

# The World as a Palette: Painting with Attributes of the Environment

**Kimiko Ryokai**

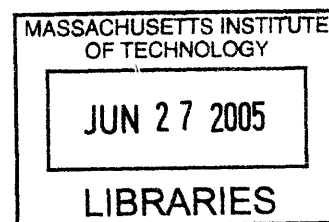
B.A., Linguistics and Psychology, State University of New York at Stony Brook. 1997  
M.S., Media Arts and Sciences, Massachusetts Institute of Technology. 1999

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 2005

© Massachusetts Institute of Technology 2005  
All Rights Reserved



---

Signature of Author:

*[Handwritten Signature]*  
Kimiko Ryokai  
Program in Media Arts and Sciences  
May 6, 2005

---

Certified by:

*[Handwritten Signature]*  
Hiroshi Ishii  
Associate Professor of Media Arts and Sciences  
Thesis Supervisor

---

Accepted by:

*[Handwritten Signature]*  
Andrew B. Lippman  
Chairman, Departmental Committee on Graduate Students

**ARCHIVES**



# **The World as a Palette: Painting with Attributes of the Environment**

by

**Kimiko Ryokai**

Doctoral Dissertation Committee

---

Thesis Advisor

Hiroshi Ishii  
Associate Professor of Media Arts and Sciences  
MIT Media Laboratory

---

Thesis Reader

Mitchel Resnick  
Associate Professor of Media Arts and Sciences  
MIT Media Laboratory

---

Thesis Reader

Kevin Brooks  
Senior Research Scientist  
Motorola Center for Human Interaction Research



# **The World as a Palette: Painting with Attributes of the Environment**

**Kimiko Ryokai**

Submitted to the Program in Media Arts and Sciences, School of Architecture and Planning, on May 6, 2005 in partial fulfillment of the requirements of the degree of Doctor of Philosophy at the Massachusetts Institute of Technology

## **Abstract**

To create everyday art monuments through which we express ourselves--whether in the form of a self-portrait or a life-story—is human nature. Our drive to do so is evident in the natural artistry of young children--representing themselves, people and things around them—through a variety of expressions such as drawing, storytelling, and construction with objects. Yet these creations with diverse media decrease dramatically as traditional forms of literacy take over in school, emphasizing decontextualized and depersonalized forms of expressions.

This thesis is about how people, particularly children, create and interact with everyday art monuments, with an emphasis on techniques to support the narrative connection between the creator, creation, and material the creation is made of. This thesis introduces the concept of building visual art projects with elements extracted directly from the artist's personal objects and his/her immediate environment, thus allowing child and adult artist alike to turn their world into a palette of color. For example, by picking up a texture from his pet dog's fur, movements of his own blinking eye, color from his favorite yellow shirt, and by combining these elements into a unique drawing, an artist can not only create a thoroughly personalized piece, but also breathe a new kind of life into the canvas.

A number of key design features of the system were developed through observing both adult and child artists using the novel tools over the course of two years. During the final five-week study in a kindergarten classroom, the tools supported children's individual creative styles (e.g. 'visualizers' versus 'dramatizers'), and children's work reflected upon the aspects of objects and interactions with these objects that were dear to them. In addition, evidence suggests the children acquired an expanded view of art, associating features in paintings with attributes in their environment. The potential of this new medium that allows artistic expression using attributes taken from the real world is discussed.

Thesis Supervisor: Hiroshi Ishii  
Title: Associate Professor of Media Arts and Sciences



---

## Acknowledgements

First, I would like to thank my advisor, Hiroshi Ishii. My words alone would fail to express how much gratitude I feel towards his support and trust in me over the last two years. His unreserved care and intellectual guidance helped me pull it all through.

I would like to thank my thesis readers, Mitch Resnick and Kevin Brooks for their invaluable comments and support. Mitch always shared his wisdom of how to learn about learning. Kevin always patiently listened to my fragments of ideas and helped me put these pieces together to tell a bigger story.

I was fortunate to have brilliant undergraduate students, Josh Monzon and Rob Figueiredo, who helped design and write the I/O Brush software with amazing speed and skills. I am grateful for their hard work.

Special warm thanks to the teachers, Janice Lund, Pat Kelly, Karen, and the children at the Baldwin School, who welcomed me and shared their experience with me during the last three years. Thanks also to Anna Pandolfo for her help with the experiment.

Special thanks to Ann Hoban who opened up her home for the I/O Brush palette and helped unleash artistic possibilities with I/O Brush!

I am grateful to Gerfried Stocker who gave me the opportunity to exhibit I/O Brush at the Ars Electronica Center and Gerold Hofstadler who helped me to make it a reality.

Thanks to the members of TMG, James, Hayes, Amanda, Dick, Vincent, Jason, Kazue, and Mahoro for always being there, being cool, and inspirational. Thank you especially to James, Hayes, and Amanda for welcoming me as a colleague since the summer of 2003.

Thanks to Lisa Lieberson for helping me with all the little things I needed help with. Thanks also to Linda Peterson and Pat Solakoff.

My special thanks to Tim and Hannes, my PhD buddies, friends, and mentors. My warm thanks to friends near and far—Cati, Hiroko, Yukiko, Mike, Jennifer, Ian, James D, Polly, Anna, Nick, Deborah, Joanie, Fernanda, Barbara, Tara, Erik, Oren, and Elisabeth.

I would like to thank Hansruedi, Helene, Ralph, Manu, and Lily, my Swiss family and friends. Thank you Sky, Xiaorong, and May, my American family (thank you Sky for saving the title and always being

---

there to help). And Mom, Dad, and Nori, my family in Japan, for always being there for me.

**And my deepest gratitude and love to STEFAN, without whom I could not have stayed sane and finished this long journey. E ha di gaern forever. This thesis is dedicated to you!**



---

# Table of Contents

<i>ABSTRACT</i> .....	3
<i>ACKNOWLEDGEMENTS</i> .....	7
<i>TABLE OF CONTENTS</i> .....	9
<i>1. INTRODUCTION</i> .....	13
<i>2. BACKGROUND</i> .....	17
2.1. Development of Drawing .....	17
2.1.1. From Scribbles to Artistic Expressions .....	17
2.1.2. Function of Children’s Drawing .....	19
2.2. Narrative Connections .....	22
2.2.1. Drawing and Narrative / Storytelling .....	22
Art Therapy / Drawing as Mental Test .....	24
2.2.2. Drawing and Emergent Literacy .....	24
2.1.2. Golden Age of Drawing – Age of Synesthesia .....	26
2.3. Social Context .....	27
2.3.1. Drawing as Object to Think with .....	27
2.3.2. Drawing in Peer-to-Peer Collaboration .....	28
2.4. Meaning of Environment .....	29
2.4.1. Evocative Environment .....	29
2.4.2. The Way We Look at the World .....	32
2.5. Related Systems .....	33
2.5.1. Technologies for Children’s Creative Learning .....	33
2.5.2. Technologies for Digitally Capturing and Manipulating Images .....	34
<i>3. NEW DESIGN SPACE: THE WORLD AS A PALETTE</i> .....	39
3.1. Craftsmanship in Digital Art .....	39
3.2. Attributes of Personal Objects .....	41
3.3. Expanded Design Space .....	42
3.4. Building Personal Paint Box .....	43
3.5. Canvas with history .....	44
<i>4. IMPLEMENTATION</i> .....	49
4.1. The Brush .....	49
4.1.1. Background .....	50
4.1.2. Challenge .....	51
4.1.3. Solution summary .....	51
4.1.4. Design Solution details .....	53
Simplicity .....	53
Scale, form, and orientation .....	54
Touching the portrait .....	56
Offer a place to work with the ink: Palette .....	57
4.1.5. Early Prototype .....	61
4.2. The Palette .....	63

---

4.3. The Canvas with History .....	64
4.4. Synergetic Creation .....	65
5. <i>EVALUATION</i> .....	67
5.1. Kindergarteners .....	67
5.1.1. Study Design.....	68
Classroom space .....	68
Schedule and Curriculum .....	69
Questionnaires .....	71
5.1.2. Kindergarten Results .....	74
Mastery of Tool .....	74
Mastery of Expressions .....	81
Personal Objects and Peer Culture.....	86
Looking at the Environment Actively .....	89
Children’s creations from “Draw Faces” prompt.....	94
Summary .....	96
5.2. Case Study with an Artist.....	97
Session One at the Media Lab.....	97
Session Two at Ann’s House.....	98
Session Three at the Media Lab .....	102
Summary .....	106
5.2.3. Beyond Static Collages .....	106
6. <i>DISCUSSION</i> .....	111
6.1. Developing Synergetic Creations.....	111
6.2. Future Designs .....	112
6.2.1. Future Design of the Brush .....	112
Size and Shape of the Brush.....	112
Portability of System.....	112
Previewing Ink .....	113
6.2.2. Synesthetic transformation.....	114
6.2.3. Extending the I/O Brush idea with different sets of sensors .....	115
6.3. What “The World as a Palette” Means .....	116
7. <i>CONCLUSIONS</i> .....	119
<i>APPENDIX A: PERMISSION LETTER TO PARENTS</i> .....	121
<i>APPENDIX B: I/O BRUSH TECHNICAL MANUAL FOR ARS ELECTRONICA CENTER</i> .....	125
System diagram.....	128
Components .....	128
Brush .....	128
Breadboard, USB hub, RS232-to-USB hub .....	132
Schematic of circuit on breadboard.....	134
PC.....	135
Touch panel overlay.....	136
Interactive art piece .....	136
Video station .....	137
Start-up procedure.....	137
Tips for info-trainers: Do’s and Don’ts for visitors .....	138
General treatment:.....	138

---

---

General handling:.....	138
Movie mode.....	138
Color mode.....	139
Restarting.....	139
Other hints.....	139
Software.....	139
PC software.....	139
Microcontroller software.....	141
Interactive art piece software.....	141
FAQ.....	142
Appendix: Microcontroller code.....	143
<i>APPENDIX C: I/O BRUSH HANDLING INSTRUCTIONS FOR ARS ELECTRONICA CENTER.....</i>	<i>147</i>
<i>REFERENCES.....</i>	<i>159</i>

---

---

---

# 1. Introduction

“It has been remarked that the very essence of civilization consists of purposely building monuments so as not to forget.”

