mediated by the pen gesture interactions which engaged participation and collaboration. In the unstructured free-drawing session, users responded to each other's flick by flicking back. As they flicked back and forth in turn, they naturally evolved this process into collaborative creation, building upon the other's drawings flicked onto the shared screen, turning that into a story, a game, or a complete sentence. Participants reported, "I noticed my partner flicking their pen, which made me pay more attention to them and to what they shared on the screen."

7.2.3 Impact on the creation process

42.11% of the participants reported that, after using the MoveInk pen and see the animated version of their creation with their partner, they changed what they wanted to draw next. This indicated that using the

MoveInk pen impacted on either their creativity or the creation process. The primary reason was that they could plan ahead and used the pen to make an animated collaborative story:

“Yes. Since this will come in the order that I draw, I might be thinking about ways to take the advantage of animation to make a story or at least something more than a still image.”

“Yes, because they are quite different and animated version give you animation idea.”

“It really changed how we draw and what we draw next, and this would change the final visual effect.”

In addition, using MoveInk helped them see their partner’s intention and impact on their next move:

“I can understand the other person's intention more just by watching the animation.”

This also changed their composition on the canvas:

“yea. I saw a lot more room and that influenced me to go bigger and expand the picture.”

Other participants were not consciously influenced by the use of MoveInk. The main reason was because they already had a pretty set plan in mind about what to draw and they did not care about what happened on the screen:

“No, there has been a picture that I imagined, or a direction I wanted to go for drawing, so it doesn't really matter if seeing the animated version or not.”

“Not really. Before I draw, I already have some kind of idea in my mind on what to put on the paper.”

Other reasons included:

“Not really, I actually just enjoyed seeing it animated. I wasn't really thinking about drawing anything else.”

“No. The interaction with the other artist impacts what I draw more than what is on the screen.”

The ability to turn a paper sketch into an animated work impacted on people's creation process. This function allowed people to plan ahead to draw in certain sequence to be later viewed as an animated story. In addition, the use of MoveInk pen in the collaborative session impacted primarily on one's ability to reveal their partner's intention. Through the gesture animation, users understand the collaborative work from their partner's perspective. The results were further confirmed in the next session.

7.2.4 Engagement and self-reflection during the collaboration process

High ratings

73.68% of participants rated that they felt more engaged in this collaborative work using MoveInk comparing to using a regular pen. Among them, 71.43% felt somewhat more engaged, and 28.57% felt much more engaged. These participants mentioned that using MoveInk changed their responses to their partner's creation:

"I was inspired by my collaborators idea and have a brief time of pause to think what is my next step."

"Seeing the animated version made me think about this: at what point in my drawing did I make my partner decide what to respond to my work?"

"Because MoveInk can record the process, I can see how my partner created his part. This made me want to build on it and have more collaboration with him to finish this picture."

"It triggers some discussion."

"We could think about new ways to draw a story."

Low ratings

27.32% of the participants did not feel a significant change in their engagement in the collaboration using MoveInk, comparing to using a regular pen. These were the same individuals who rated that they liked MoveInk less comparing to using a regular pen. The reason was the same given the computer being too slow at their session, or that they had already had plans in mind about what to draw so using different pens

didn't make a difference. Given these, none of the participants rated that using MoveInk made them feel less engaged in the collaboration process.

Interestingly, beyond our expectation to receiving feedback on the collaboration process, most of the participants reflected on their own drawings rather than focusing on their partner's contribution. For example, participants reported that

"I saw the details more meticulously, so I can improve the flaws."

"It made me more deliberate in my drawing so that my lines were less sketchy."

This indicated that MoveInk's animation playback function not only impacted on the way people created with their partners and engaged collaborators more, but also played an important role in giving individual feedback on their own drawings. In turn, people used it to improve their drawing in their next creation.

7.3 Selective Sharing

7.3.1 The Selective Sharing gesture usability

93.8% of users rated the *Selective Sharing* gesture "desirable" or "very desirable." They reported that the selective gestures were easy to select and easy to share the selected content. They reported that

“The circle method [i.e., the Selective Sharing gestures] made things easy to select and share”;

“I don’t have to worry about things I wrote wrong being seen by others”;

“It was great that I could select only what I want to show and I get to keep my doodles private.”

In addition, the design and computer graphics algorithms developed for *Selective Sharing* also allowed users to continue to draw after they have made a selection and share the content at a later time. Alternatively, participants could also select any content previously generated on the same paper to share them at the current time as the conversation went. All of the participants rated *Selective Sharing* very intuitive when using it in a collaborative session.

Participants commented in the questionnaire:

“It is convenient to share [my] work by flicking the pen and see the work appear on the screen instantaneously rather than sending it through email or other tools with my computer.”

“It is just a hassle to scan what you have written, attach them to an email and send it.”

“Sometimes, I just draw it on paper and use the webcam to share with others; however, it’s very inconvenient and not intuitive.”

Users also reported, *“The fact that one can write on a piece of paper and send it to the a computer screen makes the technique more intuitive than a regular tablet.”*

7.3.2 The Selective Sharing gesture usability

In the remote meeting session, we compared the results from the first phase where participants used regular pen and paper with phase 2 of the session where participants used MoveInk pen’s *Selective Sharing* function. 78.95% participants preferred using *Selective Sharing* to using a regular pen (Figure 17). In addition, comparing the results from the two phases, participants found that using MoveInk *Selective Sharing* was easier than using a regular pen in the remote meeting ($p=0.003$). For participants who rated the *Selective Sharing* “extremely easy” or “very easy” (36.84% rated 5 and 26.32% rated 4 on a 1-5 scale), they also reported in the questionnaire that

“[It was] cleaner and clearer way to share ideas; more immediate sharing than holding up to camera.”

“They could immediately see my drawings and only the ones that I wanted them to see. That feature was quite useful.”

“It makes things easier for me to develop multiple designs, knowing that I can choose which to share later.”

“ideas can be shared easily and effectively. No need to copy or scan my drawing. Saves time and effort.”

“do not have to worry about lighting of environment to share drawing.”;

“can share drawing live.”

“Video conferences can be really blurry and I think the MoveInk pen has potential to present a lot more detail.”

“ makes it easy to select what you want to share.”

“I can filter out all the things that I didn’t want to share on the screen.”

Among all users, one person preferred regular pens to *Selective Sharing* because “the system was buggy.” This was the same person who commented that the computer was too slow.

We also observed that in phase 1, most people shared their final design by folding their paper to hide the content that they were unwilling to share with their boss in the videoconference. Some people responded in the questionnaire the reason they prefer *Selective Sharing* was that “I don't like folding paper” and there was no time allowed in the meeting for them to redraw the final design to present to the boss.

84.21% of the participants rated that *Selective Sharing* was useful for videoconferences. The people who did not rate this useful or responded “maybe/not sure” was for the reason of the computer operation speed being too slow. For those who rated it useful, their reasons include:

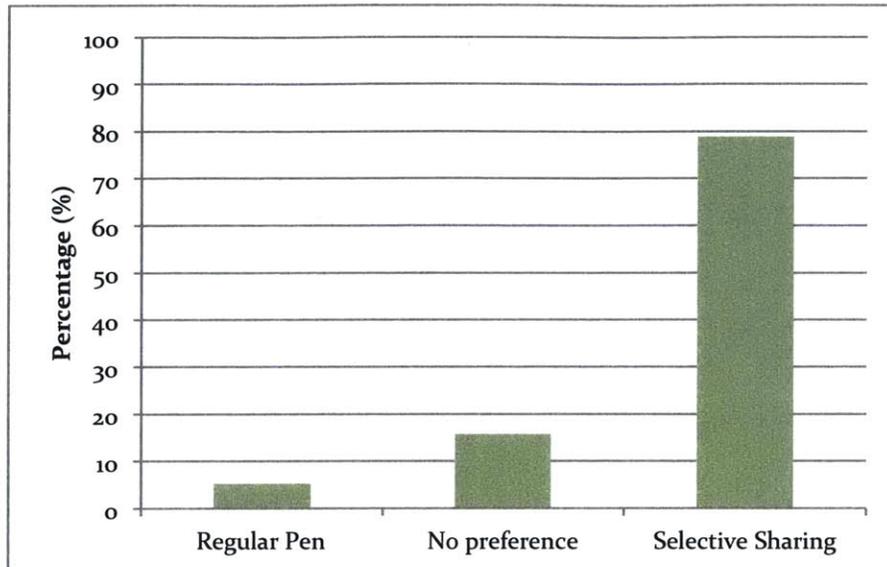


Figure 17. When communicate ideas in remote meetings, users prefer using FlickInk pen's *Selective Sharing*.

"It is very convenient and I can finish the request on one paper and just show the perfect part."

"It is generally difficult to show a drawing on the monitor during a video meeting. Selective Sharing made it easy!"

"Because it was extremely easy to share my drawings and I could let the boss to see my work without the distraction from the previous drawings."

"It help designer not to worry about what he doesn't want to show."

"It gives me options to choose the best work out of my design iterations much quicker and easier."

7.3.3 Comparing those who enjoy being in the spotlight vs. those who are shy

One assumption about *Selective Sharing* was that for those who feel comfortable developing ideas on the whiteboard while others are watching, may not find it desirable using *Selective Sharing* comparing to those who tend to be shy, sociophobic, or nervous being on the spotlight. In this study, we investigated the correlation between the personality type and their ratings on using *Selective Sharing*.

