Drawing the Electric: Storytelling with Conductive Ink

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ABSTRACT
We explore conductive ink as an expressive medium for narrative storytelling and interaction design with children, introducing StoryClip, a toolkit that integrates functional materials, computation, and drawing. The StoryClip kit consists of silver ink, ordinary art supplies, and a hardware-software tool, allowing a child's drawing to function as an audio recording-and-playback interface. We exploit craft and artistic practice to motivate technological exploration, turning a conventional illustration into a multimedia interface that promotes multi-level engagement with children. In this note, we describe the design of our system and discuss our findings from two workshops with children.

Keywords
Paper, conductive ink, creativity, storytelling, creativity, expression, prototyping

Categories and Subject Descriptors
H.5.m. [**Information Interfaces and Presentation (e.g. HCI)**]: Miscellaneous

1. INTRODUCTION
Despite enormous competition from other technologies, paper remains unmatched in its versatility, affordability, and ubiquity. An infinite variety of forms can be created with a sheet of paper and a pencil, and the nature of making a mark on a surface is meaningful and natural. It is not surprising that art supplies are among the earliest tools that children become familiar with.

Here, we exploit the natural affordances of such materials and their accompanying craft-practices to explore multimedia storytelling. To do so, we develop a hardware-software toolkit, StoryClip, that links a drawing made with conductive ink to software that allows for the recording and playback of sounds.

With StoryClip, we see ourselves in the tradition of Papert and others, who have advocated a diversity of constructionist approaches to education [8]. Our tool exploits the natural tendencies of children to tell stories and to draw, introducing a novel outlet for structured, multi-modal expression. At this early stage, our chief contribution is in exploring possibilities for a synthesis of functional materials and structured storytelling, allowing children to interact with technology in new ways.

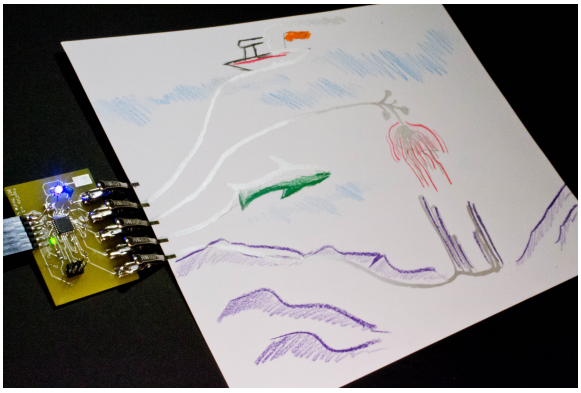

Figure 1: The StoryClip board attached to an illustration done with conductive ink.

2. RELATED WORK
Our technical inspiration is two-fold. Advances in conductive materials and drawable electronics [11] have opened up new fronts in creative interface design. Such materials enable new form-factors for interaction and new methods of technology-making. The opportunities that such materials present in creativity and learning—particularly in a craft context—are many [5].

For instance, Teardrop microcontroller kits provide deep flexibility in working with paper and conductive inks, allowing for a synthesis of embedded computational elements and paper-based arts [1]. Teardrop introduces programming and circuit design while allowing for creative expression with unconventional materials.

Conductive paints and integrated electronics have also been explored in creating responsive wallpapers and interactive pop-up books ([9], [2]). Paper as a medium for rapid-prototyping tangible interactions [14] and for creating interactive devices ([12], [7]) are also sources of inspiration. Such efforts, however, have principally focused on new techniques for working with conductive materials and on the production of novel artifacts—and far less on creating contexts for learning and creative expression.

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Our work has also been motivated by a set of tools that create new interactions with sound, drawing, and art. Many have focused on children. A number have leveraged the natural resistivity of pencil-graphite as a means of sound-generation ([13], [3]). Jabberstamp allows children to make use of conventional art materials, using a device that maps sounds onto digitally-tracked stamps using a WACOM tablet [10]. The Makey Makey uses an auxiliary board and resistive sensors to allow a diverse set of materials to be incorporated into devices[4].

A considerable amount of research has explored the affordances digital technologies can offer in synthesizing new ways of storytelling and sharing. Most have focused on integrating users' images and recordings into a completely digital medium [6]. Commercial products, like Hallmarks Recordable Storybooks have explored a similar space, though such efforts have typically focused on enriching pre-existing content.

3. OUR SYSTEM

The StoryClip system consists of three modules: a computer running a purpose-built Java application; a custom circuit-board running a capacitive sensing library; and conductive ink that is applied to ordinary paper. The combination of conventional drawing and storytelling—as well as converting a paper-surface into a functional input device—make our system unique. Because all computation is offloaded to the StoryClip board and computer—the drawing itself consists simply of paper and pigment. It can be folded or crumpled and retain its functionality. Decoupled from a computer, the drawing stands as what it is—a drawing, that can be posted to refrigerator or hung on the wall.