—Vygotsky (1978, p.51)

What distinguishes human memory from animal memory, Vygotsky explained, is our use of symbols, our tendency to construct huge concrete objects—or small marks on paper—that mediate our relationship to the world without and, at the same time, to the world within. “It is symbols that link the individual mind and the collective consciousness of culture. Members of a culture come to share common ways of infusing various forms (such as sounds, actions, marks on paper, and monuments in the park) with meaning. These symbols—these connections between forms and meanings—connect us to others and, at the same time, organize our own feelings, experiences, and thoughts” (Dyson, 1993, p.25).

In this thesis, I look at everyday art ‘monuments’ created by people, and the *narrative* connection between forms and meanings. We embrace monuments/symbols, whether it is a painting on the wall or a rugged family quilt made by the grandmother, that carry with them a plethora of stories behind their creation. Yet, those remarkable stories behind the process are usually under-documented, if they are documented at all. People who come in contact with the artistic creations rarely have the chance to hear those stories. While we can simply be left to imagine the richness of its creation, discovering the actual stories behind the creation—the historical context of the creator, as well as learning how the creator came to certain design decisions and where the materials come from—could be powerful as it helps us to situate and appreciate the creation, and even inspires us to expand our own creative thoughts. But how would we create such synergetic art that includes storytelling? Is there a natural mechanism in which narratives could be embedded during the process of creation?

From a developmental perspective, it is interesting to keep in mind that our own artistic development begins with the synergy of diverse media. In young children’s creation, easy, natural exchange among various media occurs (Gardner, 1982). The child may sing as she draws, may dance as she sings, may tell stories while she plays in the bathtub or in the backyard. Children also engage in artful performances, through which they hope to gain others’ attention and respect (Dyson, 1993). Children draw material from popular culture to establish social cohesion, but there are artistic tensions between drawing, talking, and writing, tensions that come from differences in the space and time

---

conventions of these diverse media. Gradually, children begin to assume greater control of the kind of information they would include in each medium. Their pictures become, more and more, illustrations of key ideas. Over time, their creations become more embedded in and allow the children to make connections with their social lives.

But as children grow older into elementary grades, such synergetic creations disappear. Their play and use of symbols start to follow rules and conventions adults approve, and less experimentation and novel approaches are attempted. This so happens to coincide with the school's efforts to teach separate subjects. Art class becomes an activity separated from writing, poetry, or literature, and an act of storytelling becomes strictly a discourse form containing no drawings or other visual art form. What happens to the "golden age of artistic innocence"? Is there a technological way to preserve this synergy? If so, how can children continue to develop such synergetic creations?

This thesis is about how people, particularly children, create and interact with art monuments, with an emphasis on techniques to support the narrative connection between the creator, creation, and the materials that make up the creation. This thesis proposes technology that documents the process of visual art creation automatically via an imaging device embedded inside the drawing tool. The finished portrait serves as a medium for communication as it can reveal to both the artist and the audience, the process of creation and the stories behind the art piece. This thesis also introduces the concept of building visual art projects with elements extracted directly from the artist's personal objects and his immediate environment, thus allowing child and adult artist alike to turn their world into a color palette. For example, by picking up a texture from his pet dog's fur, movements of his own blinking eye, color from his favorite yellow shirt, and by combining these elements in an interesting way to make a drawing, an artist can not only create new art forms but also breathe a new kind of life into the canvas. The cross-boundary experience of being both the producer of materials and tools used for paintings as well as the painter who creates a piece of art empowers artists with a sense of greater possibilities and control over their creations. But most of all, it is the strong personal value behind these elements that make up the art that facilitates the storytelling by the creator and appreciation by its observers.

In summary, this thesis contains the following contributions:

- Technology to turn personal objects found in the immediate environment of the creator into elements of construction, thus leveraging the powerful connection people have with physical objects to encourage "meaning making" beyond the surface. The technology invites people to expand their perspective by actively associating new meaning with attributes of objects found in their physical world.

- 
- Technology that allows people to capture the motion of objects and further combine it with variety of dynamic motions made on the canvas enabling inventions of new artistic expressions.
  - Technology that documents the process of visual art creation. Via images and sound, it captures the occurring verbal explanations and the origin of the materials that compose the art. Technology that allows artistic creations not only to be appreciated from a fixed point in time, but as an active portrait with the memory of its process of creation. In this approach, the stories about the evolving creation are part of the creation that could be shared, and appreciated by its viewers. This access to a 'historical perspective' has the potential to empower both the creators and the observers as it opens up a channel for sharing the process of creation, and facilitates inquiries around the creation, such as where the materials that are used come from.

This thesis contributes to the effort of inventing new media for artistic expression and creative learning, by providing child and adult artists alike with the experience to create art pieces where their personal stories about the materials and processes could be interwoven, and shared with the audience. This is empowering for artists as they become aware that creative expressionists can invent new tools or materials instead of using the off-the-shelf products. The approach of this thesis combines the techniques and technologies from the disciplines of education, storytelling, and digital/interactive art.

---



---

## 2. Background

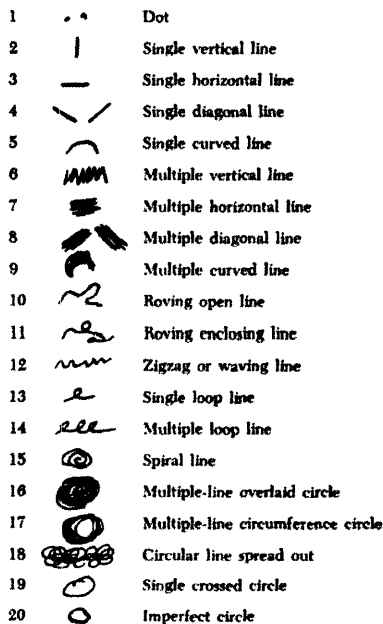
In this thesis, I focus particularly on young children's creation of artistic monuments as development of their artistry happens in a remarkable combination of art, storytelling, and interaction with objects. Through their drawings, they create representations of what they know about the world and learn to express their ideas through sharing their symbolic meanings with people around them.

In this chapter, I will review work in developmental psychology, education, and art that is relevant to building new tools that support child and adult artists' construction of artistic monuments with personally meaningful materials. Later in this chapter, I will also review work that has been done on technologies to support creative learning.

### 2.1. Development of Drawing

Children as young as twenty months engage in artful scribbling. Scribbling and the basic development of drawing seem to occur universally among children around the world.

#### 2.1.1. From Scribbles to Artistic Expressions



20 basic scribbles (Kellogg, 1969)

The pleasure children get out of scribbling comes from the combination of vision and movement, and child art has meaning for both capabilities. The motor pleasure children get out of their scribbling is evident in their dynamic movements. One may even argue that the basic scribbles could be made even without any visual guidance. Yet a child will stop her scribbling if she discovers that her crayon no longer leaves marks because it has broken into pieces. Therefore, visual pleasure is an essential part of child art, or else children would not make markings.

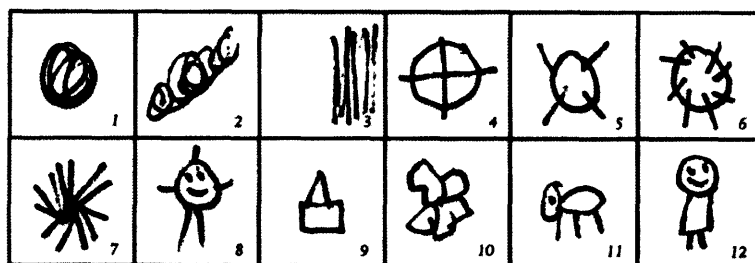
The patterns that emerge from children's scribbling are first made spontaneously, without coaching or copying, and they are made in response to the visual stimulus of the children's scribbling process itself. This self-reinforcing visual-motor activity seems universal as similar scribbling forms can be found in art of young children around the world (Kellogg, 1969).

In the 1960's, psychologist Rhoda Kellogg has conducted an exhaustive analysis of children's scribbles and drawings from her collection of over half a million drawings of children around the world. Her analyses emphasize pattern and organization of children's drawings, based on

---

Gestalt theory. “Gestalt” means form, and Gestalt theory states that when a child looks at his scribblings, his eyes see millions of dots reflected from the lines and the paper. The child’s brain must organize these dots into meaningful Gestalts, that is, into shapes that “make sense.” Gradually, children take more control of their scribbling in coordination with their physical movement and perception, and move on to produce sophisticated lines and shapes.

The shapes to be found in children’s art seem to evolve from the children’s perceptions of their own scribbling. Children perceive and remember those scribbles that suggest shapes, but scribbles that do not suggest shapes are not so easily recalled (Kellogg, 1969). After weeks and weeks of scribbling, children make the discovery of art—a drawn symbol can stand for a real thing in the environment. Later symbols become more complex, reflecting children’s observations of the world around them.



Twelve basic line formations (Kellogg, 1969)

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 (Naested, 1998) (which include color, shape, line, form, texture, contrast, pattern, and balance), but also develop their ability to classify, sort, think critically, and communicate (Goldberg, 1997).

Few parents may want their children to become artists, but all parents want them to succeed in school subjects, including art if the school expects success in art. According to Kellogg, a child is willing to learn the symbol systems if he thinks he can succeed, be it language, mathematics, or art. In the domain of art, his difficulties are twofold: his mind is full of his own naturally made art symbols, which he wants to draw, but adults want him to learn new and different Gestalts.



*Humans that most teachers would like (five to seven years)*



*Humans that few teachers would like (five to seven years)*

From early stage, adults' expectations influence children's artistic development.

### 2.1.2. Function of Children's Drawing

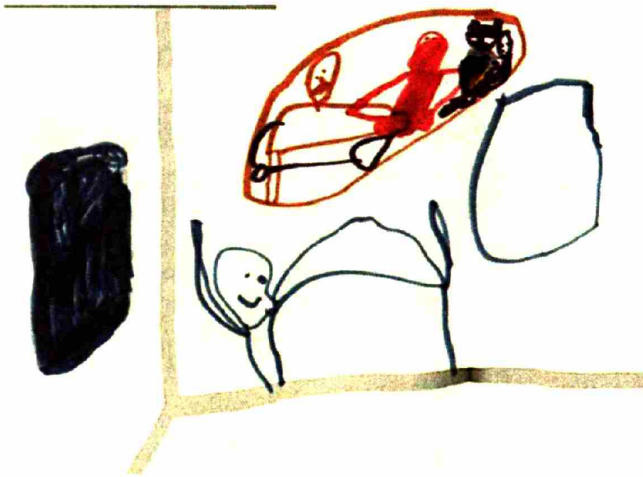
Children approach drawing differently from adults. While adults may draw a still life portrait by looking at objects on a table, children draw from memory. When asked to draw a mother sitting in front of him, a child does not look at her, but rather draw her from his memory. According to Piaget and Inhelder (1963), preschoolers draw what they

---

know about the world, rather than attempting to capture a photographic mirror of reality.