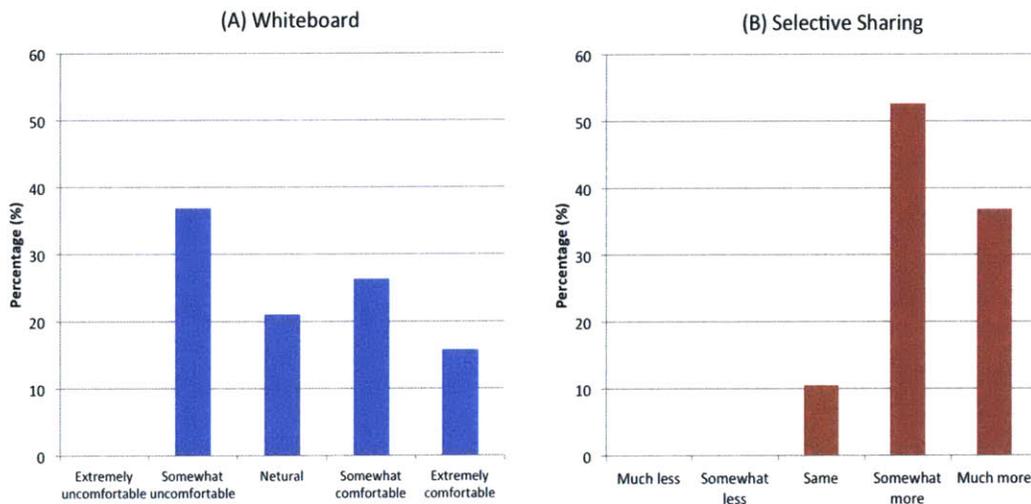


Figure 18. (A) The majority of users feel comfortable or neutral when developing ideas on whiteboard in front of people. (B) Comparing to using a whiteboard in front of others, the majority of users find it more/much more comfortable using *Selective Sharing* to develop ideas privately and share only selected content.

In this study, 36.84% of the participants rated that they feel somewhat uncomfortable when developing their idea on the whiteboard

with other people watching, 21.05% of them rated neutral, while 42.11% of people rated themselves comfortable or extremely comfortable on a whiteboard developing and sharing ideas while others were watching (Figure 18A). However, among them, 89.47% of the participants rated that using *Selective Sharing* felt more comfortable comparing to using a whiteboard. 10.53% of them rated the two indifferent. None of them chose whiteboard over *Selective Sharing* even though the majority rated themselves either somewhat comfortable or extremely comfortable developing ideas in front of people (Figure 18B). We further analyzed each individual's rating. There was no significant difference between those who were shy and those who enjoyed the spotlight in their ratings on using *Selective Sharing*. The correlation between their comfort level being in the spotlight and preference using *Selective Sharing* was negatively correlated but the correlation was low ($r=-0.38$, Figure 19). The finding rejected the assumption that only people who found themselves uncomfortable being in the spotlight would prefer using *Selective Sharing*. Overall, people rated *Selective Sharing* as either the same or more comfortable comparing to using developing ideas in front of others, no matter what their personality type was ($p = 0.007$).

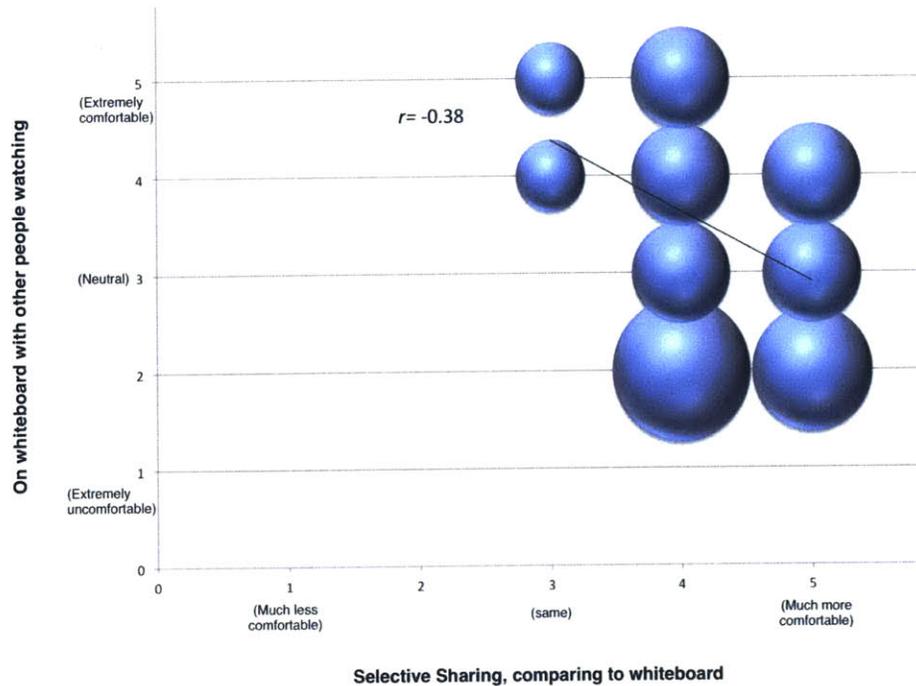


Figure 19. According to individual user’s ratings, being uncomfortable in the spotlight is negatively correlated with their preference using Selective Sharing ($r=-0.38$). The size of the bubbles indicates the number of participants at each data point. The finding rejected the assumption that only people who found themselves uncomfortable being in the spotlight would prefer using *Selective Sharing*.

7.3.4 Potential new applications using Selective Sharing

Participants in this session not only evaluated the usability of *Selective Sharing*, they also provided valuable feedback on potential other situations where *Selective Sharing* may be useful, such as when people were “debating”; at “Auction, bidding”; “online tutoring”; “brainstorming”;

“creating artwork”; “composing music”; “architectural design”; “idea sharing in classrooms”; “showing instructions”; “project management.” One particular participant responded “I have my own graphic design business, so this would be very useful for discussing potential design sketches with my clients.” Another participant found *Selective Sharing* particularly useful for preparing engineering designs and share only the content that was specific to certain clients at a later time, at a different location: “Anytime you need to do something that can be more easily drawn, or when notes need to be taken. When charts need to be shared when two people are not in the same place.” This opened up new possibility using *Selective Sharing* and MoveInk in potential future applications in various areas from education, art, design, to engineering and business management.

7.4 Other Findings

When asked if this prototype were produced with an excellent form factor, 89.47% of the participants would recommend MoveInk to a friend (Figure 20). Participants commented that what they liked the most about the overall experience with MoveInk was:

“How easy it was to share my drawings, and especially the Selective Sharing.”

“The ability to record the progress of drawing, it gives the art piece more life.”

“I love how it tracked the creation process and allow me to rewind/play.”

“I enjoy how we can use gestures and interact with things through the pen.”

“[It] can trace my own thoughts, and remind me what I did along the process to come to the final picture.”

“The ability to instantly transfer my drawings elsewhere and see it on the big screen.”

“When I was using selective share, I can quickly draw many ideas without worrying about how to show them.”

“Seeing a drawing happen in real time.”

“It senses pen movement, that I can have both a hard copy and a digital copy. Which is different from other digital pen. Also I don't need draw it on a sensor pad. The Selective Sharing is good, so I don't have to care about showing unrelated notes to others.”

“Using the pen was very easy and enjoyable.”

“It was fun and new.”

“I've never seen anything like this, so it's very interesting and fun experience. I really like the Selective Sharing, for designers it is a great tool.”

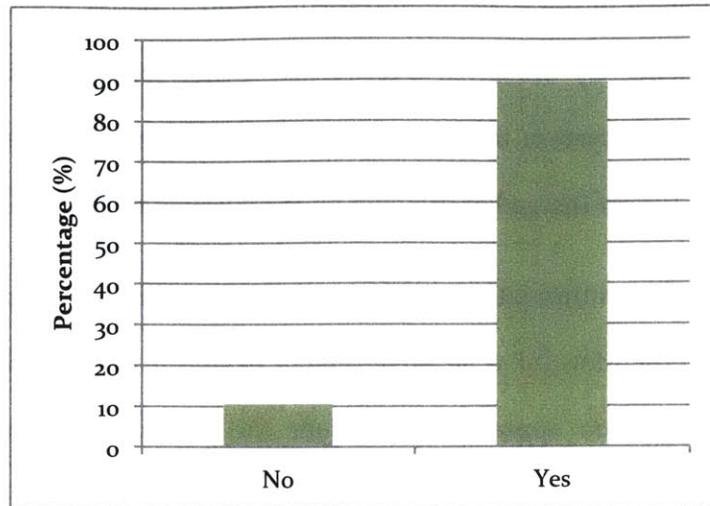


Figure 20. According to users' ratings, the majority would recommend MoveInk to friends.

