I/O Brush: Drawing with Everyday Objects as Ink

Kimiko Ryokai, Stefan Marti and Hiroshi Ishii
MIT Media Laboratory
20 Ames Street
Cambridge, MA 02139 USA
{kimiko, stefanm, ishii}@media.mit.edu

ABSTRACT
We introduce I/O Brush, a new drawing tool aimed at young children, ages four and up, to explore colors, textures, and movements found in everyday materials by "picking up" and drawing with them. I/O Brush looks like a regular physical paintbrush but has a small video camera with lights and touch sensors embedded inside. Outside of the drawing canvas, the brush can pick up color, texture, and movement of a brushed surface. On the canvas, children can draw with the special "ink" they just picked up from their immediate environment. In our preliminary study with kindergarteners, we found that children not only produced complex works of art using I/O Brush, but they also engaged in explicit talk about patterns and features available in their environment. I/O Brush invites children to explore the transformation from concrete and familiar raw material into abstract concepts about patterns of colors, textures and movements.

Categories & Subject Descriptors: K.3.2 [Computers and Education]: Computer and Information Science Education

General Terms: Design, Experimentation, Human Factors.

Keywords: Children, Drawing, Building Blocks, Explaining, Storytelling, Input Device, Toy, Tangible User Interface.

INTRODUCTION
Creating visual art—the process of choosing colors, determining where a line should go, selecting shapes, and discovering the effects of different combinations—seems to contribute to children's cognitive development. Through visual art, children not only develop conceptual understanding of the Elements and Principles of Design [21] (which include color, shape, line, form, texture, contrast, pattern, and balance), but also develop their ability to classify, sort, think critically, and communicate [12]. Such activities through visual art may be especially important for young children who do not yet read and write, as drawing serves as a non-laborious way to represent their ideas on a paper and allows them to reflect on their thoughts through abstract representations [32].

Yet the success of such abstract thinking may depend on how it is grounded in the child's own reality. Indeed, school oriented (namely American middle-class) parents make great efforts to create connections between new concepts and real life by talking about them (e.g., "The duck in this book is yellow, just like the one in our tub!") [14]. The new information the child is trying to make sense of needs to be grounded in some reality to be useful, but cannot be if it hasn't been acquired in terms of that reality [28]. Therefore, learning to deal with new concepts while staying connected with familiar surroundings and objects seems to be important in developing new skills.

In this paper, we discuss a novel approach to this important connection. We present I/O Brush, an augmented paintbrush that can pick up textures, colors, and movements from the real world, and allows children to immediately use, explore and make drawings with them. We will discuss I/O Brush's potential as a tool to support young children's transformation from concrete and familiar material into abstract representations in visual art projects.

Taking Samples from the Real World
There are many sophisticated, commercially available drawing tools designed for children today. KidPix [19] is one of the classic multimedia drawing software programs that allow children to paint with a variety of digital ink, as well as to play with their art by adding preprogrammed special effects such as wipe, glitter, and even some sound effects. Kai's Power Goo [18] lets children manipulate realistic digital pictures (e.g, pinch/stretch a scanned-in picture of a face). Other software tools allow children to stamp or draw with clip art (e.g., a butterfly, tree, smiley faces, etc). While these commercially available tools are capable of importing more personal images from children's life, because of the number of steps involved in scanning in a single image, parents and children usually end up playing only with the clip art the software comes with.

On the other hand, more economical digital imaging devices such as still and video cameras are available today. Despite of young children's fascination with cameras and

CHI 2004, April 24–29, 2004, Vienna, Austria.

photographs, the use of such devices and the access to digitally captured images are still quite limited for young children.

Children tend to spend more time investigating their projects when the material they work with directly concerns their personal objects and interests, and feel that they have a special sense of ownership [25, 22]. We look into a technology that allows young children to take samples (specifically, the color, texture, and moving patterns), which can be found in their immediate environment, and use these personal elements to build their visual art projects. The idea is that children are not only constructing visual art projects of their interests, but also working with the palette they find meaningful. Our hope is that as children work with their own palette, they are more likely to investigate the elements and principles of design than working with a preprogrammed digital palette.