3.1 Silver Ink

We used commercially-available silver-based conductive ink.[1]The ink was diluted with a solvent—butyl cellosolve—to a thickness consistent with conventional acrylic paints, and applied with an inexpensive plastic-fiber brush. The resulting mixture air-dries in several minutes on a porous sheet of 50lb drawing paper. It is conductive when dry, with a resistance of 15 ohms square, more than adequate for the purposes of sensing touch. In some cases, we speeded the drying process by curing the ink in a conventional toaster oven at 120C. While that process significantly increased the ink's conductivity, we found it generally unnecessary for capacitive sensing, though it made for a better workshop experience.

3.2 StoryClip

The StoryClip auxiliary board is an Arduino-compatible custom circuit-board, consisting of an AVR microcontroller controlling sensing on five pins. Each pin is broken out to a toothless alligator clip, which provides a secure, durable connection to the edge of a sheet of paper. The metal alligator clip makes a persistent electrical connection to the painted silver on the page. When the conductive silver is touched, the action is detected and forwarded to an application running on a neighboring computer. Multiple actions can be passed at the same time, so all five pins can be actuated simultaneously.

3.3 Software Application

Our software was written in Java using libraries from the Processing project to manage Serial IO and sound generation. As we wished to focus users' attention on the page, the interface is minimal. Five circles reflect the status of the five capacitive touch pins: black initially, then changing to red while recording, and then to a unique color when associated with a sound. Effort was made to minimize the interaction with the computer as much as possible, as we hoped to focus participants' attention on their artwork and stories.

[1]AG-530 Flexible Silver Conductive Ink from Conductive Compounds (http://conductivecompounds.com/)

4. WORKSHOPS

We explored the effectiveness of our tools in two workshops with children, aged 6 to 12, and their parents. We worked with ten children, six girls and four boys, recruited from a variety of email lists. Each child attended one three-hour workshop. In the workshops, each child was provided with a StoryClip circuit board and a laptop computer, as well as conductive ink and colored pencils. After introducing participants to the materials and the basics of the interface, they were left to explore. Participants drew using colored pencils and conductive ink and connected their drawings to the StoryClip circuit board. They recorded their voices using our software and played them back by touching their drawings. Over the course of roughly two-hours, participants created between 2 and 3 works each of varying complexity.

4.1 Methodology

We conducted pre-and-post workshop surveys to evaluate the effectiveness of our tools. We gauged participants' technical and demographic backgrounds with a series of questions. We also solicited feedback about their experience. We photographed and video-taped participants while they worked and recorded the approximately half-hour-long discussions we led after each workshop. We analyzed our surveys and transcribed the workshop recordings, focusing on two key areas of interest that capture salient affordances of our toolkit: first, participants' *familiarity* with art materials vis-a-vis the toolkit; and second, the kinds and breadth of creative expression our toolkit generated. We discuss these findings in more detail below.

4.2 Leveraging Familiar Materials

While we had been initially concerned that participants would be over-eager to use the technically-novel StoryClip board and accompanying software at the expense of drawing and painting, our concerns were misplaced. Participants of all ages immediately seized on the art supplies provided—principally colored pencils—and drew with gusto. It was with some prompting that they began to turn their attention to the conductive ink and the StoryClip tools. The conductive ink, itself, is indistinguishable from gray paint, and the children treated is as such, applying it however they wished with a brush.

We take this as indication of the efficacy of incorporating conventional art materials in lowering the barrier-to-entry and intimidation that some feel when confronted with technology. It also provided natural entry to working with the sound recording and more sophisticated elements of the toolkit. Once familiarized with the possibilities StoryClip presented, participants were eager to add audio recordings to their drawings.

4.3 Creative Expression

Through the course of the workshops, participants created a broad range of artifacts showcasing a variety of different approaches. Some uses we predicted; others were completely unanticipated. A number of participants used StoryClip as a storyboarding tool, record-

Figure 2: Workshop participants with examples of their work.

ing their voices to animate a series of frames, similar to a comic strip. One participant drew a conductive border around a series of panels. When each panel was touched, it played out the sequential narrative contained within, telling "the story of a seagull who stole a ham sandwich from a sailor."

Such narrative storyboarding, however, was the exception, not the rule. Other participants created more free-form vignettes, capturing a specific set of character interactions by giving voice to pictorial representations. One recurring choice was to draw voice bubbles containing written text and recording an audio gloss over them, acting out the illustration (left, Figure 2). It is worth noting that once proficient, participants created such artifacts naturally—conceiving entire story arcs and adding the requisite sounds and voices.