Furthermore, we also gathered valuable feedback on other things that participants wished they could do with MoveInk that they cannot do now. Some participants mentioned that the pen could draw lines at different weight on paper but the shared digital version did not reflect the line weight. One specific feedback was *"It would be cool to be able to see weighted lines on the shaded screen..."* Such comments were from people who rated themselves as skillful at sketching and drawings. The majority commented that they wish the pen had erasing function. The counterclockwise twisting gesture could erase part of the drawings but would be performed in the sequence when the drawing was developed. Other feedback included allowing for different colors: *"More colors will significantly increase the experience of drawing;"* change of animation speed or sequence *"[It] would be better if we don't need to worry about*

the sequence of the drawing in the animation ... better if we can re-order the sequence by ourselves afterwards.” Other feedback was to have a “built-in grid system in the background for engineers”, or the ability to “draw in the air instead of drawing on the surface” of the paper.

Other comments specifically on the usability includes *“I found the shape on the MoveInk a bit inconvenient in that it was a little awkward to draw with. I do appreciate how light the pen was.”* However, on the contrary, another person commented, *“Pen is heavy.”*

One feedback about the use of gesture: *“I'd like to be able to navigate through the animation of drawing by moving the pen left/right to navigate the video (similar to the way we can navigate computer videos today using the bar below the video.) It's basically the ability to see an overview of the animation and to move to the parts that I'm most interested in.”* However, moving the pen left or right can be very similar to the movement people commonly have when using a pen.

In the end of the questionnaire, we collected general comments from the participants. These comments were listed below:

“I would totally buy this if it were commercialized. It's a really cool concept!”

“Cool design!”

“Another idea is maybe make a detachable thing that lets you put the MoveInk sensor on any pen you want... So the user can choose any pen they desire. Also easier to replace ink when the pen runs out of ink.”

“Impressive.”

“...make the sketching space bigger than the existing rectangle...”

“I really enjoy participating in this research!! To see how technology could help us go far and beyond.”

“Great work. I think you just need to find the best application, and design around those people's needs...”

“Is this product out in the market right now?”

Chapter 8

Real-world Deployment

8.1 MoveInk as an Interactive Art Installation

The process of creating art itself is an art. However, the creation process is usually non-visible in the completion of the final form. What if artists are given an effortless way to revisit the creation process embedded in the ink trajectory, as if they were travelling back in time? What if we could leverage the advantage of pen and paper sketches, but go beyond their static final form?

In order to point out the importance of the real-world deployment, the director of the Media Lab Joi Ito contended that “Deploy or die” should extend Nicholas Negroponte’s “Demo or die” as the measure of success for innovation. Although he primarily refers to bringing designs and innovation to the market in the context of business, the spirit of real-world deployment can be also valuable in the creative and artistic field.

In addition to doing a demo and documentation in the laboratory setting, the research was deployed into the real world through art exhibitions. In museums, the general public can be exposed to the freedom and flexibility of creating and imagining new possibilities. We were able to observe how people interacted with MoveInk unguided.

MoveInk was first exhibited as an interactive art installation in the ACM Multimedia Art Gallery in FAD Museum⁹ curated by international committees. The FAD Museum, recognized as the first and primary centre for design and architecture in Catalonia and Spain, is a place where people are more prone to creative endeavors. This exhibition provided an opportunity for us to see how MoveInk enriched artistic expression and participatory experience in the real world outside of the laboratory.

⁹ The FAD museum, also known as Fostering Arts and Design Museum was the ACM Multimedia Art Gallery Exhibition Museum in 2013. It is located in downtown Barcelona adjacent to the Barcelona Museum of Contemporary Art (<http://www.fad.cat/contents/view/aboutus>).

Different from laboratory settings that require test subjects to perform specific tasks, the museum exhibition was free for visitors to interact with the MoveInk installation without rules. This real-world exhibition opened up opportunities to see how the audience may come across different ways of interacting with MoveInk and with each other when they were given different perspectives.

In addition, this exhibition provided an opportunity to explore the impact of MoveInk's gesture interactions on how people do creative work in real world. More particularly, given the design of MoveInk for its ability to dynamically transform still artwork into animated forms, I wanted to explore if MoveInk as an art installation could allow the artists and audiences alike to revisit the creation process of an artwork. From there, this exhibition allowed us to explore if this could allow the audience to take the artist's perspective and vice versa, switching from being a viewer to being a creator. This led to further observations on how MoveInk enabled creation and interactions across time. Furthermore, this allowed us to see its impact on how people create individually or collaboratively, as a function of time.

8.2 The Museum Exhibition Design

The exhibition experience consisted of two components: an interactive experience and a viewing experience. To bring the experiences into a real-world setting in a museum context, the exhibition required

specific setup not only to allow the visitors to *interact* with the installation comfortably, but also to provide an inviting but not distracting space for the audience to *view* the artwork.

8.2.1 The interactive experience

The interactive experience was designed with the goal of allowing visitors to freely pick up the MoveInk pen and create on paper. With this design, they could interact with their own creation through gestures to transfer the paper sketches onto the digital canvas, and to transform still sketches into an animated trajectory. The goal was also to provide opportunities for museum visitors to interact with each other in the gallery space through MoveInk and through the artwork they created.

8.2.2 The viewing experience

In designing the viewing experience, the goal was to engage the museum visitors, as they walked into the gallery, in seeing the animation on canvas as well as in comparing that with the original creation on paper. In addition, an extra viewing experience was designed for this museum exhibition -- another MoveInk pen was displayed in the pedestal along with a documentary in video form, with the goal of presenting its artistic statement and design metaphors.

8.2.3 From exhibition design to technical implementation

Considering the above components, Figure 21 presents the sketches used to implement the designs for the interactive experience and the

viewing experience. As illustrated in this exhibition design, the table was designed to be at the height for people to comfortably use in their standing position. On the surface of the table, MoveInk pens would be installed. The tables were also designed particularly for this exhibition so that it could host computers equipment required for this interactive installation without distracting the viewers. In this exhibition design, the entrance to the gallery was arranged in the way that it opened towards the video display and the canvas on the wall so that visitors walking by could view the artwork on the canvas as well as seeing other museum visitors' interactions happening in the gallery space. The TV screen planned to display the video was arranged on the side facing the entrance. An optional wall was planned in this original design sketch so viewers can have a quiet, undisturbed space to create and to interact through MoveInk. The side table and chairs were arranged towards the side of the gallery space for museum staff to manage the gallery exhibition.

Preparing for an exhibition requires careful planning, communication and coordination with the exhibition curators and the museum staff, especially when it was in another country. In the process of the exhibition preparation, the curators were located in England and the museum managers, staff, and the gallery constructors were based in Spain, while the installation, my team and I were in the United States. The primary means to coordinate among the international teams was through emails with drawings and text in order to communicate the exhibition

designs and implementation plans. We transformed the original design sketches (Figure 21) into a technical drawing (Figure 22) with precision in shape and distance for the museum managers and engineers on-site to construct the gallery space.

Considering having a clean writing surface for the exhibition, it required computer equipment to be hosted inside the table allowing cables to extending to the surface. The design of the tall tables was illustrated in this technical drawing. A couple of supporting layers inside the table were planned to hold the computer equipment and a projector. The tables were designed and built specifically for this exhibition, so we designed the tables that could be easily assembled. The only wire that would need to come out to the tabletop was the sensor attached to the paper which serves as a reference point as the pen's position was recorded. I designed the tall tables and arranged two of them together with a gap in between for the wire, such that the wire could flexibly slide long the gap. This allowed people to comfortably move the paper to any place on the table. A cover board would be mounted to the front side of the tables, leaving the rear side open for projection. The front board is not shown in the technical drawing (Figure 22) in order to illustrate the interior structure of the tables.