RELATED WORK

Technology as Personal Building Blocks

Technology serving as building blocks for children's design activities has been successful in learning domains beyond math and science. For example, MOOSE Crossing [4] invited children to construct a virtual environment in which they could interact with each other. While a fun environment for children to program virtual objects and characters, MOOSE Crossing also served as a forum for children to practice their narrative writing skills.

KidPad [9] developed at the University of Maryland is a drawing program that supports the rich storytelling associated with children's drawings. Zoom-in and -out tools in KidPad allow children to embed and hyperlink their drawings in order to build a complex visual story. KidPad offers a whole new lens for children to build and share their visual art.

Tangible user interfaces [17] were applied to technologies for children to take advantage of physical affordances. A series of tangible "tools to think with" were invented at the MIT Media Lab. Digital Manipulatives [24] and CurlyBot [11] were designed to allow even young children to explore concepts of mathematics and geometry by programming with their own physical movements. These physical tools invited children's natural inquiry and discussion about rules, shapes, and numbers in a playful context.

SAGE [3] and StoryMat [27] on the other hand, embedded technology inside of children's familiar objects, especially soft materials such as stuffed animals and quilts, to support language development and storytelling that happen around these objects.

In the Physical Interactive Environments project [20] at the University of Maryland, a series of physical programming tools was developed in order to allow young children to design their own interactive physical space to tell stories. The researchers worked with children in their environment intensively to come up with usable technologies for children and teachers in real classrooms and homes.

More recently, efforts to focus on open low-tech technologies rather than over-polished products have been made [31, 7].

Our research builds on the efforts to take into account the real environment children are in, with an emphasis on technology to encourage children to make the connection between the abstract new concepts (elements and principles of design) and how these could be found in their personal objects/environment.

I/O Brush is based on the two basic functions a brush affords: Picking up attributes from the real world, and painting with these attributes. Now we turn our discussion to the related technologies.

Tools for Picking Up Attributes from the Real World

Our natural routine to picking up elements in order to transfer the content to some other location has been studied and applied to the digital domain for quite some time. Pick-and-Drop [23] is a pen-based direct manipulation technique that lets the user transfer a computer document from one computer to another. The application was file transfers and the pen tool was not used as a drawing tool. Anoto pens [1] and other sophisticated handwriting capture tools are available today as office handwriting tools. The goal of these smart pens is to capture detailed handwritten notes, and not to pick up a variety of colors and materials.

Colortron [5] is a handheld device for fashion designers that can pick up any color in the physical world and return the numeric value of the color so that the designer can have the precise color number to work with in their design software. Colortron is accurate in computing the colors, but it is not designed as a tool to draw with, so that the designers must work with separate tools for drawing/sketching their designs. Sharaku by Fuji Xerox is a scanner and an ink-ribbon printer in one handheld device. It was not designed as a drawing tool, so people simply used it to "transfer" texts and images, and not to draw with.

Figure 1. "Picking up" different attributes of an object with the I/O Brush.

Manipulating and Drawing with Digital Images

Technologies to control digital images as ink have been developed and are commercially available. For example, the Image Sprayer tool in Corel's Photo-Paint [16] and the Magic Nozzle tool in Fractal Design Painter are sophisticated drawing software tools that allow users to spray any bitmap image on a digital canvas. However, a number of processes are involved in preparing the images to draw with, so the users generally end up drawing only with the software's clip art images.

Photomosaics by Rob Silvers [30] incorporates algorithms to use thousands of images as pixels.

Drawing Prism [13] is a large optic-based translucent prism on which any light-colored object (e.g., light colored brushes and human hand) can be used as an input device. Easel [26] is a large physical painting easel equipped with video cameras and a video projector. The artist can paint with live video images captured by the cameras positioned near the canvas (e.g. aiming at the artist him/herself or a room). Surface Drawing [29] developed at Caltech is another interesting approach for using the body as the brush in a completely virtual environment. Users may either wear a glove or use a tangible tool to directly draw in the virtual environment.

Efforts to allow people to mix colors in the digital world have also been made. AntBrush [33] is a software program that allows users to blend digital colors on a digital palette as if they were real paint. Digital Palette [15] is a physical palette that allows users to mix colors of light. The user can then dip a small physical cube into the palette to paint the cube. The LEDs inside the cube change their color to give the effect of painting the physical cubes.