Their reliance on memory is evident in their drawings where they may depict both the outside and inside of an object at the same time. In these “x-ray drawings,” a child may draw a picture of a person, but at the same time draw the person’s stomach or a wallet in the person’s pocket, on top of the figure. Things he knows but cannot be seen could be freely portrayed.

Drawings of these young children may not only disregard but also directly contradict the actual perception of the object. They are not concerned with representation first. Children are much more symbolists than naturalists and are in no way concerned with complete and exact similarity (Vygotsky, 1978, p.112).



A picture of “my room” by a 5-year-old. The boy is sleeping in the bed but something else is going on in his mind or in the other room.

Children also relate to drawings as if they were objects rather than representation. For example, when a drawing shows a man with his back to the observer, the child will turn the sheet over to try to see the face (Vygotsky, 1978). Even among five-year-olds Vygotsky observed that, in response to the question, “Where is his face and nose?” children would turn the drawing over, and only then would answer, “It’s not there, it’s not drawn.”

Representation is the process by which children depict objects and experiences through a variety of developing activities such as imitation, pretending, building, artwork, and written language. Infants and toddlers build their experience through their ongoing sensory-motor explorations. They learn to imitate the actions of others, interpret pictures and photographs of actions and objects they have experienced, and begin to use actions and materials to show or represent something they know about their world. With repeated experiences, they begin to



“Where is his face and nose?” Children would turn the drawing over, and say, “It’s not there. It’s not drawn.”






form mental images of the object or person. This process is the beginning of representation—the ability to internalize or mentally picture an absent person, object, or action.

Representing is important developmentally because it indicates that young children, who tend to see things in very concrete terms, are moving toward a more abstract understanding of their world: from the world that they only understand through their senses, to the world that they understand through symbolic thought.

Three- and four-year-olds develop other generic symbols for the repeated drawings of common objects like sun, dog, and house. As children learn to draw in a more realistic manner, they may go back and forth between realism and earlier scribbling patterns, but the general movement remains toward realistic representation of what they know of the world.

While approaching realism, drawings remain fanciful throughout the preschool years with imagination leading color, composition, and content. All the actions in their drawings may be drawing in the air—people and animals hover around the paper freely, and trees, houses, and people could be all drawn the same size.

As the child moves into concrete operational thought after age six or seven we see a strong focus on drawing in a more realistic fashion. The concrete operational thinker sees the world in terms of what is, rather than what could be. Therefore, we see drawings reflecting the world in factual, realistic representations, leaving behind the wonderfully fanciful drawings of a year before.

2 years	3 – 5 years	6 years	7 – 11 years	12 years +
Sensory Motor Stage	Pre-Operational		Concrete Operational	Formal Operational
Scribbling Stage	Pre-schematic Stage	Schematic Stage	Realism Stage	Naturalistic Stage
				
Scribbling in a combination of motor and visual pleasure.	Symbols like people, house, tree emerge, but they flow freely in space.	More developed order in space relationships. Everything sits on the base line.	Concerned with how things really look.	Three-dimensional realism with lights, shadows, and perspectives.

---

## 2.2. Narrative Connections

### 2.2.1. Drawing and Narrative / Storytelling

When a child unburdens his repository of memory in drawing, he does so in the mode of speech—telling a story.

—Vygotsky (1978, p.112)

Before children's drawings reflect the world in factual and realistic representations, their drawings reflect their thoughts and memory. Vygotsky explained the similarity between children's early drawings and verbal concept in that they both communicate only the essential features of objects. Thus drawing is graphic speech that arises on the basis of verbal speech. (Vygotsky, 1978, p.112).

According to Bruner (1990), there are two modes of cognitive functioning, two modes of thought, each providing distinctive ways of ordering experience and constructing reality. One mode, the "paradigmatic" or logico-scientific mode, attempts to fulfill the ideal of a formal, mathematical system of description and explanation. The "narrative mode," on the other hand, deals in human or human-like intention and action and the vicissitudes and consequences that mark their course (Bruner, 1990, p.13). Narrative mode leads to good stories, gripping drama, believable (though not necessarily true) historical accounts.

Drawing to young children, then seem to serve as space for reflection of their narrative thought. Indeed, when asked, "What's going on?" children can describe events and thoughts portrayed in their pictures that may not be obvious from a quick glance at their pictures. Narrative is fundamental to human understanding of intentional behavior (Bruner, 1990) and such "narrative thought" seems to come naturally to children.

The styles in which they portray their narrative thought may be different individually, however. Take, for example, drawings done by two kindergarteners, Jacob and Tyana, both 5 years old. They were asked to draw their favorite park on the same piece of paper. The way they approached the project was quite different.



Jacob's drawing. He lets his elaborate picture tell all. His talk during or after drawing is minimal.



Tyana's drawing. As she draws, she narrates, "And there is a wind! All around the park!" using the dynamic drawing as backdrop for her narration.

To borrow Howard Gardner's terms, Jacob could perhaps be categorized as "visualizer" and Tyana as "verbalizer" or "dramatizer." Although Gardner and his colleagues found tremendous individual differences, some patterns did emerge in their analysis of children's performances. Some children were verbalizers; less concerned about the task of drawing, but they produced copious amounts of language. Others are committed visualizers; though they certainly could talk, they did so minimally. And instead, they would plunge directly into drawing or building, but offering linguistic comments sparingly (Gardner, 1982). Therefore, in a classroom, it seems important not to favor/exclude one medium over another in supporting children's development/ability to represent their ideas.

---

## Art Therapy / Drawing as Mental Test

Drawings have been also used as medium for therapy/test as they capture some of drawer's thoughts and feelings symbolically on paper. A child may leave an imprint, however incomplete, of this inner self on his drawing. In a therapy situation with children, assumption is that pictures sometimes could portray more than words they can say. Unwittingly, a child may sketch in some details of her own traits, attitudes, behavior characteristics, personality strength and weaknesses. The very lines, timidly, firmly, boldly or savagely drawing, convey some information (Klepsch & Logie, 1982).

Goodenough (1926) published the first test for systematically evaluating children's drawings on a point scale method. Harris (1963) revised and extended this procedure, which became know as the Goodenough-Harris Draw-a-Man Test. Scoring systems for estimating IQ from figure drawings have been developed by Buck (1948) for the House-Tree-Person Test. Machover (1949) analyzed human figure drawings (HFDs) with a view to measuring the projected self. Her analysis was based on "draw a person" related intimately to the impulses, anxieties, conflicts, and compensations characteristic of that individual.

### 2.2.2. Drawing and Emergent Literacy

A major emphasis in school education is literacy. Since the early 60's through the 80's, the majority of educators thought that the instruction of reading and writing could only begin efficiently when children had mastered a set of basic skills. What happened before formal instruction was irrelevant, as long as sufficient teaching and practice in a logical sequence were provided when formal instruction began (Teal & Sulzby, 1986). Since the 80's, however, studies of psycholinguistics and developmental psychology have begun to establish connections between oral language and written language, and begun to establish a new notion that the preparation for reading and writing skills starts long before children begin receiving formal instruction.

The connections between drawing and writing are quite close for young children because both symbol systems involve the use of the same tools—pencils, crayons, and paper. Drawing seems to contribute to children's emergent literacy learning on at least a couple of different levels.

First, young children's physical ability to form letters does seem to emerge from their scribbling practices. Pellegrini et al. (1991) used Vygotsky's framework to explain the connection between representational competence exhibited in children's early writing and symbolic play. Vygotsky (1978) proposed that early writing originates from symbolic play and travels a developmental route through drawing

DRAWING 20: 'I feel sad.'

**The Drawer**  
Boy, nine years old; above-average ability; school performance poor; unhappy in class; has fine- and gross-motor learning problems.

**The Projection**  
Overall Impression: Unhappiness  
Specific Indicators:  
• Face: (he is miserable)  
• Feet: emphasis (evokes a firm footing or security which he does not have; also has fine motor problems and is clumsy)  
• Arms: in different directions (they do not perform well for him)  
• Hands: motionless (suggests insecurity and difficulty in dealing with environment, in this case, school)



An unhappy face may reveal emotional conflict inside the child.



---

to writing. Drawings and initial forms of written language (e.g., scribbles on a piece of paper that represent a bill in a pretend bank play) are examples of children demonstrating their first symbolization. However at this stage, the symbols they use represent objects, not words (e.g., a drawing of a car of the written word car at this stage represents the object, not the word car). In the second symbolization, the written word represents the oral word and thoughts instead of objects (Pellegrini et al., 1991).

According to Sulzby (1986), rather than drawing preceding writing developmentally, children are learning to differentiate marking into the two representation systems. Children go through increased abstraction from real-life activity, to pretend play, to gesture, to drawing, and, finally to, writing (Vygotsky, 1978). Sulzby identified six major categories in such process of all children: writing via drawing; writing via “scribbling”; writing via letter-like forms; writing via well-learned units; writing via “invented spelling”; and writing via conventional English orthography. However, the order of appearance of the two systems in which marking is used does not appear to be linear, although control of recognizable drawing may seem to precede recognizable writing (Sulzby, 1986).

Five-year-olds in kindergarten do distinguish between drawing and writing, at some level. Some children will draw when asked to write, but when they reread or discuss their writing attempts, they seem to indicate distinctions, even though they convey these with a great deal of ambivalence (Sulzby, 1986). They know the difference, but they use them interchangeably.

On the second level, drawing could be also used as a prop for their literacy skills. Beginning writers plan their stories through their drawings and these drawings are thus a “rehearsal” for writing (Gleason, 2001). In a kindergarten classroom, children are first encouraged to draw and then explain to their teacher what is going on in their picture. The teacher then writes down what children say about their work. Eventually, children are expected to write down the words themselves.

A horse is a wild  
Animal. a horse should  
Be free. a horse should  
Be left like it want to be  
The horse



---

Not all children however, have a smooth transition from expressing ideas freely on the paper with drawings to actually writing the ideas with words without the aid of drawings. Some children may benefit from having extra help from working their ideas visually and orally (Dyson, 1993).