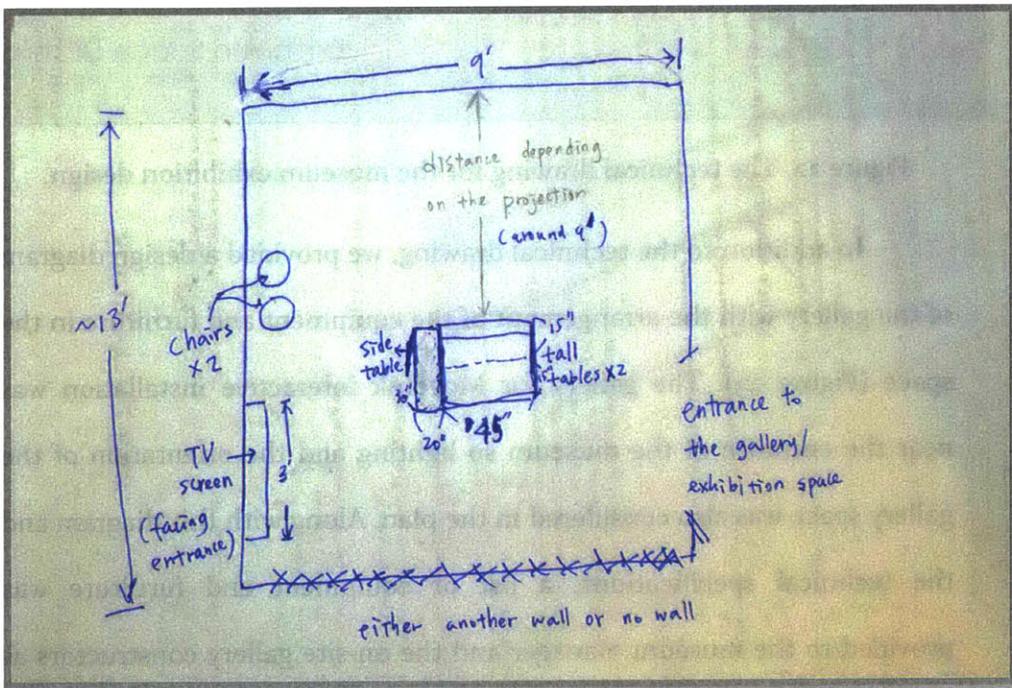
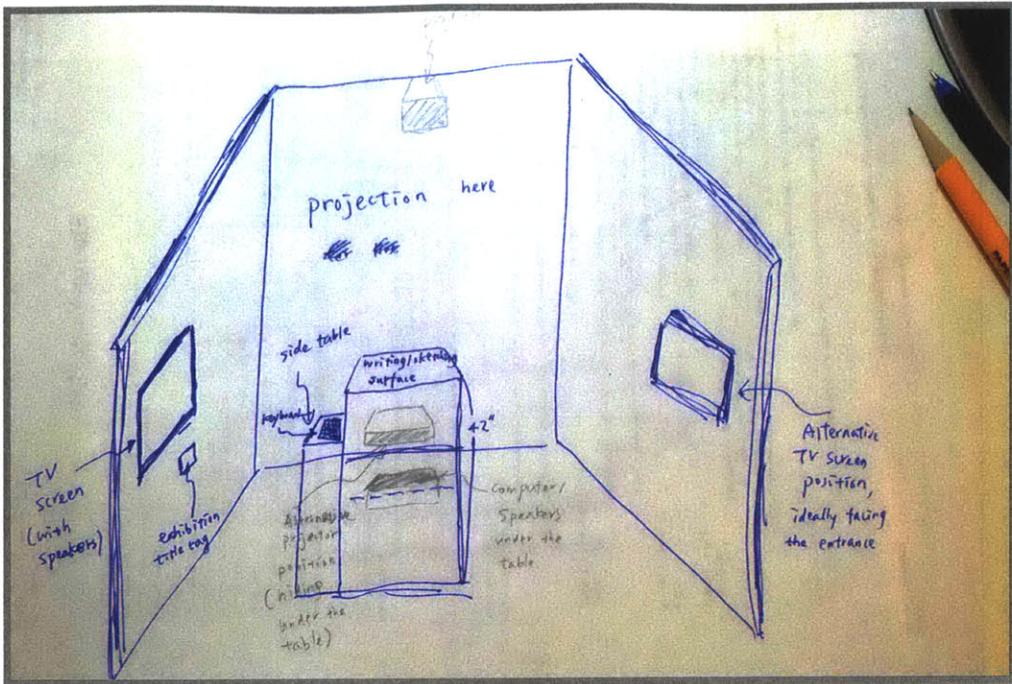


Figure 21. The original sketches for the exhibition design.

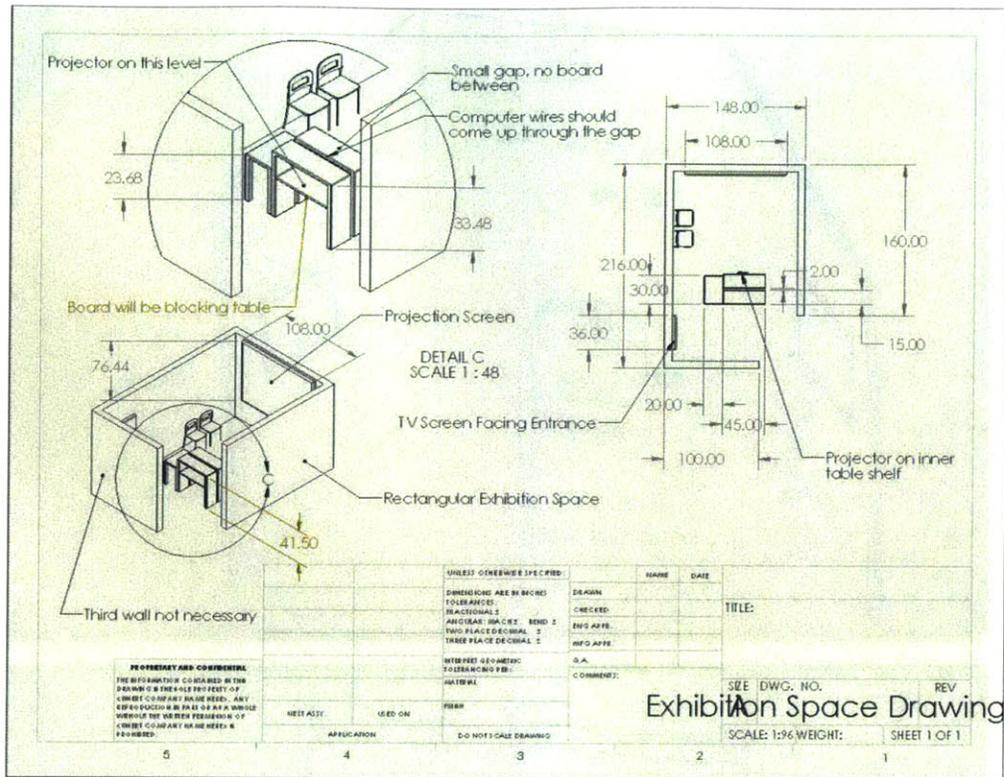


Figure 22. The technical drawing for the museum exhibition design.

In addition to the technical drawing, we provided a design diagram of the gallery with the arrangement of the equipment and furniture in the space (Figure 23). The gallery for MoveInk interactive installation was near the entrance of the museum so lighting and the orientation of the gallery space was also considered in the plan. Along with this diagram and the technical specifications, a list of equipment and furniture was provided to the museum manager and the on-site gallery constructors as follows:

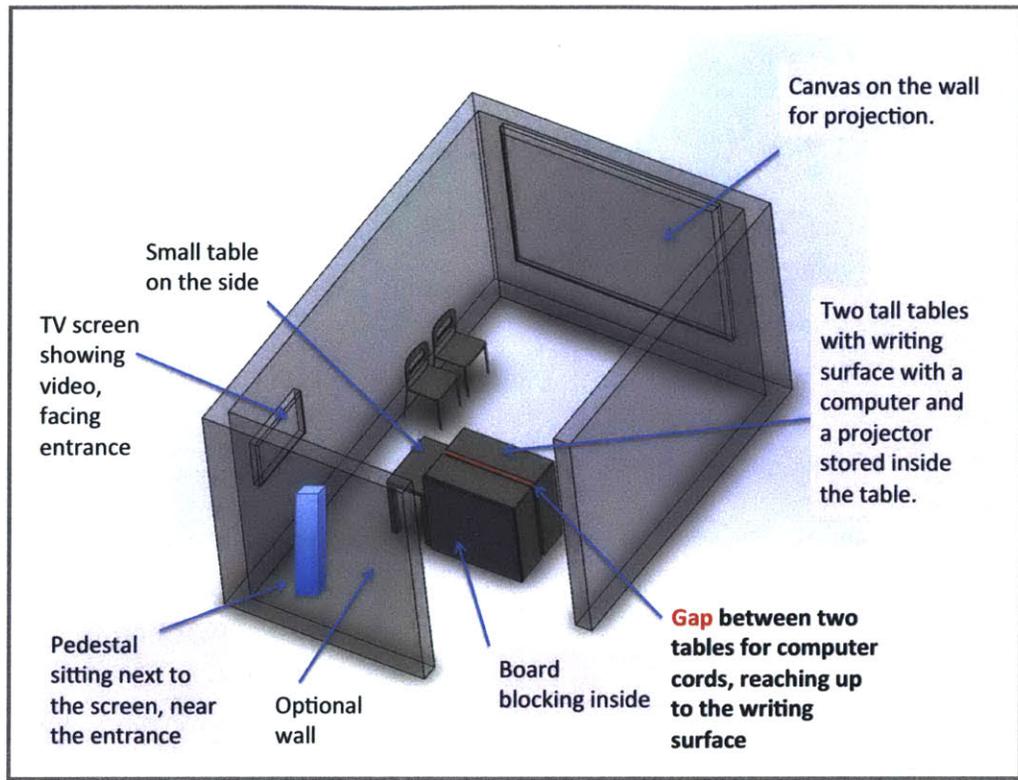


Figure 23. The exhibition design diagram.

1. Two tall tables (36" L x 15" W x 42" H each) for the audience to draw/sketch on, in their standing position while they can see the projection. Requirements for the table:

1.1 The table facing the audience has a cover board on the front side.

1.2 The table facing the projection screen has no cover board in case the projector needs to go under that table.

(Projector: if the projector is not mounted on the ceiling in the gallery, it can be set up underneath the table.)

1.3 There is no board in between these two tables, as a couple wires connecting to the computer needs to reach the top of the tables. The wires may come out from the gap in between the two tables.

1.4 Two layers should be built under the table to support the computer (and the projector at appropriate height).

2. A small table (30" L x 20" W x 32" H):

This small table would be used for the exhibitor and museum staff to maintain the installation when necessary.