The contribution of the I/O Brush technology is to allow people to take color, texture, and movement of any physical object via a tangible drawing tool, and to immediately draw with that attribute using the same tool.

DESIGNING I/O BRUSH

Most drawing tools/pens we use today allow only a one-way flow of ink, and we are oblivious to how the content of the tool came to exist inside. What if we could not only have control over the outflow of the ink, but also have influence on what goes inside? Indeed, old fountain pens served as both tools to pick up and release the ink, and paintbrushes still preserve that function. We bring back this tradition of a drawing tool as both an input and output device, but instead of picking up the liquid ink, I/O Brush lifts up and captures photons.

Historically, before paint was sold in stores, artists searched for colors and patterns in real life and nature. In their art, artists tried to simulate the palette of colors they saw in nature. In the process, they extracted colors directly from clay, rocks, sand, and minerals. That is how the colors and pigments we use today came to exist [2, 8, 10]. Our hope is that I/O Brush will push children to develop the same kind of acute eyes as these artists had many years ago in identifying colors in their life.

We also found that the brush as a physical tool fits well in achieving the goal of reinventing the tool to pickup elements from the world, because the brush as an input device affords much more intimacy than pointy pens or syringes. Because of its soft tip, the brush is often used as a tool on our body (e.g., makeup brush, hair brush, lint brush, etc). The brush is perhaps one of the few tools that we allow to touch soft surfaces like our face.

IMPLEMENTATION

The I/O Brush system has two components: the brush and the drawing canvas. The brush houses a small (3x3cm) CCD video camera in its tip with supplement light bulbs around it (Figure 2). Spring-based flexible/bendable touch sensors that resemble the property of brush tips are also embedded inside of the brush. When the brush touches a surface, the lights around the camera briefly turn on to provide supplemental light for the camera. During that time, the system grabs the frames from the camera and stores them in the program. Also, woven into the brush tip are 150 optical fibers. Once the "ink" is captured, the fiber optics light up, i.e., the brush tip is lit up, to indicate that the brush has picked up ink from that surface.

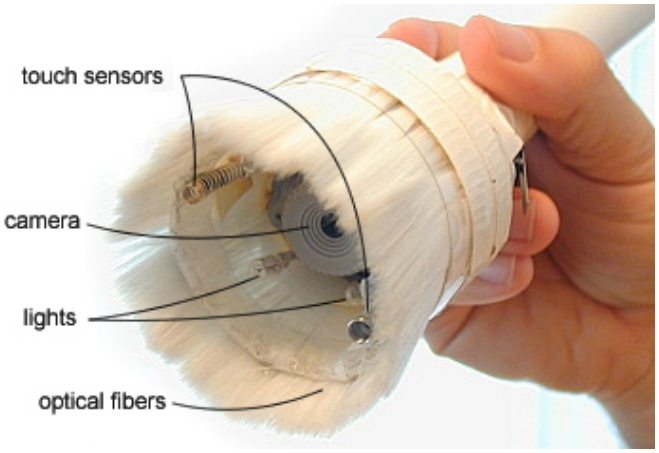

Figure 2. The I/O Brush tips.

For the canvas, we currently use a large Wacom Cintiq screen with a built-in graphics tablet. The coil of the Wacom pen tip is embedded inside the I/O Brush's tip to allow the system to detect the presence or absence of the brush on the canvas. Once on the canvas, the brush lets the child draw with that special ink s/he has just picked up.

Currently, I/O Brush has three modes for picking up ink: Texture, Color, and Movement. The Texture mode captures a snapshot of the brushed surface, which consists of one frame. The Color mode computes the RGB values of all the pixels in the captured frame (resolution of 640x480) and returns the most common RGB value so that the child can draw with a solid color. The Movement mode grabs up to 30

consecutive frames of the brushed surface and lets the child draw with the movement. When the child moves the brush across the canvas, the system drops off the successive frames, but the end of the stroke shows the captured 30-frame animation in a loop. For example, the child could brush over a surface with a stripe pattern for a couple of seconds. S/he could then paint with that moving ink to apply a 'scrolling' stripe design on the canvas. Or, the child could brush over his/her own blinking eye with the brush, and apply that 'blinking-eye' ink to paint the eyes of a cat on canvas.