### **2.1.2. Golden Age of Drawing – Age of Synesthesia**

Harvard “Project Zero” lead by Howard Gardner and his colleagues is observing children as they participate, or cease to participate, in a range of artistic activities. While neither they, nor their colleagues elsewhere, have come to definite conclusions, they have been moving toward an understanding of the drawings, songs, and metaphors created by young children. The key to children’s artistry, they have come to feel, lies in understanding children’s overall patterns of development.

Between the ages of five and seven is the period of what Gardner calls “golden age of drawing.” “Most children of that age range in our society achieve notable expressiveness in their drawings. Having mastered the basic steps of drawing and learned to produce acceptable likenesses, they go on to produce works that are lively, organized, and almost unfailingly pleasing. One feels that the child is speaking directly through the drawings, that each line, shape, and form conveys the inner feelings as well as explicit themes in the young child’s efforts to understand the world.” (Gardner, 1982, p.128)

There is also at this age, “perhaps for the first and sometimes the last time, an easy, natural commerce among various media. The child sings as he draws, dances as he sings, tells stories while at play in the bathtub or in the backyard. Rather than allow each art form to progress in relative isolation from the others, children move readily and even eagerly from one form to another, combine the forms, and play them off against one another. In fact, an age of synesthesia begins: a time when, more than any other, the child effects easy translations across sensory systems; when colors can readily evoke sounds and sounds can readily evoke colors; when motions of the hand suggest lines of poetry or lines of verse stimulate a dance or a song.” (Gardner, 1982, p.128)

Yet, this golden age of drawing does not last much after a child starts school. Why would this be? First, because a child grows out of the period of egocentric thought and fantasy, what Piaget calls preoperational stage (2-7), and moves onto the “concrete operational” stage (about 7 to 11 or 12 years) where a child becomes more sociocentric and can engage in concrete logical thought. But secondly, it is because school in general has the tendency to push children to become more formal in their presentations. In primary grades’ “sharing time” for example, as teachers encourage children to focus on

---

“one topic” and scaffold their storytelling to follow that teacher’s model, children’s language style becomes more and more “expository,” which is the most valued style in school. The goal of such oral language exercise in sharing time is to appropriate children’s oral language styles into the style valued in school, not to listen to what they have to say as sadly illustrated in Michaels’ (1991) work. Children’s personal and evaluative voices are suppressed in order to support expository structure (Michaels, 1991). Therefore, as children move onto older grades, they practice more and more expository writing and less and less storytelling and story writing that reflects their personal voice (Gleason, 2001). In public schools from first through twelfth grade, much of the classroom routine is shaped by an emphasis on rote learning, a strict adherence to standardized textbooks and workbooks, and a curriculum that is often enforced with drill and practice (Schank & Cleary, 1995).

## 2.3. Social Context

Social context plays an important role in children’s developing expression—cognitively, socially, and emotionally.

### 2.3.1. Drawing as Object to Think with

As described in previous sections, children do not draw from “life.” They first learn to draw by observing their own drawings but also those of their peers. Drawing may serve as an object of reflection.

Constructionist learning happens when learners engage in actively constructing external artifacts to share with and for critique by others (Papert, 1980; Resnick 1996). Artifacts in constructionist learning environments serve as a point of reference and thus become “objects-to-think-with.” Thus, no wonder 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 as observed in works by (Resnick, Rusk, & Cook, 1999; Papert, 1980). Learning is driven by the natural need to do so, and doing and attempting to do is at the heart of children’s natural acquisition of knowledge (Schank & Cleary, 1995). The “natural” inquisitiveness of early childhood should not be wasted.

Papert (2000) described the idea that comes out of building personally meaningful projects is:

- powerful in its *use*, as a learner can use the idea to solve a real problem that had come directly out of a personal project,
- powerful in its *connections*, as ideas are directly connected with other situations in the world and they lead to the understanding of a large class of phenomena, and

- 
- powerful in its *roots*, as the idea has roots in intuitive knowledge that the learner has internalized over a long period (i.e., *syntonic*).

For children, drawing is such a personally meaningful project and object of reflection. For younger children, drawings are representations of their understanding of the world. Older children may use drawings for understanding the world by studying the details and realism of their drawings.

### 2.3.2. Drawing in Peer-to-Peer Collaboration

Children need the opportunity to articulate their intentions, and then to know if others indeed understood those intentions (Rogoff, 1990; Dyson, 1993). In early years of schooling, children typically practice sharing their ideas in activities like “sharing time” or “show-and-tell.” During such activities, children talk about their favorite objects, including their own drawings. A partial goal of such sharing exercises is to incorporate the audience in the process of generating the story. Through explaining, children linguistically externalize their thoughts and ideas for their peers, which is key to producing audience-based language (Daiute et al., 1993).

Children engage in social interaction as they draw with or show their creations to others. As young children sit and draw together, they talk, critique, share stories, and trade materials. Children need an authentic situation where they can practice and learn prosocial behaviors.

There are artistic tensions between drawing, talking, and writing, tensions that come from differences in the space and time conventions of these diverse media. Children engage in artful performances, through which they hope to gain others’ attention and respect (Dyson, 1993). Gradually, children begin to assume greater control of the kind of information they would include in each medium. Their pictures become more and more illustrations of key ideas. Over time, their creations become more embedded in and allow the children to make connections with their social lives.



Children learn to represent their ideas through observing, critiquing, and modifying their work with peers.

---

Peer cultures are also sources of motivation, expression, and learning (Fiske, 1989, Willis, 1990) as preadolescent children are intensely involved with their peers. Children draw material from popular culture to establish social cohesion and develop their own identities in relation to their peer culture. If children are to be able to think critically about school subjects, current events, and ideas in their lives, they must ground themselves in a culture and common point of view. They need a firm basis from which to critique as well as to create ideas.

Emotionally, children may save their pictures to show their parents demonstrating their use of drawing for social interaction as well as emotional support.

## **2.4. Meaning of Environment**

Finally, the kind of physical environment we present to children plays an important role in supporting their meaningful exploration. How do external factors such as the environment children grow up in influence children's development of drawing and storytelling?

### **2.4.1. Evocative Environment**

We continually personalize and humanize the given environment as a way of both adapting to it and creating order and significance.

— Csikszentmihalyi (1981, p.122)

The environment in which one develops plays an important role. Preschool years for children are the period of natural artistry. Providing children with many materials and exposing them to works of different kind (stories, drawings, etc.) are a necessity. With the onset of school and the preoccupation with rules and convention, the environment must assume an even more active role (Gardner, 1982, p.89).

We live in a physical environment and create a cultural environment within it. Children need the physical world and access to nature in order to keep their interests and fascination in nature or things around them. This need for immediate, physical feedback that produces enjoyment is the main factor behind the object preferences of youth, who need it to build concrete evidence for the existence of an autonomous self (Csikszentmihalyi, 1981).

Studios of scientists and artists are filled with gadgets and goodies, including personal objects, from which they find inspirations for their inquiry and explorations. Every artist uses objects “to create a little world of my own,” a world in which he or she can play out vicariously dynamic situations from which he or she can learn, and can show others, how the world operates (Csikszentmihalyi, 1981, p.28).



“Cabinet of Curiosities”

Affluent households even sent off explorers with 'shopping-lists' of curiosities that reflected their particular interests and obsessions. Below is a part of one dated 1625:

- holy relics from a Spanish ship
- all sorts of shining stones or of any strange shapes
- all sorts of serpents and snakes skins
- a back-scratcher
- earthen pitchers and porcelain from China
- a Madonna made of feathers
- stone shears
- a canoe with paddles
- Arabian coats
- the horn and tail of a rhinoceros
- the horn of a bull seal
- a unicorn's tail
- the baubles and bells of Henry VIII's fool
- the Turkish emperor's golden seal

...Anything that Is strange...

One extreme example could be seen in “Cabinet of Curiosities,” which was developed among British royals in the 17th Century as a collection of things of wonder. Originally, its purpose was to facilitate an encyclopedic enterprise—the collection and preservation of the whole of knowledge. They were the personal and often idiosyncratic collections of individual, wealthy owners and contained Art (man-made artifacts), Science (natural artifacts) and Spirituality (sense of wonder at God's works) in a physical form.

The main function of the cabinet was to provoke a sense of curiosity and wonder in the viewer; in many ways they represented a world-view that valued the 'wonder' in an artifact much more than the need to analyze and classify that artifact. The idea of the cabinet was that it is a site of collection and display, where the whole of nature could be brought together in microcosm, for the benefit of closer and more detailed analysis. There were not yet universal systems of scientific classification and each collection sported its own unique organizational structure. The control of nature was the goal of the early collecting practice, and was the driving force behind the ordering and cataloguing of objects and artifacts.

---

In a way, one can say that every parent/educator wants the children's environment to be that sort of cabinet with curiosities. When one walks into a kindergarten classroom, it is filled with rich textures, colors, and patterns, and that is no accident. Teachers carefully choose their material according to shapes, sizes, colors, and tactility, etc. and decorate with them.



Kindergarten classrooms are filled with colorful objects carefully chosen and decorated by the teachers.

Parents influence children's art by providing children with art materials, by neglecting to do so, or even by prohibiting their use at home.

Coloring books are popular material given to many young children at home. These books help to fix in the child's mind certain adult-devised formulas for representing objects. Picture books, magazine art, newspapers, comics, and animated creatures on TV all have similar effects. Pictures on the walls of the home, church, store, or museum, being repeatedly seen and explained to children, influence the child's visual and mental absorption of adult-made Gestalts to which special pictorial meanings are attached. (Kellogg, p.145)

The success of abstract thinking may depend on how it is grounded in the child's own reality. School oriented 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!") (Heath, 1983). 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 (Schank & Cleary, 1995). Therefore, learning to deal with new concepts while staying

---

connected with familiar physical surroundings and objects seems to be important in developing new skills.

### 2.4.2. The Way We Look at the World

Every time we interact with an object the possibility of new learning is potentially there.

— Csikszentmihalyi (1981, p.182)

Philosopher John Dewey described that there are two modes of experiencing the world—through recognition and through perception. *Recognition* describes a falling back on some previously formed interpretive schema or stereotype when confronted with an object. In other words, recognition refers to looking at the world the way it is. On the other hand, *perception* involves an active receptivity to the object so that its qualities may modify previously formed habits or schemes (Dewey, 1934).