Younger participants tended to leave written text out. One drawing illustrated the sordid tale of "Little Bunny Foo Foo," depicting a variety of ill-fated field mice, a bunny, and the good fairy. Each character was connected to a different clip using conductive ink. By touching each character in sequence, a recording of the participant's voice singing the accompanying song was played back verse-by-verse. A similar drawing depicted an aquatic scene (center, Figure 2).

Another participant used the interactive nature of the drawings to create an unanticipated class of artifacts: scientific diagrams (Figure 3). "This is the lifecycle of the frog. When you touch one of the stages it says what stage the frog is in." The same participant also drew a picture of the interior of the earth, marking each layer with conductive paint. When the layer was touched, the software played back his recording of its name. By integrating conductive ink into the final illustration, the drawing of the layers, the recording of their names, and its subsequent playback—the participant created a holistic combination of functional and aesthetic affordances that fit his specific needs.

As participants began to understand the nuances of the system, they explored other kinds of interfaces. Because sounds trigger repeatedly when a drawing is touched, it was easy to create musical instruments. One participant drew the various components of a rock band: guitar, drums, microphone, and recorded corresponding vocal samples. Another drew a "Monster's Quintet," the members of which were programmed to sing back "Jingle Bells" (right, Figure 2).

4.4 Discussion

In post-surveys, nine of ten participants reported feeling "comfortable" working with the conductive ink, and all used it in tandem with the other art supplies. Some participants wove the conductive ink directly into their drawing in ways that highlighted its versatility: silver ink formed the spinning record on a turntable in one illustration and the abdomen of a spider in another. Other designs spanned an entire page, forming dense networks of capacitive sensors that while impressive, were sometimes difficult to actuate reliably. Many participants connected multiple clips to single conductive regions, triggering them at the same time.

One emergent design pattern was to use the conductive paint in a more formulaic way, as a schematic web. Intricate images drawn with colored pencil were connected back to the StoryClip board with conductive leads. Of course, the nature of our boards' imple-

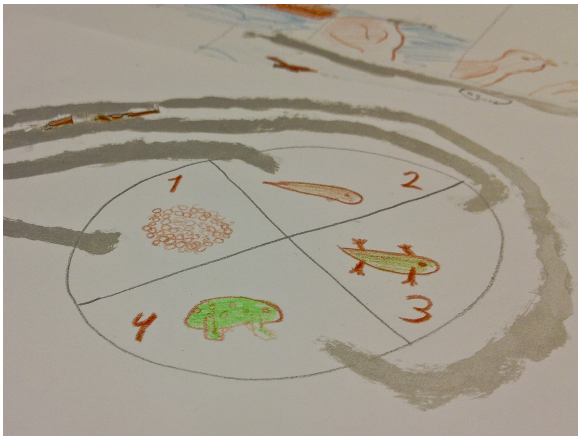

Figure 3: When each segment is touched, the participant's voice describes the lifecycle stage of the frog.

mentation forced certain design decisions on participants' aesthetic choices: to use all five clips, the conductive leads must converge on a relatively small area.

All the same, participants were resourceful in finding rationale for their choices: "There are four bugs and they are trying to pull a flower out of the ground. A spider made little strings tied to them and to the roots of the flower," said one participant. The "little strings" in question were conductive silver lines. The strings, when touched, however, were associated with "character" of the bugs, repeating back their voices. Others, upon realizing that they did not necessarily have to integrate the silver ink into their drawings to trigger the recording-and-playback functions of the software, drew discrete buttons that were not necessarily part of the overall image. They treated the silver ink as an explicit tool for interface design: a possible direction for future research. All the same, we would like to move towards a toolkit design that will more pointedly encourage artistic and functional integration.

5. FUTURE RESEARCH

We're interested in exploring free-form interface design, particularly with children, as well as contexts in which users can rapidly sketch interfaces to suit their needs. Such user-generated designs may give interfaces additional embedded meaning and significance, not to mention utility. We're also interested in exploring the opportunities presented by adding various forms of output (thermochromic ink, for instance), as well as other types of sensors. Understanding how these kinds of techniques can help people understand difficult-to-grasp electronic concepts like capacitance is another potential avenue of research.

6. CONCLUSION

We have introduced a toolkit that leverages conductive ink as an outlet for creative expression and storytelling. We tested our device with two groups of children and found that it created rich and engaging experiences. Despite the novelty of our materials to participants, we found that working with conductive ink was intuitive and natural for children. In functionalizing art materials with minimal technological overhead, we believe our toolkit motivates a wealth of possibilities, providing an initial avenue for considering a new synthesis of aesthetic expression and narrative structure for children.

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