The paint in all three modes is masked to appear as a round-shape and its translucency level is set to a slightly lower value so that the child can layer ink like water color by quickly moving the brush, or paint with thick color by slowly moving the brush. The brush allows the child to paint with the same ink indefinitely until s/he picks up different ink.

The modes are switched by the simple turn of dial on the neck of the brush.

Finally, we believe that I/O Brush should not only look like a real brush but also should feel like one. So the soft acrylic hair from real paintbrushes was transplanted onto the tip of I/O Brush, giving it the authentic feel of a soft brush tip.

I/O BRUSH STUDY

In order to study children's interaction with I/O Brush, we have set up the I/O Brush in a corner of a kindergarten classroom. Twenty kindergarteners, ages 4-5, played with I/O Brush in pairs. Each pair spent at least half an hour with the I/O Brush during his/her "choice time" activities. In the first couple of minutes, a researcher gave an introduction of how to pick up the ink and draw with it using I/O Brush. Then the researcher stepped aside and the children were invited to draw whatever they wanted to draw by taking turns with each other. They were invited to play as long as they wanted. The children's interactions were videotaped for analysis.

Children's Interaction with the I/O Brush

Children embraced the idea of I/O Brush quickly and found it easy to work with. They assisted each other in the process of choosing and picking up colors. The fiber optic light on the brush tips seemed to serve as a confirmation of their color picking process. For example, one child asked his partner, "Did you pick it up?" He answered his own question by pointing at the colored tip of the brush and saying, "Yep, you did!" The children also seemed to grasp the idea of "ink" well. As she observed her partner who was brushing a surface for a long time, a child said to her partner, "That should be enough ink!"

Items that Children Cared for

As soon as the researcher passed the brush to the children, the children's eyes were everywhere—searching for things to try out and immediately reaching out to try them. For the first few minutes, they usually tried things within their reach (e.g., tables, chairs, walls), but soon after, they usually asked if they could bring other items from the classroom, both public and personal spaces like their own cubby/locker. The items the children brought and used are summarized in the Table 1.

Figure 3. The children bring different materials from their classroom to explore.

Classroom items (46%)	Blocks (wood and plastic geometry blocks, LEGO blocks), beads, stuffed animals, cookie jars, furniture (tables, chairs, shelves), walls and floors.
Clothes (22%)	Shirt, pants, jeans, skirt, belt, shoes, jacket.
Personal belongings (18%)	Backpacks, picture books, notebooks, folders, spelling books, stuffed animals, rice crispies, leaf, feathers, toys, their own artwork, souvenirs, fruits.
Body (11%)	Skin, hair, eyes, mouth, tongue, belly button.
Items with teachers' permission (3%)	Teachers' clothes, teachers' stationary (e.g., staplers), hand cream.

Table 1. Items children used for their work. (Percentage based on the total # of brush strokes/pickup attempts)

Approximately, a third of their time was used in searching for items they wanted to work with. From the public space, they looked especially for colorful items. It's not an accident that kindergarten classrooms are filled with colorful materials and rich textures chosen carefully by the teachers. In their personal cubbies/lockers, the children found personal items

such as rugged stuffed animals, sweaters their grandmother gave them, and souvenirs.

Children also wanted to bring leftover fruits and candies they had from the snack time to paint with. It is interesting to note that Crayola [6] not only names their crayons "old penny," or "fuzzy wuzzy brown," but also "cotton candy," "macaroni and cheese," etc.

Another personal and popular item was their own body. Children brushed over not only their own bodies, but also asked if they could sample their friend's face, skin, and hair. The softness of the brush tip seemed to allow children to play around with different shades and patterns they can find on their body.

The children also looked for colors in unusual places such as the underside of a table and behind the closet, using the brush as a tool to gain access to colors they usually do not see.

Figure 4. The children trying out different shades of colors and patterns they can find.

Children's Talk about Their Drawings

Children drew a lot of pictures by using the objects they cared for, and they took great pride in their choice of color and resulting artwork. Many stories and explanations were associated with each picture, and they could not wait to explain to their classmates and teachers what their pictures were made of. Children told stories about both real events (e.g., "My sister gave this doll to me yesterday.") and fantasy (e.g., "It's a monster eating a boy. Yellow is the monster and the pink is the boy!" where "pink" was taken from the child's own skin!).