Getzels and Csikszentmihalyi (1976) have also found that creative artists were no more technically proficient or intelligent than those who were uncreative. What distinguished the two groups was that the former tended to approach a task as a “discovered problem,” whereas the latter faced it as a “presented problem.” Creative artists did not look at an object or composition in terms of given aesthetic categories (e.g., pleasing color, strong texture, exciting vanishing point) but discovered unique peculiarities and relationship in the objects they were about to paint. Therefore, perception seems to be a prerequisite to creativity (Csikszentmihalyi, 1981, p.182).

According to Csikszentmihalyi, perception is also important to learning. As long as things mean only what they are “supposed” to mean, a person cannot grow beyond the boundaries set by culture and socialization. Perception involves an active, critical receptivity to the object so that its qualities may modify previously formed habits or interpretive associations. An experience of perception means that the scheme through which we interpret an object is changed or enlarged, which is how learning occurs, by enlarging or changing the habitual framework of interpretation.

Therefore, perception is a precondition to enjoyment, to learning, to growth, to freedom—hence to the qualities of experience that transform people from totally determined entities into open systems of self-cultivating energy (Csikszentmihalyi, 1981).



---

## 2.5. Related Systems

In this section, I will review the work on technology designed for children and art/creative learning areas.

### 2.5.1. Technologies for Children's Creative Learning

There are many sophisticated, commercially available drawing tools designed for children today. KidPix™ 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™ 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.



KidPix™ is packed with pre-programmed ink.

On the other hand, more economical digital imaging devices such as still and video cameras are available today. Despite young children's fascination with cameras and photographs, the use of such devices and the access to digitally captured images are still quite limited for young children.

Technology serving as building blocks for children's design activities has been successful in learning domains beyond math and science. For

---

example, MOOSE Crossing (Bruckman, 1997) 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 (Druin, et al., 1997) 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 (Ishii & Ullmer, 1997) 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 (Resnick et al., 1998) and Curlybot (Frei et al., 2000) 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 (Bers, 1997) and StoryMat (Ryokai, 1999) 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 (Montemayor, 2002) 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 (Stanton et al., 2001; Decortis & Rizzo, 2002). The I/O Brush 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. The technique used in the I/O Brush technology is based on the two basic functions a brush affords: Picking up attributes from the real world, and painting with these attributes.

### **2.5.2. Technologies for Digitally Capturing and Manipulating Images**

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 (Rekimono, 1997) 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 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.

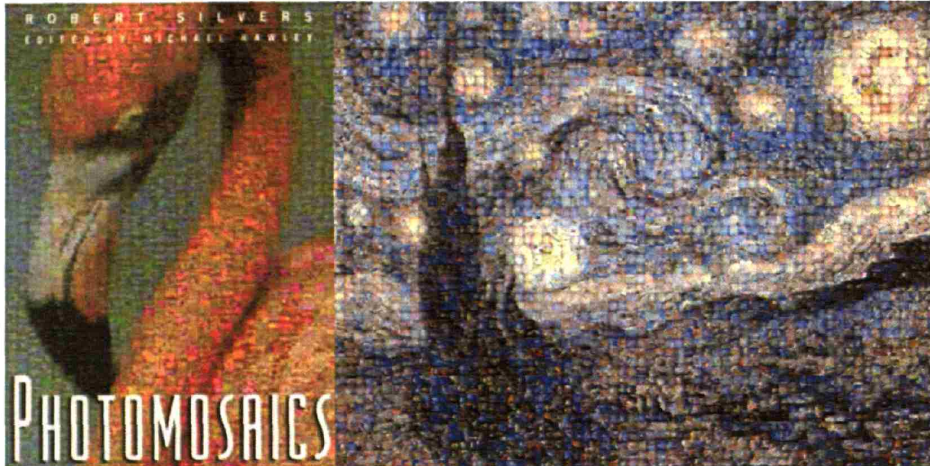
Colortron™ is a handheld device for fashion designers that can pick up any color in the physical world and return the numeric value of the color so that the designer can have the precise color number to work with in their design software. Colortron is accurate in computing the colors, but it is not designed 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.



Colortron™ is a spectrometer for designers to work with precise color values.

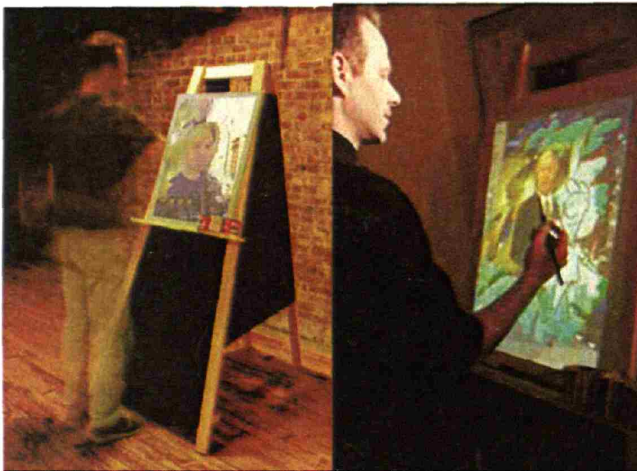
Technologies to control digital images as ink have been developed and are commercially available. For example, the Image Sprayer tool in Corel's Photo-Paint™ and the Magic Nozzle tool in Fractal Design Painter are sophisticated drawing software tools that allow users to spray any bitmap image on a digital 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 (1997) incorporates algorithms to use thousands of images as pixels. Drawing Prism (Greene, 1985) 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.



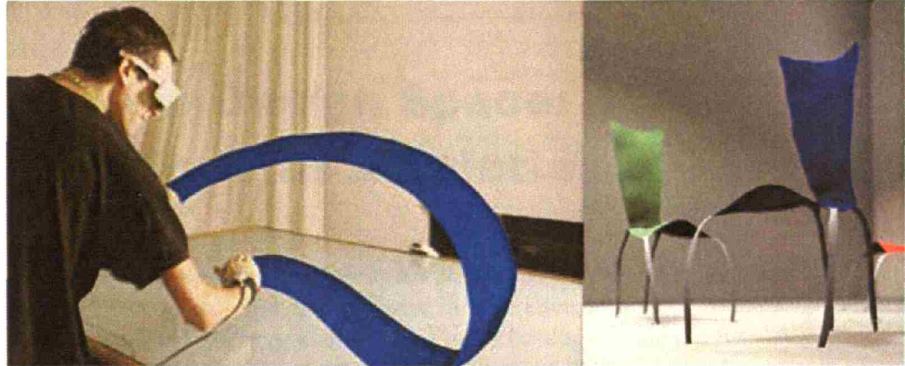
"Photomosaics" by Silvers (1997) give audience two perspectives (near and far views) to appreciate the portrait.

Easel (Rozin, 1999) 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).



"Easel" by Rozin (1999)

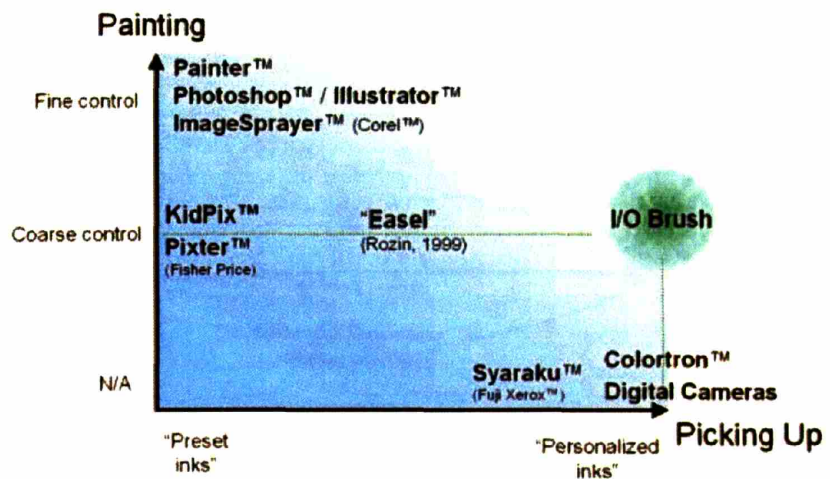
Surface Drawing (Schkolne, 2001) developed at Caltech is another interesting approach for using the body as the brush in a completely virtual environment. Users may either wear a glove or use a tangible tool to directly draw in the virtual environment.



“Surface Drawing” by Schkolne (2001)

Efforts to allow people to mix colors in the digital world have also been made. AntBrush (Tzafestas, 2000) is a software program that allows users to blend digital colors on a digital palette as if they were real paint. Digital Palette (Heaton, 2000) 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 I/O Brush technology bridges both the technology for “painting” and “picking up.” This is summarized in the graph below:



Technologies for “painting” and “picking up”

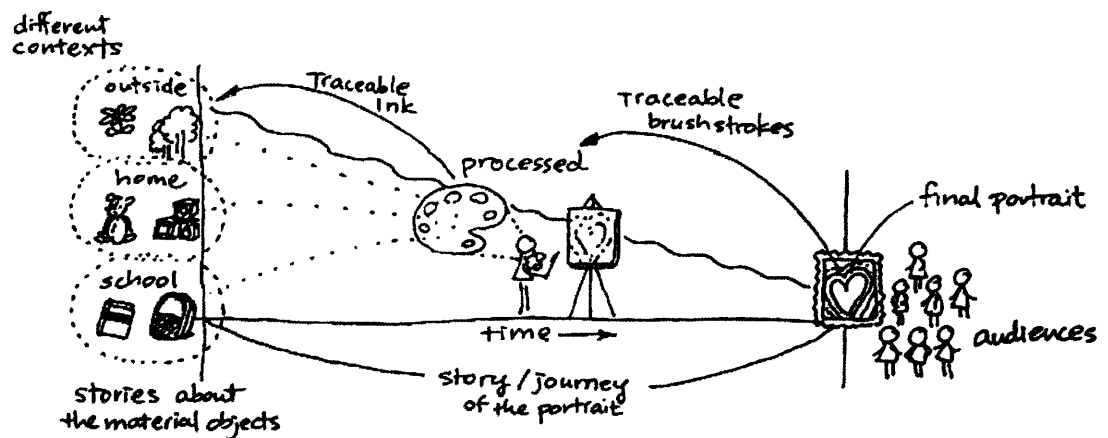
---

---

---

### 3. New Design Space: The World as a Palette

This thesis presents a suite of tools for child and adult artists to explore colors, textures, and movements found in their environment by “picking up” and painting with them. The technology inside the brush allows artists 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. The palette allows artists to build their own paint box by mixing and processing the attributes taken by the brush. Finally, the brush strokes artists make on the canvas are linked to the movies that document where the artist picked up the materials so that the portrait can take both artist and audience back through the journey of creation and reveal the stories behind the special palette of colors. The goal is to empower child and adult artists by allowing them to build their own paint box by taking elements from their world, create portraits with their personal paint box as the technology automatically records the process, and allow them to share with the audience both the portrait and stories that represent the process behind the portrait. The following graphic illustrates the process:



In the following sections, I describe each new feature introduced by the I/O Brush system.