3. The gallery space: (4mL x 3mW space or 13' x 10').

4. Four power sockets (13amp/220-240v) and extension cords to support US plugs.

5. Two chairs.

6. The video has sound. Quiet space is required.

8. A 36" TV screen with built-in speakers and USB input:

This should be mounted on the wall facing the entrance to display a video.

10. A pedestal with cover (15" W x 15" L x 42" H).

11. Lighting should keep dim in the gallery besides a spotlight at the pedestal.

8.2.4 Bringing the exhibition to life

I had the privilege to work with the curators and professors Marc Cavazza and Antonio Camurri and coordinated with the museum managers and on-site constructors to bring this exhibition to life. While the exhibition installation was taking place in Spain, the MoveInk interactive installation, along with related projects, had been on view in America for another live demonstration and exhibition. However, the Barcelona exhibition opened before the exhibition in America ended. My team and I duplicated the system in order to make both demonstration and exhibitions happen in parallel for the time overlapped. However, there was no one who could set up the system in Barcelona while I had to lead and run the demonstrations in America. Fortunately, I found Dr. Jochen Huber, who was in MIT, and Yichao Jin, who was in Singapore, would both be travelling to Barcelona. Before I could leave to set up the interactive installations, Jochen kindly helped me transport the non-interactive part of the installation materials to the exhibition site in Barcelona. Upon Yichao's arrival, he picked them up from Jochen and arranged them based on the exhibition plans as illustrated in Figure 23. At the same time, the museum gallery and furniture was being built. By the time my plane arrived Barcelona, all the construction was completed and the MoveInk non-interactive components were in place for the viewing experience. This allowed me to finish setting up the MoveInk system and

the rest of the installation for the interactive exhibit in time for the exhibition opening.

Although none of us have ever met each other before, the remote coordination and collaboration with Jochen, Yichao, Marc, Antonio, and various museum staff and volunteers brought the exhibition to reality (Figure 24).

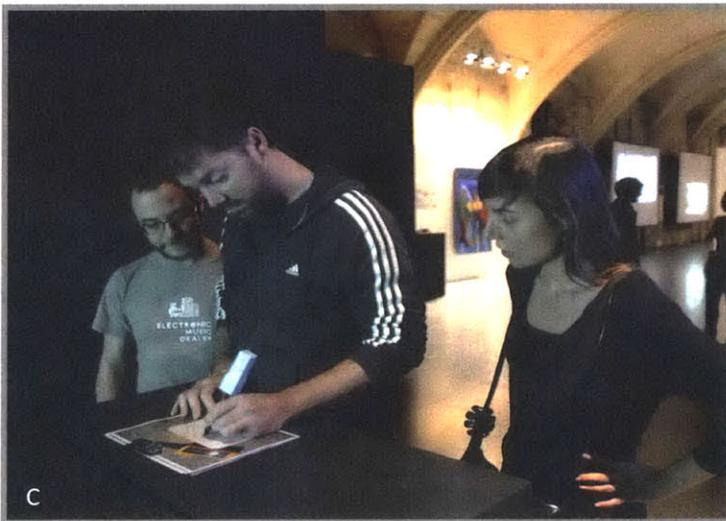


Figure 24. The MoveInk exhibit. (A) Exhibition design was implemented. Museum visitors entered the gallery to (B) view or (C) interact with MoveInk.

8.3 Audience Participatory Experience: Changing Perspectives

This section and the following sections document the real-world interactions that international visitors experienced with MoveInk. Visitors to the museum generally expected to see artwork on the wall created by artists, but instead, in this exhibition of MoveInk, the audience became the artists themselves.

Figure 24 shows the viewing experience (Figure 24B) and interactive experience (Figure 24C) as visitors came in to the gallery. Through interacting with MoveInk, the museum visitors took on an artist's perspective. By deciding when to transfer their own creation from paper to canvas, and in what direction to show the animation through MoveInk gestures, museum visitors were producing their own show for themselves and other audiences to view.

Interacting with MoveInk transformed the visitors' role from passive observer to active creator. Without receiving further instruction, museum visitors picked up the MoveInk pen and started to draw on the paper on the tall table (Figure 25A). They interacted with their creation by using the MoveInk gestures to transfer content from paper to canvas, to animate it, and to erase or reverse the animation (Figure 25B and C₁-C₄). The museum visitors not only created their own artwork in the private

workspace (the paper) but also showed it in the public space (the canvas) where they could express their ideas to other visitors.

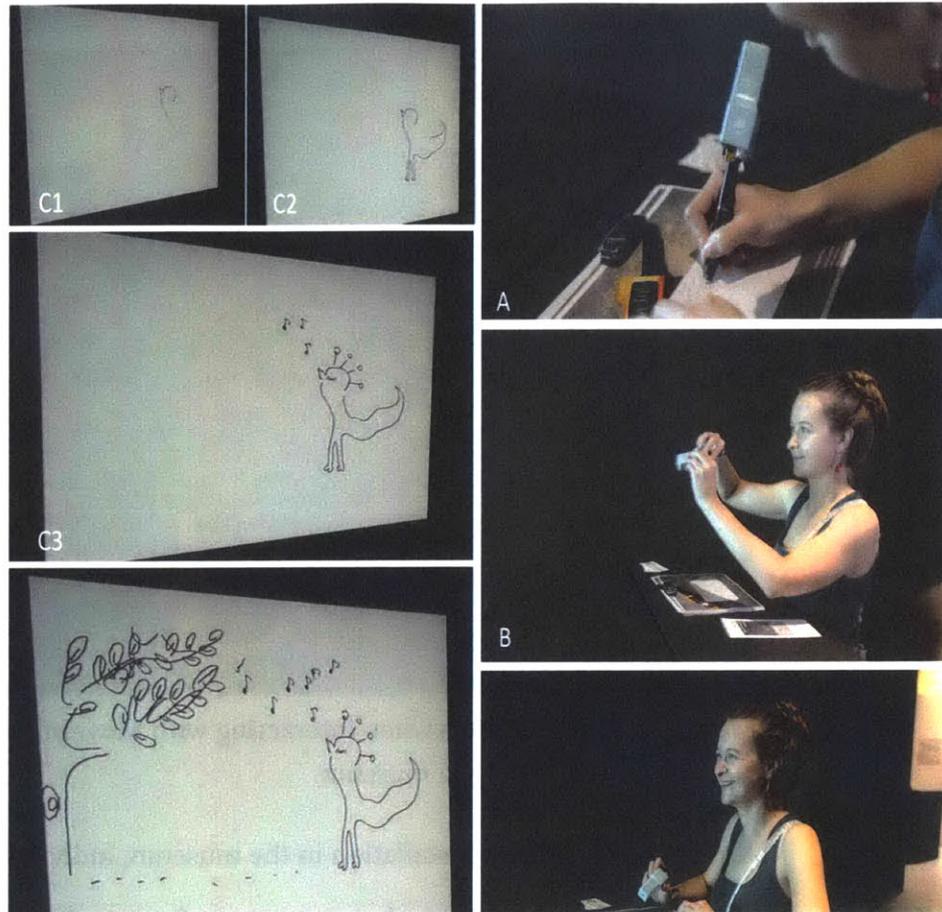


Figure 25. A museum visitor interacting with MoveInk. (A) The visitor drew on paper. (B) Through gestures, she made her creation appear on canvas, and she used the twisting gestures to transform her drawing into an animation (C1-C4). (D) The museum visitor's perspective changed from being the artist back to the audience.

Alternating the use of different gestures, they interacted with their artwork on canvas in real time. Once they initiated the animation, most of the museum visitors stopped gesturing. Instead, they watched the

trajectory animations emerging on canvas (Figure 25C1-C4 and D). As they watched each line they created appear on canvas, their facial expressions changed, indicating feelings of excitement and enjoyment (Figure 26).

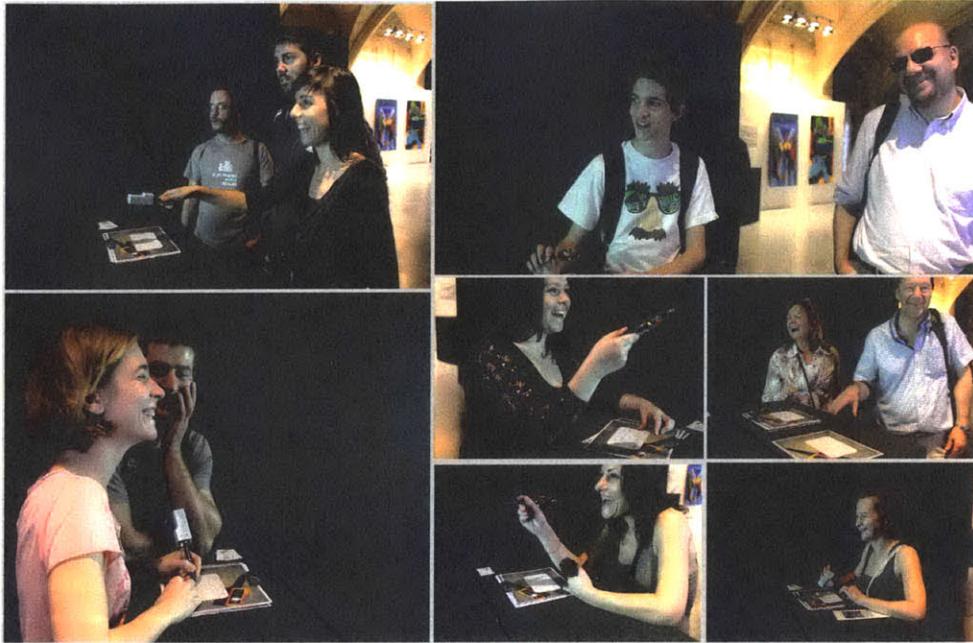


Figure 26. Visitors reactions when interacting with MoveInk in the museum.