The following is a transcript of a typical conversation during the session, which illustrates the children's excitement of working with I/O Brush and exploring the patterns and colors children find in their environment:

```
[A (5-year-old boy) and C (5-year-old girl) are
painting with I/O Brush together]
A:   I want to try this again. [A touches a
     plastic plate with the brush]
C:   Yeah! That color. You get any color!
     [A paints on the canvas as C watches]
A&C: Oooh!
C:   That's so cool! [looking at A's color]
A:   Oh! Maybe if we choose different places, it
     takes different colors. Maybe a bottom…
C:   Bottom? [of the plastic plate]
     [C tries the bottom of the plate]
A&C: Oooh! [Both looking at the result]
A:   Yeah!
C:   That looks like a frog! Frog color.
     [C points at the color]
A:   What if… Let's see. It looks like some…
C:   Moss or something!
A:   Looks like a cave, or rock. Yeah, it looks
     like a rock! Looks like a cave rock! [A
     continues to paint with the color]
C:   Oh, that looks like a rock and clay.
     There's where you enter [pointing at A's
     drawing] and that's the top of it.
A:   Yeah! Let's keep doing that [painting all
     over the canvas] and it will look like a big
     cave! Oh, what if we build it all like that?
     [A intends to fill the canvas]
C:   Well, and then we won't have any more
     colors! Then you have to like, do it all
     over again.
A:   Sooo? Isn't this awesome! [A takes C's
     suggestion and does not fill the canvas
     completely]
A:   Now I'm going to try… Hey! We haven't tried
     the chairs!
C:   Oh, the chairs!
     [A & C continue with the chairs]
```

Children also talked explicitly about different patterns, colors, and movements they found and used in their works of art. As they pointed at their works of art, they explained to each other and to their teachers where the lines and colors on the canvas came from:

```
[A (5-year-old boy) talking to his partner]
A:   That's the same color as my pants!
     [pointing] I got that [color] from my pants
     and you got that [color] from your shirt!

[S (4-year-old girl) talking to her partner]
S:   First let me do the stripes! It's a good
     color to add to my rainbow.  I'm going to
     make an awesome rainbow! [S draws a part of
     a rainbow] Isn't that a good rainbow? I had
     the stripes [pointing at her pants].
```

By working with the Movement mode of the brush, children explained to each other what kind of movement they wanted to work with. For example, one girl and boy pair did their work by taking elements from their picture book. The girl suggested to the boy with the brush, "Do it like this. Make it jump around," as she gestured the movement with her hand on the book. She suggested the boy to make a particular movement while "picking up", but the boy mistook the suggestion as making the movement on the canvas. The girl then explained what she meant by gesturing and assisting directly as she held the brush together. "Drag it around, like this!"

Figure 5. "Look it! This came from my shoe! This line right here, is this line of my shoe!"

They also explored and talked about elements of design while they were looking for items in the classroom. Since the children spent so much time outside of the I/O Brush work area looking for their materials, the researcher decided to also follow the children around. One child was looking through a pile of stuffed animals in the "doll corner." As she picked up a white stuffed bunny, she said, "This bunny is no good 'cause I've already done white!" She then found and grabbed a purple teddy bear and added it to her drawing.

Children also made distinctions among different shades and patterns of color (e.g., "Not this red. I want THIS big red!"). As they walked around their classroom, the children were not randomly looking for colorful materials, but were searching for particular objects with particular features for their work.

Children's Works of Art

Finally, how did the drawings come out? Most children found the process of bringing out the items and trying out colors from them on canvas fun. In fact, it was so much fun, much of their artwork looked like doodles with no title (the top row of the Figure 6 contains typical doodles). Some children did work towards a piece with a concrete title such as "Bunnies and rainbows" (bottom row of Figure 6).

Although not explicitly reflected in their work, children did use and explore the I/O Brush's three modes quite thoroughly. They seemed to understand the functionality of each mode and used each mode selectively during their drawing. For example, one boy said, "Now I need the plain old COLOR (as opposed to the Texture) because I'm going to draw a rainbow." Another girl said, "I want the TICKLISH one (Movement mode)!" as she wiggled her body to capture the movement of her tummy with the brush.