#### 3.1. Craftsmanship in Digital Art

Using one’s own environment as a color palette to paint with introduces a unique challenge for artists where the artist must not only be conscious about the kind of portrait s/he draws but also the kind of

---

material s/he chooses to work with. A historical perspective behind the art of craftsmanship gives us insight into the benefit of having control over one's own materials and tools.

Before the 19<sup>th</sup> century, artists had a great deal of interaction with nature in preparing their art as they searched for base colors in 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.

By the late 19<sup>th</sup> century, however, almost all artists' supplies were made and sold by professionals called "colormen" who not only prepared pigments, but also supplied and made canvases and brushes for artists (Finlay, 2002). During this period, the act of painting started to move from a craft to an art— "For 'craftspeople' the ability to manage one's materials was all important, but for 'artists' the dirty jobs of mixing and grinding were simply time-consuming obstacles to the main business of creation" (Finlay, 2002, p.17). One of the disadvantages was that the artists in that period started to lose the basic knowledge about how the materials interacted chemically on their canvas when they painted. For example, the artists did not know why the colors on their canvas changed over the years, as they never had to grind a rock, powder a root, burn a twig, or crush a dried insect. They no longer had total control over the materials that made up their work.

A similar tradition of craftsmanship existed in the discipline of science. Scientists too used to develop their own instruments to run their experiments with. "By building their own instruments—and understanding the capabilities and limitations of those instruments—scientists have historically gained deeper insights into the phenomena under investigation" (Resnick, Berg, & Eisenberg, 2000). But this craftsmanship in science similarly weakened as modernized and mass produced scientific tools became available.

The goal of this dissertation work is to reawaken the tradition of "craftsmanship" in the activity of drawing/painting by giving artists a connection to and a sense of control over the materials they work with. Two unique opportunities for learning may arise from engaging in the art of craftsmanship. First, preparing one's own materials and tools gives the artist greater control of one's trade. Second, knowing the basics of his/her trade gives the individual opportunities to work with a wider range of collaborators including specialists, and the artists would know what the specialists are talking about.

Inviting people to play the role of "color maker" as well as that of a painter may lead to creative thinking as it encourages them to shift their perspectives and become aware that there are alternative ways to approach familiar activities. Coming up with a creative solution to a problem often involves seeing the problem from multiple/unconventional angles (Csikszentmihalyi, 1996). "To see a problem from a qualitatively different vantage point requires a person



---

to become aware that there is another perspective, but first, the individual must become aware of and interested in exploring alternatives to his/her own perspective” (Rogoff, 1990, p.142). The I/O Brush system invites that kind of inquiry about alternatives by having artists play multiple roles that force them to cross the boundary between painter and color maker. As learning involves changing or expanding the habitual framework of interpretation (Dewey, 1934), being involved in the preparation of one’s own tools and materials may provide the individual with extra ‘lenses’ s/he can wear to expand the possibilities and solutions for the problems one is trying to solve.

### **3.2. Attributes of Personal Objects**

This dissertation presents technology that empowers people today to develop the same kind of acute eyes artists had many years ago in identifying colors in their life and making color palettes directly from the environment. Instead of squeezing out colors from the paint tubes bought from an art supply store, the I/O Brush system invites child and adult artists to extract visual attributes of objects found in their personal environment, and immediately use these attributes to make drawings.

Having the environment as a direct source of one’s project invites people to work with attributes taken from their personally meaningful objects. When people work with materials and objects that have personal meanings, they are naturally encouraged to go beyond the immediate value of “what it is,” and are pushed to deal with multiple meanings of “what it represents” or “what it could be” that is associated with these materials and objects (Csikszentmihalyi, 1981).

For young children, the tactile quality of objects is also important in making this transformation because children move from building their experience through sensory-motor explorations to representing and internalizing actions, objects, and what they know about their world.

Gardner and his colleagues have observed individual differences in how children related to their objects in their play. Some children they observed were “object-dependent,” paying attention to the physical attributes of objects and insisting upon having objects present throughout their pretend play (e.g., the children looked for a round object to portray a pie, a long object for a rocket ship). Other children were more “object-independent,” using just about any block or object to stand for what they want to suggest (Gardner, 1982). In either case, objects seem to serve as a point of departure for children’s developing abstractions.

The goal of the I/O Brush technology is to support these abstractions but still allow people to use objects as concrete reminders for their operations. For example, when a child paints her princess’s hair brown (in a portrait) with brown-colored fluffy texture taken from her own

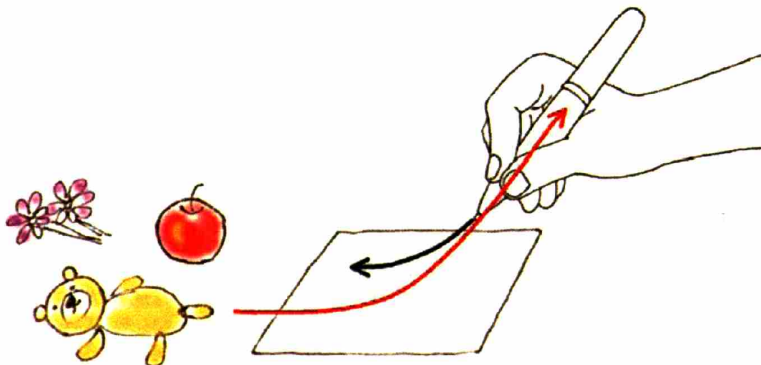
---

teddy bear, the child is engaged in a transformation of a concrete object into new meanings in several different ways. First, the child is engaged in an abstraction by extracting a feature of her teddy bear (i.e., the color brown) and transforming it into the color of another (i.e., hair of a princess). Yet, at the same time, the child may be also taking the meaning associated with her personal teddy bear (e.g., the softness, warmth, and even love) and transferring that to the property of another (e.g., the softness of the princess' hair in the portrait). As Vygotsky wrote, imagination is “a transforming, creative activity directed from the concrete towards a new concrete... with the help of abstraction” (Vygotsky, 1991).

The I/O Brush system leverages the connection people have with their personal objects to encourage ‘meaning making’ beyond the surface. The technology encourages children and adult artists to create a palette of colors that have symbolic function. There is an abundance of opportunities for such kinds of symbolic transformations as the materials and objects children and artists work with are charged with personal meanings.

### 3.3. Expanded Design Space

The key idea behind the I/O Brush technology came from thinking about the limitations of the drawing tools we use today. 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. This tradition of a drawing tool as both an input and output device is brought back, but instead of picking up the liquid ink, I/O Brush lifts up and captures photons.



Can we use attributes of our environment as ink?

When the ink inside of a drawing tool is no longer limited to flowing out in a one-way direction, and when we have active control over what

---

goes inside of the drawing tool, the design space becomes larger than what it used to be. This dissertation is about the change that could be brought out in the way people perceive this extended design space.

Finlay (2002) tells an interesting story about the invention of portable paint boxes. For centuries, artists had to store oil paints in pigs' bladders. With the invention of the collapsible tin tube, portable paint boxes were born. Jean Renoir once told his son that without oil paints in tubes "There would have been no Cezanne, no Monet, no Sisley or Pissarro: nothing of what the journalists were later to call Impressionism." "Impressionism, after all, was a movement that depended on recording nature in nature. Without being able to use colors outside it would have been hard for an artist like Monet to record the impressions that the movements of the light had made on him, and so create his atmospheric effects." (Finlay, 2002, p.19)

In a way, the I/O Brush technology also opens up a new arena where children and artists have access to elements that were difficult to obtain (or rather did not even think about obtaining) before. As the technology allows children and adult artists to take advantage of the context they are in, they inescapably pay attention to the objects and elements that surround them. The portrait also serves as a remembrance of the context the artist has been in. For example, a portrait a child creates with the I/O Brush system in a classroom may have a palette of colors quite different from a portrait the child creates in her own room at home. Like wise, a portrait an artist creates in an urban setting may use different colors/tones from the one the same artist creates in a country setting.

Vygotsky (1935) discussed that the environment is not a setting but a "source of development of these specifically human traits and attributes, most importantly because these historically evolved traits of human personality [...] but the only way they can be found in each individual human being is on the strength of his being a member of a certain historical period and in certain historical circumstances." Paying attention to the environment and building projects with elements that surround the artist may be powerful because pieces of the creator's life and culture are recorded and woven into the portrait.

In summary, artists' connection with personal objects and environment becomes the pivot point for creating, inquiring, and sharing their works of art.

### **3.4. Building Personal Paint Box**

The I/O Brush system creates a space where personally meaningful objects can be collected and further processed.

The system provides a physical palette on which children and adult artists can mix the materials they collected from their environment and

---

build a personal palette of colors. The personal materials they collect become objects, which they can further explore by adding and combining new elements. For example, a child may gently brush over his eye with the Brush to capture the image of his eye. He can drop off the “ink” on the palette, and take another element, color of green, from his favorite “Hulk” backpack. He can then combine the two elements on the palette to make the special “green eye” ink that is made of his own eye and the color that came from his favorite backpack. (This is further discussed in the chapter 4, “Implementation.”)