Through this MoveInk installation in the museum, individual visitors were given an opportunity to switch perspectives, from audience to artist and vice versa. Thus the audience is an integral part of the art installation. Without the audience participation, the piece would not be complete. MoveInk as an art installation also connected the audience with the art and mediated the transition between different perspectives.

8.4 Audience Participatory Experience:

Inspiration from the Creation Process

In the MoveInk exhibition, as the museum visitors first started to use MoveInk gestures, they remained engaged with the system after their first drawing. Viewing their own creating process inspired them to further build on existing creation. The animated trajectory of their drawings on canvas allowed them to access the past upon the completion of the still drawing.

Museum visitors animated their creation and interacted with it on canvas using the twisting gestures clockwise or counterclockwise multiple times until they continued to draw more. This implication of this observation suggested that revisiting the creation process can encourage one to create further and can impact on the spontaneity and divergent thinking leading to creativity.

Furthermore, museum visitors came up with creative ways to create, leveraging the interactivity that MoveInk provided. For example, a visitor started with a curved line on paper. It was not clear what that could mean. He continued to draw more on the paper, and with each flick, he introduced a new object into the composition on canvas, which displayed to other viewers in the museum (Figure 27). In the end, he combined the twisting gestures to transform the still sketches on paper into an animated story. Each stroke he created back when he worked with

paper turned out to be meaningful in directing the flow of the story in the scene.

Although it was unclear if he had the attempt in creating a story with the whole sequence of the animation planned out ahead of time before he started to draw or if it evolved along the way as he interacted with the artwork through MoveInk, the museum's creative use of MoveInk opened up new opportunities in artistic expression and interactive story telling across time.

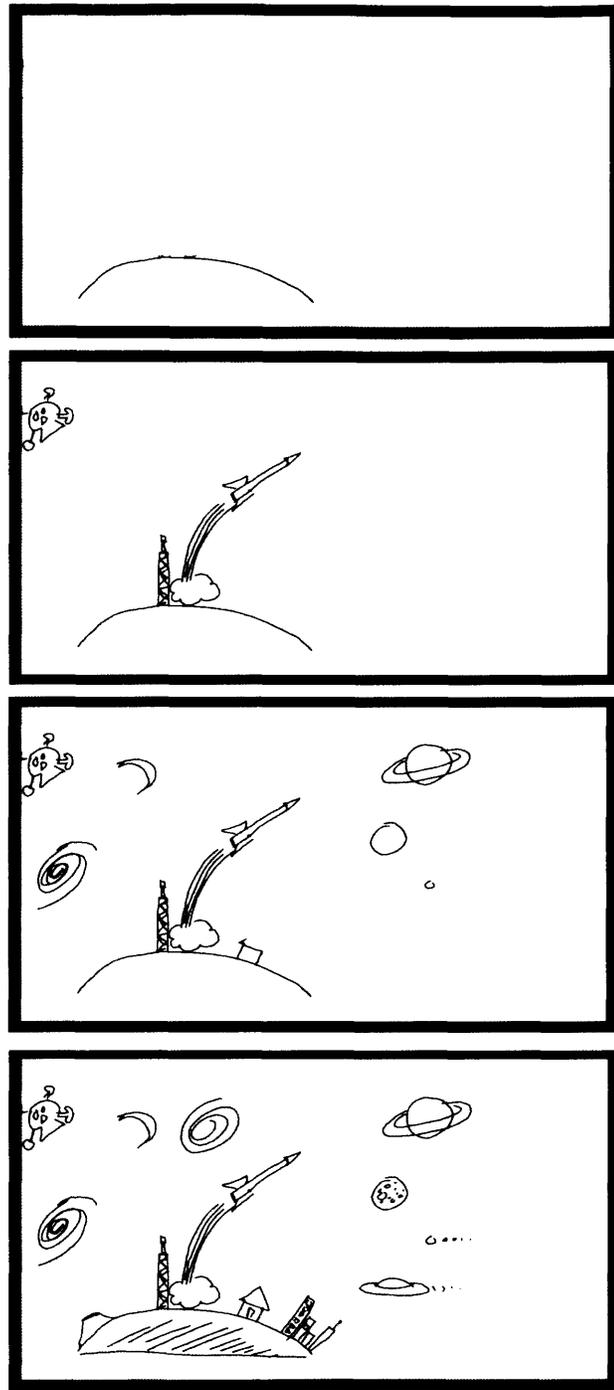


Figure 27. Progression of an animation created by a museum visitor. His combined use of gestures and sequences of drawings transformed paper sketches into an animated story.

8.5 Audience Participatory Experience: Engaging Audiences through Gesture Interactions

Originally, we planned to have museum staff sitting in the gallery room in order to provide assistance to visitors as they interacted with the installation. In the end, we did not have any museum staff on site providing any instructions. It turned out that MoveInk installation was self-explanatory. In addition to changing perspectives between audience and artist, the MoveInk gestures impacted the participatory experience by playing an unexpected role in mediating interactions among the audience.

Figure 28 documents the moment when a couple of visitors created a new piece of artwork through MoveInk. As they animated their artwork on canvas, their use of MoveInk gestures started to engage other museum visitors to view and to further interact with the artwork and with each other. For example, by watching the first group of people who animated their work on canvas, the second group of museum visitors mimicked the MoveInk gestures with bare hand from the back (Figure 28). This viewing experience engaged the second group of visitors, who later followed up to create their own artwork through MoveInk without a staff providing any further information.

In addition, upon the gestures performed, the animation on canvas further engaged these other visitors watching from the back. As opposed to viewing prior artwork as a still image on canvas, the gesture-mediated

animation was maneuvered in real time by the creators of the work. The gestures, along with the animation on canvas, invited these other visitors to enter the thought process of the creator. Even though these two groups of people were complete strangers and they did not talk to each other, the gesture interactions mediated the flow of information from the first group to the second without language.

Though the gestures were originally designed to interact with the artwork, their impact on the participatory experience exceeded our expectation. The gesture interactions, though originally designed to serve the purpose to interact with the artwork, was now a way to open up new dialogs among individuals as well as to demonstrate the gestures from one visitor to another.

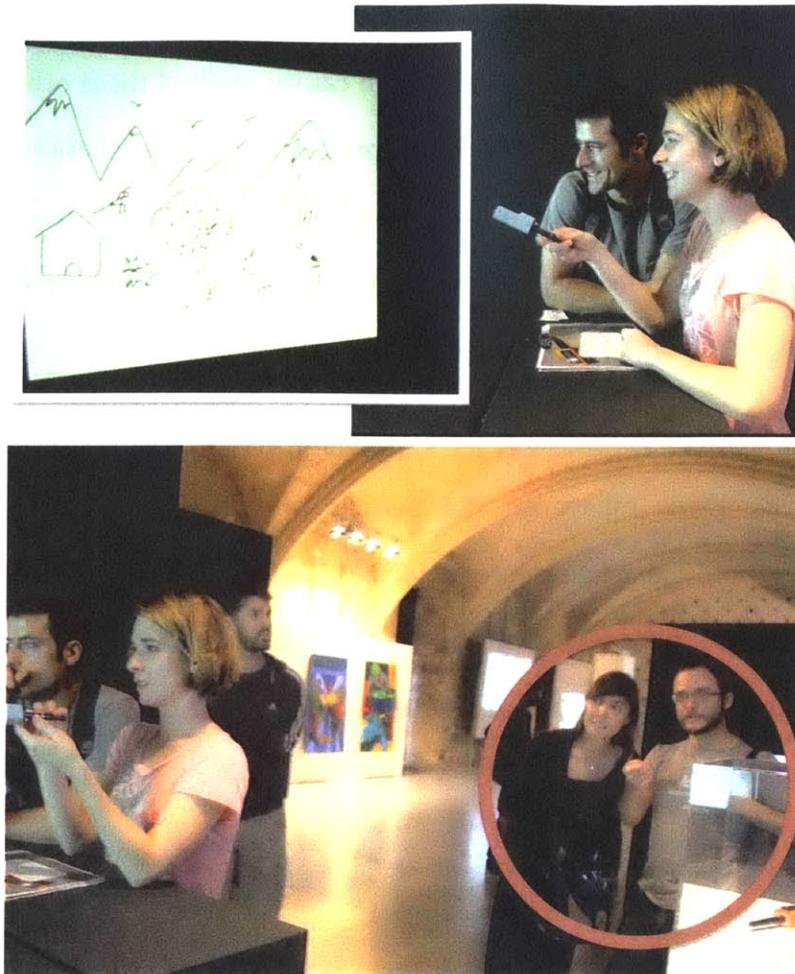


Figure 28. MoveInk gesture interactions, along with the animated sketches on canvas created by the first visitor, further engaged other visitors in the artwork and the interactions.