What we did not see in their artwork was integration of the different modes offered by I/O Brush. A couple of children did create pictures of an animal with its eyes blinking because the animal's eyes were drawn with the Movement mode. However, these children drew these pictures themselves only after the researcher has shown them that such a portrait is possible. Perhaps, if they used I/O Brush for a longer time, they might have started to produce more complex drawings on their own. We will continue to discuss this in the future work section.

Each child's artwork was printed on a piece of paper so that they could take it home and share with their family.

Mixing Colors

We intentionally designed the ink to have some transparency so that they can mix the colors on the canvas by applying successive layers of ink. However, to the children it seemed more natural to mix the ink in the physical world. Some children made attempts to mix colors by brushing off several different surfaces in sequence before applying the ink onto the canvas. This points to a possible direction for future development.

FUTURE WORK

Occasional glitches produced unexpected colors on the canvas. This happened when the brush was used on uneven surfaces, and therefore caused the camera to have either too much or too little light based on how the brush made contact with the surface. In such a case, children quickly identified the mismatched colors and usually gave it a second try. The touch sensors would need to be more sensitive to accommodate different kinds of uneven surfaces, and the lights may also need to be adjusted based on the specific surfaces.

It seems important to make the brush wireless. While it was fun for the children to go out and find different items and come back with an armful of materials, some children at the end of the session said, "I wish it didn't have the wire so that I can walk around with it." Even with a wireless brush, children will still need a large drawing surface to draw.

The I/O Brush system running on a tablet PC would be one solution. Yet another solution is to keep the large canvas on one side, and provide a physical palette (e.g., via PDA with a large color LCD screen) that works with a wireless I/O Brush. Children may walk around with the wireless brush and the palette to collect samples in their environment. On the palette, the children may mix different colors, materials, and movements they have picked up, prior to applying them to the big canvas. This would resemble the real world more closely while allowing more flexibility.

Another direction is to allow the use of multiple brushes for more collaborative drawing activities. The current implementation introduced one brush with three different modes of picking up the ink. However, multiple brushes with each having its own personality/functionality, e.g.,

"Ticklish Brush," "Color Brush," and "Pattern Brush," might be an interesting direction and may invite more interesting collaborative painting among children.