For adult artists, the palette may become a space where they are able to extract and experiment with features of familiar objects to create new forms. “Many painters and sculptors are constantly involved in seeking objective counterparts for ideas or feelings they experience. Creative artist are those who can find a convincing visual solution for a problem that was never previously formulated. In the solution, and even in the formulation of creative problems, objects stimulate and help develop the artist’s thought” (Getzels & Csikszentmihalyi, 1976, pp.244ff)

The space to modify and process elements of their personal objects is important as it gives children and adult artists not only the opportunity to explore features that consist of the objects they are familiar with, but also to combine them in creative ways. This kind of creative imagination introduces “something new into the flow of our impressions, the transformation of these impressions such that something new, an image that did not previously exist, emerges” (Vygotsky, 1960). Vygotsky discussed that creative imagination is necessary for effective functioning in society. That is, people with a less developed creative imagination have difficulties removing themselves from the immediate stimuli of the environment. With zero imagination, “an individual is in a state where he is unable to abstract himself from a concrete situation, unable to change it creatively, to regroup signs to free one’s self from under its influence” (Vygotsky, 1931).

The I/O Brush system provides an opportunity for people to explore their personal materials through playful modification and transformation.

### **3.5. Canvas with history**

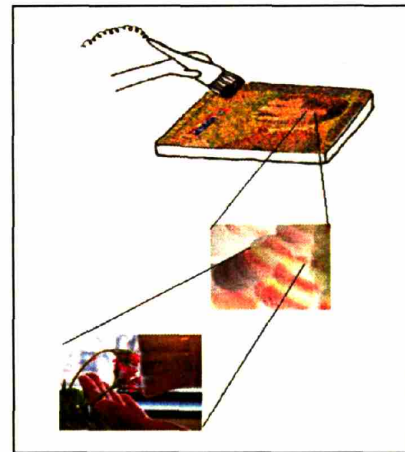
While creating projects with the I/O Brush system, artists draw from materials in their immediate environment. This invites artists to associate and share with others their stories and explanations around their creations. In a pilot study I conducted with kindergarteners, the children produced many drawings 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. For example, as a child points at the part

---

of her portrait, she says, "I got this pink from my jacket. My grandma bought me this jacket just yesterday!"

Artists also have a strong affinity with their objects, and that connection plays an important role in their creation. Csikszentmihalyi quoted one painter describing his work: "I paint only objects with personal significance, those that have meaning for me. With them I create a little world of my own." According to Csikszentmihalyi, every artist seems to use objects to create a little world of my own, "a world in which the artist can play out vicariously dynamic situations from which he or she can learn, and can show others, how the world operates" (Csikszentmihalyi, 1981, pp.28-29).

The I/O Brush system was designed to capture and store some of the processes artists go through in creating the portrait so that they can be documented for the artists themselves to see and/or to be shared with others. The processes are captured by a video camera inside the brush as a movie of where the brush has been. The video serves as a documentary from the perspective of the brush tip, revealing where the brush traveled to and which object it zoomed into. The captured movies are then linked to the respective parts of the final portrait, and can be revealed on the canvas via playback of the movie when the audience touches certain areas of the canvas.



The brush strokes on the canvas have linked visual history.

The system also records the sound while the video is being captured, so when the artist speaks (e.g., "Now I'm taking the flowers from my garden..."), that audio speech is recorded while the video zooms into the flowers. In this way, artists can embed little background stories about the materials that make their art.

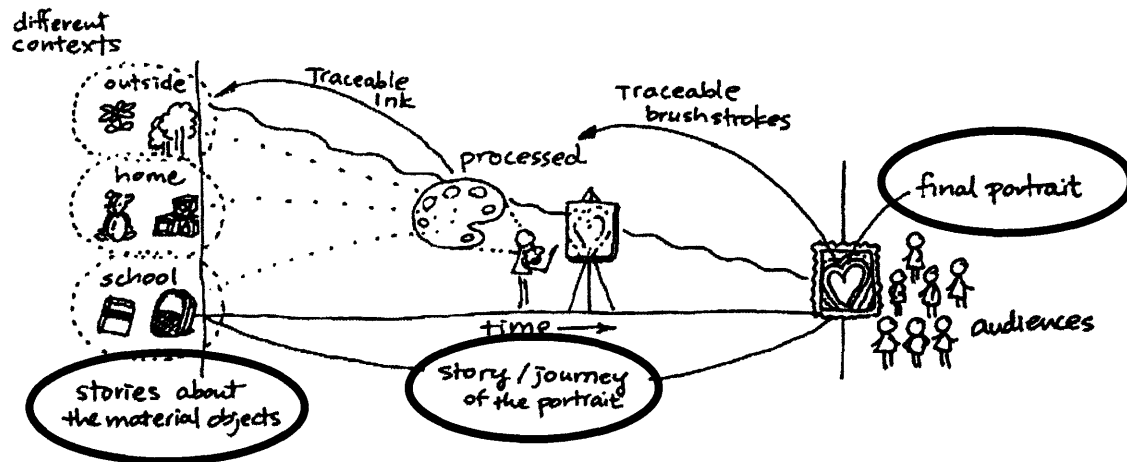
For children, this function to record sound and movements may serve as a mechanism to capture their synergetic creations, as young children's creations involve multimodal expressions (e.g., speaking, pointing, moving around during the creation). The technology helps capture multimodal attributes (movements and sound in addition to the visual attributes) of children's creation processes. For example, a child may say, "Baby worms!" as she draws squiggly lines on the canvas. Her voice is recorded and stored with a link to the lines made on the canvas. When she touches the lines on the canvas, her recorded voice plays back synchronized with the movie that reveals where she got the material from.

Audiences are usually discouraged from touching paintings especially in places like museums. In contrast, the portraits made with the I/O Brush system invites the audience to take a closer look, even touch and reveal the messages, which may be embedded behind the paintings.

Then it is also for the audience to appreciate the portraits created with the I/O Brush system and becoming aware of perspectives and messages behind the portrait. Feldman (1994) explained that creativity transforms both the creator, through the personal experience of the process, and others, through the impact of new knowledge and innovative artifacts disseminated through culture. According to Feldman, creativity is a “transformational imperative” for everyone.

For artists, the system provides a canvas with multiple layers where they may construct and embed complex messages into the portrait. For example, an artist may draw a portrait using a collection of family photos. The artist can leave an audio-visual message (via the history documenting function of the system) for each of the personal ink s/he works with. The I/O Brush system provides a channel where artists can leave a personal message behind the material that makes their art. The artist’s message behind each ink and juxtaposition of his/her ink and its meaning adds additional depth of meaning to the portrait.

The stories behind the portraits could be broken into three different types: stories about the process of the portrait, stories about the material that the portrait is made of, and the story the portrait is about.

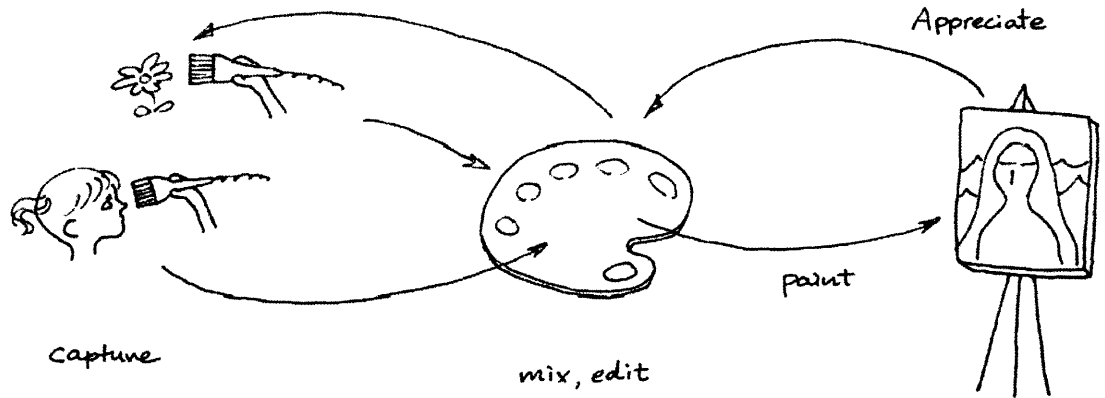


Multiple stories created and shared with the I/O Brush system.

To summarize, the I/O Brush allows child and adult artists alike to take elements from their world to build their own visual art projects. The palette serves as a space where artists can collect elements they extract

---

from their environment and build their own paint box by mixing these elements. The interactive canvas with history can offer not only the constructor and creator, but also the audience an extra creative learning experience by studying the message and processes the artist left behind. The depth behind the craft could be appreciated through viewing from multiple perspectives (e.g., painter, place, object), and providing a “macro view” of the portrait and the processes that surround the creation.



In the next chapter, I discuss specific design process and technical implementations of these tools.

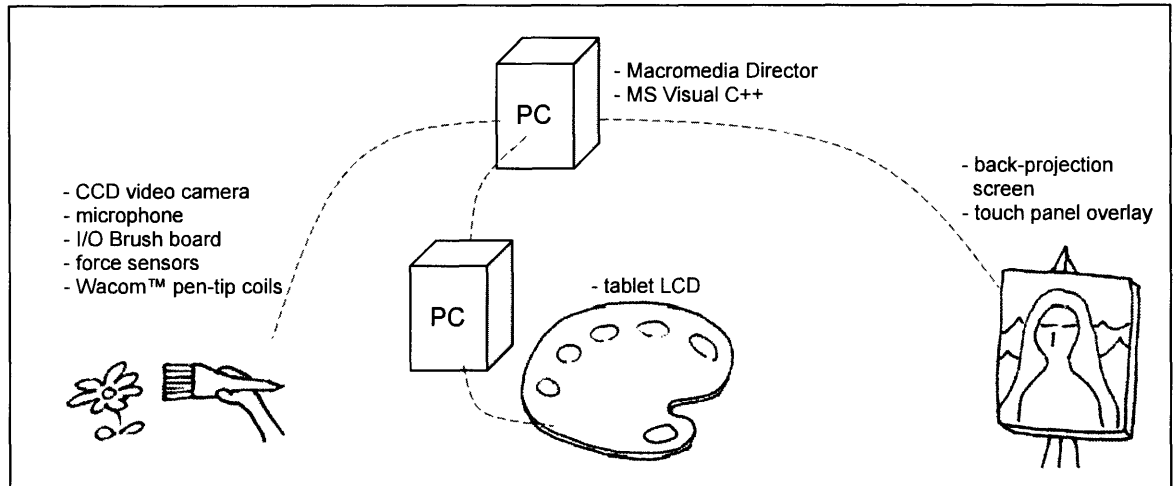
---



---

## 4. Implementation

The system is composed of three main parts: the brush, the palette, and the canvas.



The three main components of the I/O Brush system.