8.6 Audience Participatory Experience:

Spontaneous Co-creation

Besides interacting with MoveInk, visitors in the gallery spontaneously collaborated with each other in different ways. We observed two types of co-creation: synchronous group co-creation and asynchronous co-creation.

8.6.1 Synchronous group co-creation

Figure 29 documents a group of visitors interacting with MoveInk and with each other in the gallery. One visitor first created a drawing and animated it on canvas with the MoveInk pen. Upon seeing the drawing appear on canvas in response to their MoveInk gestures, the visitors' facial expressions immediately changed. Even though the other people in the gallery already saw the first visitor draw on paper, their facial expressions showed much more excitement when they saw the creation appearing on canvas. Then as the first visitor transformed his creation into an animation, the other visitors were even more engaged.

This further inspired these visitors in the following co-creation process: another visitor in the gallery space picked up the pen and spontaneously started to draw on the same paper as the first visitor. Following that, she passed the pen to the third visitor, who transformed the curvy lines created by the previous two into a creature.

This co-creation was unplanned and unguided. Visitors combined the use of MoveInk gestures during this group co-creation process by animating each individual's trajectory. Viewing the animated trajectory on canvas, individuals in the group instinctively and playfully built upon each other's creation, expanding each sketch into a new story. The spontaneity enhanced the creative dynamic.



Figure 29. Spontaneous co-creation mediated through the MoveInk gesture interactions. Upon seeing the animated creation on canvas, museum visitors were engaged and inspired to build upon each other's work to create collaboratively.

8.6.2 Asynchronous co-creation

In addition to the synchronous group co-creation described in the previous section, we observed another type of collaborative activity among

individuals who visited the museum at different times. After a visitor drew on paper and interacted with their artwork on canvas, it remained on canvas. Other visitors who came later, as we expected, viewed the artwork on canvas, saw the original sketch on paper, and animated it through MoveInk gestures.

Beyond our expectation, new work was born from asynchronous co-creation, where museum visitors composed the artwork based upon previous visitor's creation on the same sheet of paper. These visitors did not know who created the previous work, and they did not know each other. However, they were able to capture the previous creator's train of thought, which was embedded in the trajectory animation. Their lives may not have intersected, but their thoughts met, line after line, vividly merging on the same canvas.

As the next visitor built more work on the same sheet of paper, they were co-creating with the past, and leaving the door open to collaborate with the future. MoveInk connected the unknown and created with the unexpected through the asynchronous spontaneous co-creation.

Chapter 9

Conclusion and Future Work

9.1 Contribution

This thesis transforms one of the most important inventions in human history, the pen, into a new interactive medium. This new interactive medium enables users to work beyond the boundaries of paper, with particular impact in the following areas:

(1) Augmented participatory design:

The gesture interactions provide an intuitive way to transfer paper content to intended digital surfaces in the immediate environment as well

as in a remote location, allowing users to visually represent their ideas as their attention shifts from the surface of creation to the surface of attention. The design of these wireless gesture sensing and intuitive interactions improves upon previous systems by considering the convenience, accessibility, and mobility of pen and paper. The system is easy to install and is compatible with off-the-shelf digital pens and with any paper. Special lighting condition (e.g., cameras) or specific location (e.g., tabletop) are not required. The platforms and the gesture interactions can also be applied to creation surfaces other than paper as well, such as whiteboards or digital drawing pads of the user's choosing. The system integrates the power of pen and paper with the ubiquitous digital surfaces to create an augmented participatory experience. People in a space are no longer passive information receivers. As they cross the boundaries of paper, they can actively create, express, and share visual representations of their ideas.

(2) Dynamic interactions across time:

This thesis presents the interactions to represent time on physical paper. The MoveInk gestures provide a quick and easy way for people, with or without experience with computer technology, to transform static sketches on paper into animated representations. These interactions support dynamic co-creation across time on surrounding surfaces. The usability study showed that users without prior knowledge of computer graphics or animation algorithms were able to easily transform static

drawings they created on paper into animations through gestures. The majority of users commented that what they liked the most about the experience was the enjoyment in using the pen to interact and reveal the creation process. With the time-based gesture interactions, users effectively built animated stories on top of each other's drawings, and creatively turned their static sketches on paper into dynamic games.

(3) *Selective Sharing*:

The research creates an effective way to share selected content quickly and easily while at the same time maintain privacy during the creative process. *Selective Sharing* leverages the use of a pen to share only specific content that the users want to share when they want to share it. This gives users the freedom to create in a private domain and share only chosen content in the public domain without switching devices in real-time. The usability study confirmed that people preferred using *Selective Sharing* to using regular pen and paper in meetings. The pen-mediated content generation and sharing system not only grants users effortless control over privacy, but enables a personalized, private space to coexist within a collaborative, sharing process.

(4) Audience engagement and transformation of viewers' perspectives:

The installation presented in this thesis provided situations in which the audience could engage both with each other and with the

artwork. This research identifies that viewing the creation process inspires new ways to create. The gesture interactions engage the audience to participate in creation of the artwork. Furthermore, this work enables the viewers to take the creator's perspective and vice versa. The audience becomes creators, and transforms the participatory experience from passive viewership to active contribution. The interactions across time further empower unguided, spontaneous co-creation. Prior drawings can be expanded into new work. Thus, audience participation becomes an integral part of the artwork.

The museum exhibition of MoveInk draws attention to audience interactivity. Visitors to the museum originally expect to see artwork on the wall created by artists, but instead, the audience becomes the artists themselves in this exhibit. Without the audience participation, the piece would not be complete. MoveInk as an art installation also connects the audience with the art and mediates the transition between different perspectives.

The systems and interactions presented in this thesis motivate groups of people to collaborate with each other. Having the dynamic interactions across time allows both the audience and the creator to interact with the work and revisit the creation process, which is commonly not available upon the completion of a sketch on paper. The gesture interactions engage them and inspire them to spontaneously co-create. The trajectory animation reveals the co-creation process and

explores how the artwork evolves into new meanings through participant interactions.

9.2 Future Work

As the gesture pen interaction transfers sketches from paper to digital projections, it provides dynamic ways for people to communicate and express across time, location, and physical-digital boundaries. According to the usability study, participants rated the system as intuitive, easy to use, and effective. While the work of the thesis was implemented with digital displays and projection screens, these system capabilities can be used to augment the surfaces of surrounding objects. This allows users to integrate their own creations onto surrounding physical objects in a quick intuitive way, and as a result, gives users an opportunity to socially interact and engage with each other.

The usability study provided insights on new ways of social interaction mediated by pen gestures and the impact on self-reflection on individual creation process that can inform new ways of creation. According to the usability study, the system has potential for applications in design, engineering, education, art, project management, story-telling, and co-creation.

We collected valuable feedback from the usability study that may inform future work and in potential commercialization possibilities. Further improvement on the form factor may include reducing the size

and weight of the current gesture-sensing modules to make it even more comfortable when users hold and move the pen. Representing different pen strokes currently relies on the digital pens of the user's choosing. The FlickInk and MoveInk modules can be attached to future digital pens equipped with higher resolution and pressure sensibility. Functions such as erasing and changing colors, though not the primary focus of this current research, may be considered to be incorporated in future pen-based tools. The computer system can be upgraded to increase the processing speed in rendering and wireless sensing.

In the real-world deployment at the museum, both the artists and the audiences can trace, retrace, and interrogate the pen's trajectory. The artists can self reflexively revisit the creation process, and the audience can take on the artist's perspective. In this way, both discover new ways to create. Through gesturing with the MoveInk pens, they interact with the artwork as a function of time. In the future, we can investigate how revisiting the creation process can impact new directions for creativity. This leads to potential future directions to explore the impact of time-based interactions on the creation process and collaboration.

This thesis presented unique platforms for users to become active creators rather than passive observers, in order to initiate changes, communicate thoughts and express ideas individually or collaboratively. The platforms can incorporate artistic creation in the context of everyday life. With such interfaces available to the public, we can transform

everyday spaces into works of art, created by everyone. This can generate an ongoing conversation among artists, audiences, architects and occupants of public spaces. Furthermore, the four design areas investigated in this thesis may serve as the basis for future interface designs to enrich the participatory experience. This thesis can be a launching pad for further creative enhancements and lead to further research on participatory augmented environments and its impact on communication and collaboration in the future.

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Appendix

Appendix A

Usability Study Questionnaire 1

Comparing to a regular pen, how easy is it to use the MoveInk pen to sketch? *

1 = much more difficult; 3 = the same; 5 = much easier

1 2 3 4 5

Much more difficult Much easier

How easy is it to share your sketch on the screen by flicking the pen? *

1 2 3 4 5

Extremely difficult Extremely easy

How intuitive is it to animate your sketch by twisting the pen clockwise? *

1 2 3 4 5

Not intuitive at all Extremely intuitive

How intuitive is it to reverse the direction of the animation by twisting the pen counterclockwise? *

1 2 3 4 5

Not intuitive at all Extremely intuitive

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Appendix B

Usability Study Questionnaire 2.1

You just collaborated with your partner on the sketch without using MoveInk functions.

Overall, how do you like this collaborative experience using a regular pen? *

1 2 3 4 5

Do not like it at all Love it

Why? *

Based on your still sketch, what is the next thing you plan on drawing in it? *

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Appendix C

Usability Study Questionnaire 2.2

You just saw your collaboration process, and used the pen with MoveInk function.