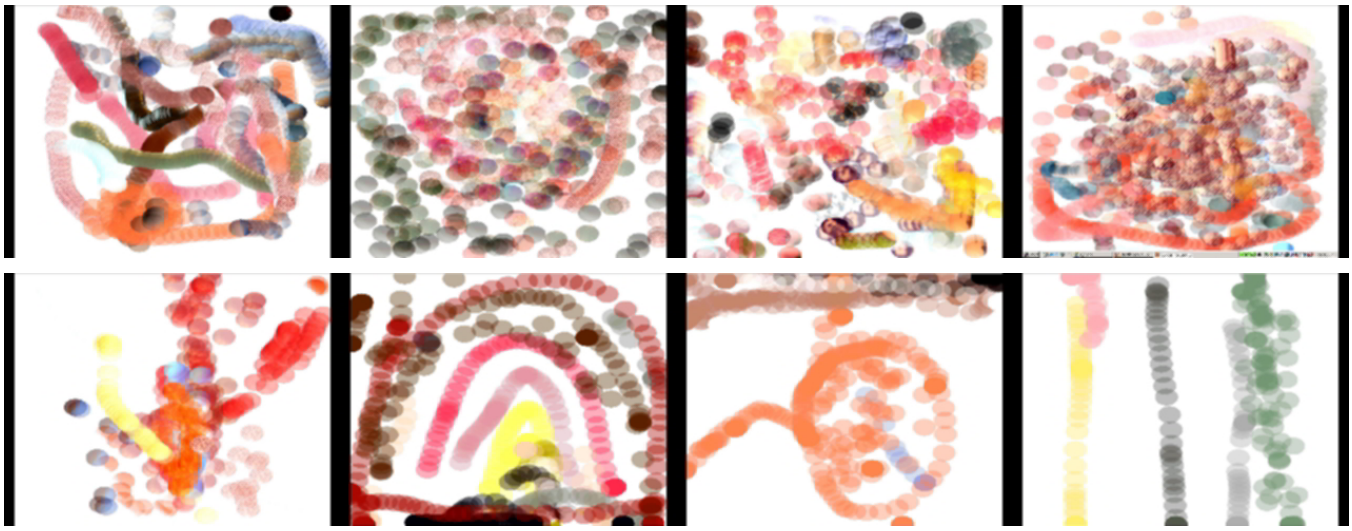

Figure 6: Children's works of art.
Top row: typical doodling work by the children.
Bottom row (from left): "A Bunny," "Rainbow," "Balloon," "Rainbow"

Allowing finer physical control over the brush, such as pressure and tilt sensitivity, may open up further possibilities for the use by visual artists. In order to assess the impact of I/O Brush with a larger user base, it would be interesting to ask questions such as how I/O Brush changes the notion or style of drawing, and how it changes the way we use drawing tools.

Yet another interesting future direction of I/O Brush may be to add the capability of incorporating non-visual properties, such as sound into the brush. What would it mean to mix our favorite music with the pattern of our favorite shirt? This leads to the idea of a synesthetic drawing tool that does not only pick up visual properties but also auditory elements of the world we live in. For example, a microphone at the end of the brush could pick up speech and music. In the case of music, it would analyze these auditory samples for parameters like tempo, loudness, and homogeneity. Furthermore, I/O Brush could extract from these samples properties like music genre and associate a color palette and patterns with them. E.g., aggressive, fast music, could create dark lines with jaggy patterns and high opacity, where as soft flowing, slow new age music would result in pastel colors with smooth patterns and high transparency. Of course the mapping between non-visual properties and concrete drawing styles will pose a considerable challenge. Even more challenging would be synesthetic mappings of olfactory properties of the real world to visual properties: e.g., the user could try to pick up the soft smell of a rose, and paint with the equivalent visual mapping of the smell, which will result in a different color palette than picking up the smell of, e.g., an onion. The artistic and creative possibilities in this direction would be tremendous, but also challenging.

Finally, we are in the process of conducting an empirical study that investigates how children's inquiry of elements and principles of design brought out by working with I/O Brush differs from working with regular paint and paintbrush.

CONCLUSION

Using I/O Brush, children not only produced complex drawings, but they also explored objects and materials that surround them, and during the process, explicitly talked about the elements and principle of design such as color, texture, and movement. Although the outcome of their artwork was synthetic and digital, the process of their work involved searching for and interacting with many physical objects that are available and meaningful to them in their life. Through such exploration with familiar objects and constructing meanings through them, children learn to take control over underlying abstract concepts. I/O Brush has the potential to make this important connection.

ACKNOWLEDGMENTS

We sincerely thank the members of the Tangible Media Group, especially Hayes Raffle and James Patten for their support, and the CHI reviewers for their insightful comments. Thanks also to James Dai, Schuyler Horton, and Kazue Kobayashi. Finally, special thanks go to Pat Kelly, Janice Lund, and the children for their inspiring work and support. This project has been funded by the Media Lab's Things That Think consortium.

REFERENCES

1. Anoto™ pen. Löwgren, C. Anoto. In *Proceedings of Man Machine Interface for Mobile*, Rome. (2000).
2. Ball, P. *Bright Earth: Art and the Invention of Color*. Farrar Straus & Giroux; 1st American Edition, 2002.
3. Bers, M. U. and Cassell, J. Interactive Storytelling Systems for Children: Using Technology to Explore

Language and Identity. *Journal of Interactive Learning Research* 9(2) (1998), 183-215.

4. Bruckman, A., *MOOSE Crossing: Construction, Community and Learning in a Networked Virtual World for Kids.* PhD Thesis. Massachusetts Institute of Technology, Cambridge, MA; 1997.
5. Colortron™ spectrophotometer. http://www.xrite.com/
6. Crayola™. http://www.crayola.com/
7. Decortis, F. & Rizzo, A. New Active Tools for Supporting Narrative Structures. *Personal and Ubiquitous Computing,* Volume 6 Issue 5-6, 2002.
8. Delamare, F. & Guineau, B. *Colors: The Story of Dyes and Pigments*. Harry N Abrams, 2000.
9. Druin, A., Stewart, J., Proft, D., Bederson, B., Hollan, J. KidPad: a design collaboration between children, technologists, and educators. *Proceedings of CHI'97*, ACM Press, (1997).
10. Finlay, V. *Color: A Natural History of the Palette*. Ballantine Books, 2003.
11. Frei, P., Su, V., Mikhak, B., and Ishii, H. curlybot: Designing a New Class of Computational Toys, *Proceedings of CHI2000*, ACM Press. (2000), 129-136.
12. Goldberg, M. *Arts and Learning: An Integrated Approach to Teaching and Learning in Multicultural and Multilingual Settings.* New York: Longman, 1997.
13. Greene, R. The drawing prism: a versatile graphic input device. *ACM SIGGRAPH Computer Graphics, Proceedings of the 12th annual conference on Computer graphics and interactive techniques*, July 1985. Volume 19 Issue 3.
14. Heath, S. B. *Ways with words: Language, life, and work in communities and classrooms*. Cambridge University Press, 1983.
15. Heaton, K.B. *Physical Pixels*. Masters Thesis. Massachusetts Institute of Technology, 2000.
16. Image Sprayer, in Corel™ PhotoPaint. http://www.corel.com/
17. Ishii, H. and Ullmer, B. Tangible Bits: Towards Seamless Interfaces between People, Bits and Atoms. *Proceedings of CHI'97*, ACM Press, (1997), 234-241.
18. Kai's Power Goo by Scansoft™. http://www.scansoft.com/
19. KidPix™. Software by Craig Hickman. Novato, CA: Broderbund Software, 1991.
20. Montemayor, J., Druin, A., Farber, A., Sims, S., Churaman, W., & D'Amour, A. Physical programming: Designing tools for children to create physical interactive environments. *Proceedings of CHI2002*, ACM Press. (2002).
21. Naested, I. R. *Art in the Classroom: An Integrated Approach to Teaching Art in Canadian Elementary and Middle Schools.* New York: NY: Harcourt Brace & Company, 1998.
22. Papert, S. *Mindstorms*. New York: Basic Books. 1980.
23. Rekimonto, J. Pick-and-drop: a direct manipulation technique for multiple computer environments. *Proceedings of the 10th annual ACM symposium on User interface software and technology* (1997).
24. Resnik, A., Martin, F., Berg, R., Borovoy, R., Colella, V., Kramer, K., Silverman, B. Digital Manipulatives: New Toys to Think With. Paper Session, *Proceedings of CHI'98*, ACM Press, 2, (1998), 81-287.
25. Resnik, M., Rusk, N. & Cooke, S. The Computer Clubhouse: Technological Fluency in the Inner City. *High Technology and Low-Income Communities: Prospects for the Positive Use of Advanced Information Technologies.* MIT Press, 1999.
26. Rozin, D. Easel. http://fargo.itp.tsoa.nyu.edu/~danny/easel.html
27. Ryokai, K. and Cassell, J. Computer Support for Children's Collaborative Fantasy Play and Storytelling. *Proceedings of Computer Supported Collaborative Learning '99*, Palo Alto, CA, (1999), 510-517.
28. Schank, R.C. & Cleary, C. *Engines for Education.* Lawrence Erlbaum Associcates, 1995.
29. Schkolne, S., Pruett, M., & Peter Schroder. Surface Drawing: Creating Organic 3D Shapes with the Hand and Tangible Tools. *Proceedings of CHI2001*, ACM Press. (2001)
30. Silvers, R. Photomosaics. Henry Holt and Company, Inc., New York, NY, 1997.
31. Stanton, D., Bayon, V., Neale, H., Ghali, A., Benford, S., Cobb, S., Ingram, R., O'Malley, C., Wilson, J., Pridmore, T. Classroom collaboration in the design of tangible interfaces for storytelling. *Proceedings of CHI2001*, ACM Press.
32. Teale, W.H. & Sulzby, E. *Emergent Literacy: Writing and Reading.* Norwood, NJ: Ablex, 1986.
33. Tzafestas, E. S. Integrating drawing tools with behavioral modeling in digital painting. *Proceedings of the 2000 ACM workshops on Multimedia*.