Overall, how do you like this collaborative experience using MoveInk? *

1 2 3 4 5

Do not like it at all Love it

Comparing the previous two collaboration sessions, which do you like more? *

1 2 3 4 5

I like session 1 (drawing on paper only) I like session 2 (drawing with MoveInk functions) much more

Why? *

Did you change your mind on what to draw next after seeing the animated version? Why or why not? *

Did you feel more engaged in this collaborative work comparing to the previous session? *

1 = much less engaged, 3 = the same, 5 = much more engaged

1 2 3 4 5

Much less engaged Much more engaged

Did seeing the animated version of your sketch affect your drawing in any way? *

Were you inspired by it? Did you change your sketching speed? Did you change the way you interacted with your partner?

Other thoughts?

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Appendix D

Usability Study Questionnaire 3

In the previous session you used a regular pen and also used Selective Sharing to share your ideas with the remote participant. Please compare them.

In the previous session, did you find it difficult to share your work using a regular pen? *

1 2 3 4 5

Extremely difficult Extremely easy

In the previous session, did you find it difficult to share your work using Selective Sharing? *

1 2 3 4 5

Extremely difficult Extremely easy

In this remote meeting, did you prefer using a regular pen or Selective Sharing to communicate your ideas? *

- Regular pen
- Selective Sharing
- No preference

Why? *

Did you find Selective Sharing useful in this video conference? *

- Yes
- No
- Maybe / Not sure

Why or why not? *

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How do you feel when developing your idea on the whiteboard with other people watching? *

1 2 3 4 5

Extremely uncomfortable Extremely comfortable

Comparing to using a whiteboard while others watching you, would you feel more comfortable using Selective Sharing to develop your ideas privately and share the desired content? *

1 = less comfortable; 3 = the same; 5 = more comfortable

1 2 3 4 5

Less comfortable More comfortable

Can you think of other situations where Selective Sharing may be useful?

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Appendix E

Usability Study Questionnaire 4

What did you enjoy most about your experience with MoveInk? *

What did you enjoy least about your experience with MoveInk? *

Is there anything that you wish you could do with MoveInk that you cannot do now?

If this prototype were commercialized with an excellent form factor, would you recommend it to a friend? *

- Yes
 No

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Appendix F

Usability Study Questionnaire 5

Gender *

- Male
- Female
- Other

Age *

- 18-25
- 26-35
- > 36

Are you right-handed or left-handed? *

- Right-handed
- Left-handed

Please rate your sketching skills in comparison to the general public. *

1 2 3 4 5

Not good at sketching at all Very skillful at sketching

Other comments?

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[Submit](#)

Appendix G

Consent Form

**CONSENT TO PARTICIPATE IN
NON-BIOMEDICAL RESEARCH**

User Study of a Gestural Pen Interface for Content Creation and Sharing

You are asked to participate in a research study conducted by Kent Larson (Architect, Director of Changing Places group in MIT Media Lab), Sheng-Ying Pao (M.S., PhD candidate in Media Arts and Sciences, MIT), and Caleb Lin (MIT undergraduate student) at the Massachusetts Institute of Technology (M.I.T.) The results of this study may contribute to a senior project, research publication, public presentation, thesis or dissertation. You were selected as a possible participant in this study because you are above 18 years of age and are capable of using a pen. You should read the information below, and ask questions about anything you do not understand, before deciding whether or not to participate.

• **PARTICIPATION AND WITHDRAWAL**

Your participation in this study is completely voluntary and you are free to choose whether to be in it or not. If you choose to be in this study, you may subsequently withdraw from it at any time without penalty or consequences of any kind. The investigator may withdraw you from this research if circumstances arise which warrant doing so.

• **PURPOSE OF THE STUDY**

The purpose of this study is to evaluate the MoveInk system and gather knowledge regarding participants' interactions with it, with emphasis on usability, stickiness, and the participation experience. We will explore what other ways participants may use the system.

• **PROCEDURES**

If you volunteer to participate in this study, we would ask you to do the following things:

- Play with the pen in a controlled and observed (via video) environment.

- Interact with other users of the pen.
- Answer questionnaires.

The study will take 45-60 minutes.

- **POTENTIAL RISKS AND DISCOMFORTS**

There is no known risks or discomforts.

- **POTENTIAL BENEFITS**

Your participation will benefit in research towards intuitive interface design.

- **PAYMENT FOR PARTICIPATION**

We will hand you a \$10 gift card on your way out if you would like it.

- **CONFIDENTIALITY**

Your identity will not be revealed or compromised except if a section of video or images from your session are chosen to be used in future publications. If you are not comfortable being recorded on video, please let us know and we will not record your session.

Any other information that is obtained in connection with this study that can be used to identify you such as your name will remain confidential and will be disclosed only with your permission. The data gathered is non-sensitive and will be used for MIT purposes only. A random number will be assigned to your data that is collected on your survey and interview responses. Names will not be recorded. The data is password protected and is only available to researchers of this study.

- **IDENTIFICATION OF INVESTIGATORS**

If you have any questions or concerns about the research, please feel free to contact:

Kent Larson kl@mit.edu

Sheng-Ying Pao aithpao@mit.edu

- **EMERGENCY CARE AND COMPENSATION FOR INJURY**

If you feel you have suffered an injury, which may include emotional trauma, as a result of participating in this study, please contact the person in charge of the study as soon as possible.

In the event you suffer such an injury, M.I.T. may provide itself, or arrange for the provision of, emergency transport or medical treatment, including emergency treatment and follow-up care, as needed, or reimbursement for such medical services. M.I.T. does not provide any other form of compensation for injury. In any case, neither the offer to provide medical assistance, nor the actual provision of medical services shall be considered an admission of fault or acceptance of liability. Questions regarding this policy may be directed to MIT's Insurance Office, (617) 253-2823. Your insurance carrier may be billed for the cost of emergency transport or medical treatment, if such services are determined not to be directly related to your participation in this study.

- **RIGHTS OF RESEARCH SUBJECTS**

You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you feel you have been treated unfairly, or you have questions regarding your rights as a research subject, you may contact the Chairman of the Committee on the Use of Humans as Experimental Subjects, M.I.T., Room E25-143B, 77 Massachusetts Ave, Cambridge, MA 02139, phone 1-617-253 6787.

SIGNATURE OF RESEARCH SUBJECT OR LEGAL REPRESENTATIVE

I understand the procedures described above. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

Name of Subject

Name of Legal Representative (if applicable)

Signature of Subject or Legal Representative Date

SIGNATURE OF INVESTIGATOR

In my judgment the subject is voluntarily and knowingly giving informed consent and possesses the legal capacity to give informed consent to participate in this research study.

Signature of Investigator Date

Appendix H

Subject Recruitment

Call for Participants for a Study on a Gestural-sensing System for Content Creation and Sharing.

The Changing Places group at the MIT Media Lab is conducting a study on a gestural-sensing system for content creation and sharing. We are looking for participants to evaluate the system. The study will be conducted in three sessions in approximately 45 minutes to an hour on the same day.

You will be using the gestural sensing system, drawing or writing on paper, and will be interact with other participants, and answering survey questions in the end of each session.

If you are over 18 years old, capable of using a pen, you are qualified for this study!

We are also looking for participants who are skillful at sketching.

You will be given a \$10 Amazon gift certificate as a thank you for your participation after the end of the session.

If you are interested in participating please contact us at studya@media.mit.edu

Thank you! We look forward to scheduling a session with you at the MIT Media Lab soon.

*This study is conducted by Changing Places group at the MIT Media Lab.
Please send your questions to studya@media.mit.edu if you need further
information.

Appendix I
COUHES Approval Letter

To: Kent Larson
E15-394

From: Leigh Finn, Chair
COUHES

Date: 09/03/2014

Committee Action: Approval

COUHES Protocol #: 1406006465

Study Title: User Study of a Gestural Pen Interface for Content Creation and Sharing

Expiration Date: 07/16/2015

The above-referenced protocol has been APPROVED following Full Board Review by the Committee on the Use of Humans as Experimental Subjects (COUHES).

If the research involves collaboration with another institution then the research cannot commence until COUHES receives written notification of approval from the collaborating institution's IRB.

It is the Principal Investigator's responsibility to obtain review and continued approval before the expiration date. Please allow sufficient time for continued approval. You may not continue any research activity beyond the expiration date without COUHES approval. Failure to receive approval for continuation before the expiration date will result in the automatic suspension of the approval of this protocol. Information collected following suspension is unapproved research and cannot be reported or published as research data. If you do not wish continued approval, please notify the Committee of the study termination.

Adverse Events: Any serious or unexpected adverse event must be reported to COUHES within 48 hours. All other adverse events should be reported in writing within 10 working days.

Amendments: Any changes to the protocol that impact human subjects, including changes in experimental design, equipment, personnel or funding, must be approved by COUHES before they can be initiated.

Prospective new study personnel must, where applicable, complete training in human subjects research and in the HIPAA Privacy Rule before participating in the study.

COUHES should be notified when your study is completed. You must maintain a research file for at least 3 years after completion of the study. This file should include all correspondence with COUHES, original signed consent forms, and study data.