### 4.1. The Brush

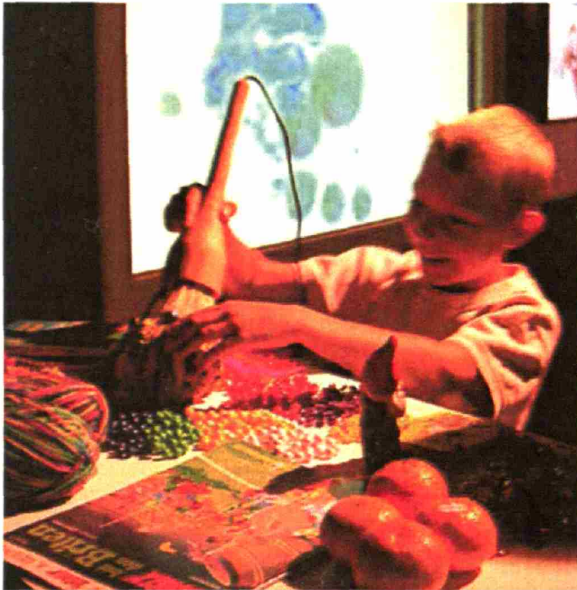
"The World as a Palette" is an ongoing effort to design and develop tools to allow artists to turn their world into a color palette to paint with. Central to this idea is the concept of building visual art projects with elements (specifically, the color, texture, and moving patterns) extracted directly from artists' personal objects and their immediate environment using an augmented paintbrush called I/O Brush. 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 colors, textures, and movements of a brushed surface. On the canvas, artists can draw with the special "ink" they just picked up from their immediate environment.

I describe my journey over the last two years of developing the I/O Brush project originally designed for children, into a suite of tools with complementing palette and an active canvas with portrait history, which could be used by artists and broader audiences to create and share art filled with personally meaningful objects and stories.

---

### 4.1.1. Background

I/O Brush was originally conceived and developed as a new creative learning tool for children. I have installed our first prototype of the I/O Brush system in two kindergarten classrooms and conducted extensive evaluations with kindergarteners. Children quickly grasped the concept of taking elements from their real world and making paintings with them. They have explored a variety of interesting colors, textures, and patterns found in their classroom, and in the process shared their explanations of their work and stories behind where the colors came from with their peers.



A child drawing with I/O Brush at the Ars Electronica Center, using a variety of everyday objects.

Given the success of and the interest generated by the proof-of-concept, I was invited to install an I/O Brush system at the Ars Electronica Center (AEC) in Linz, Austria. This gave me the opportunity to develop I/O Brush into a more robust system to be used for an extended period of time, but also to develop a system that gives artists more control so that I/O Brush can tickle the imagination and creativity of not only children but also adult artists and the more general public.

Finally, my experience developing the system for the Ars Electronica Center exhibition and observing broader user reactions has inspired me to build new features and improvements that led to the current extended system design.

Phase 1: Initial prototyping and observational study in kindergarten classrooms, July 2003 - April 2004. Phase 2: Developing and installing a version for the Ars Electronica Center exhibition, June - September

---

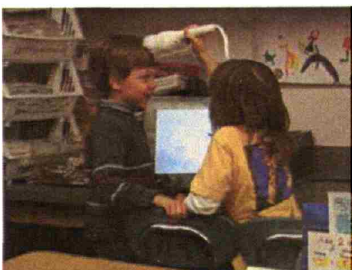
2004. Phase 3: Further design and development - September 2004 – current.

### 4.1.2. Challenge

I/O Brush was originally designed as a tool for children to explore colors, patterns, and movements found in their environment by sampling them from their environment and making visual art with them. As a drawing tool, our first prototype had only basic control. For example, no matter how hard children pressed the paintbrush against the canvas, the ink always came out in a uniformed flow, with constant stroke width. Therefore, the main challenge in phase 2 was to go from I/O Brush having relatively limited expressions as a drawing tool, to a tool that could be used by adult artists and visitors of an art museum.

The Ars Electronica Center in Linz, Austria is one of the first and oldest electronic arts museums, which attracts over 60,000 international visitors every a year. Our I/O Brush installation was scheduled to go on for at least a year. Therefore, our first research prototype, which needed constant maintenance, had to be made into a robust exhibition piece, which could be physically handled by general visitors over the course of a year. It also needed to be simple for the visitors to use, with minimal instruction or none at all.

For phase 2, the AEC exhibition, we had an extremely tight schedule for making our prototype into a museum ready piece, including shipping the equipment, and installing the system at their Linz museum site, all in just 10 weeks. Therefore, we had the challenge to prioritize our design and implementation needs.



The children trying out different colors and patterns they can find in their environment.

### 4.1.3. Solution summary

We designed and built our first proof-of-concept I/O Brush system in the summer of 2003. Our goal at that time was to support children's creative learning process through visual arts project; therefore, installing the system in kindergarten classrooms and observing children's interaction with the system was important. Working with over 40 kindergarteners (ages 4-5) gave us the opportunity to identify both the technical challenges (e.g., more robust sensing inside the brush for sampling various uneven surfaces) and design ideas (e.g., children will be able to run around freely if the brush was wireless) for the next prototype design. It is also in this phase we learned that children reach all over places with I/O Brush to sample colors and patterns in their environment (Figure 2).

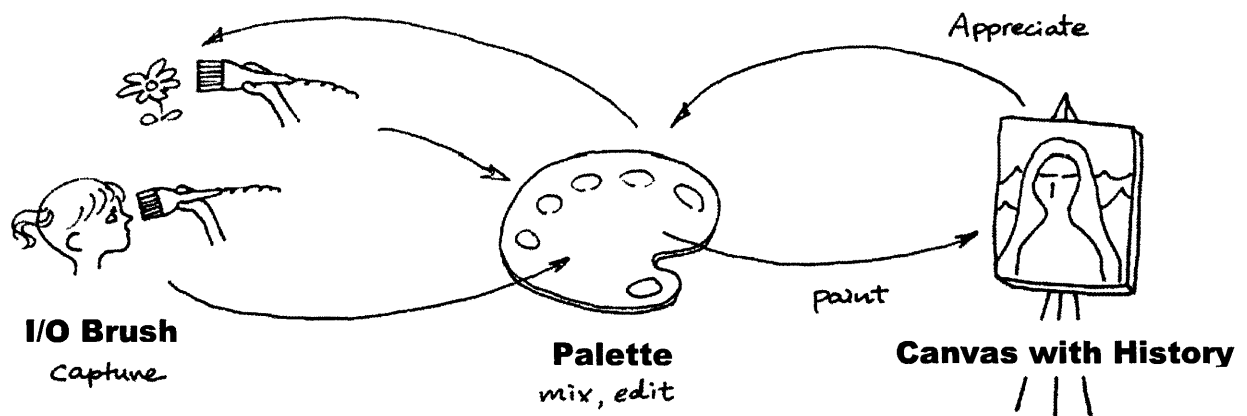
We made countless observations and lists of improvements from our kindergarten study. However, given the time constraints of 10 weeks from the invitation to exhibit and the start of exhibition, we did not

---

have enough time to implement all the features for the next AEC exhibition. As the museum exhibit was to go on for at least a year, our priority in phase 2 was to make a robust, long-term exhibit piece prepared for heavy physical uses, yet at the same time allowing more artistic expressions by museum visitors. After examining several different kinds of sensors and design considerations, an aesthetically pleasing, expressive, and robust I/O Brush was developed.

During the opening week at the Ars Electronica Center end of August 2004, several thousands people (both children and adults) used I/O Brush as an interactive museum piece. The new I/O Brush was a big hit, but we made several important observations that lead to our current design and implementation.

First, compared to our previously observed kindergarten artists, adult artists and visitors at the AEC were much more particular about sampling colors, textures, and movements with I/O Brush. Specifically, they wanted to see exactly what the ink they picked up with I/O Brush looked like before applying that ink on the canvas to draw. In reaction to this, we later developed the concept of a physical palette to accompany I/O Brush. The idea is to have the palette serve a platform to collect and process ink before applying it to the canvas, just as artists do when painting with real water color or oil paint.



Extended "the World as a Palette" system.

Another important observation we made was people's awareness and raised interests regarding the material that made up works of art. By creating paintings with colors, textures, and movements extracted from everyday material or unusual places, and by watching people make creative use of I/O Brush, people showed increased interests in finding out where the material/colors/ink that make up works of art could come from. In response to this, we developed a feature where the canvas can keep a record of where each color used in the portrait was sampled. The brush strokes artists make on the canvas are linked to pop-up movies on the canvas that document where the artists had

---

picked up certain materials. With this feature, the portrait can take both artist and audience back through the journey and reveal the stories behind the special palette of colors.

To summarize, through iterative design and multiple implementations of our project so far, what started out as a system with a single augmented paintbrush has developed into a suite of tools that has the potential to empower child and adult artists by making art charged with personally meaningful objects. The suite of tools allows artists to build their own paint box by taking elements from their world, building a portrait with their personal paint box as the technology automatically records the process, and allowing them to share with the audience both the portrait and stories that represent the process behind the portrait. (The diagram above illustrates the complete system.)



Design evolution of the brush handle.

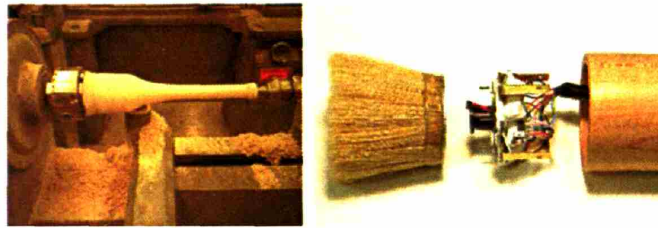
#### 4.1.4. Design Solution details

In this section, we will describe the details of our design decisions and how they were implemented into the system made for the AEC exhibition. We will then describe our current designs motivated from our observations at the AEC exhibition.

##### Simplicity

We have made an explicit decision to make the brush simple with no buttons on the brush at all. In our first prototype for kindergarteners, the brush had three buttons on its handle for changing modes (texture mode, color mode, movement mode). These buttons needed to be pressed only when changing modes. Contact switches were embedded inside the bristles, so when they were "picking up" ink from the surface, they simply needed to press the bristle slightly against the target surface. Children generally got the functions of these buttons but there was some confusion as whether to hold one of the buttons in order to sample at the beginning of play session. To avoid any confusion, for the AEC exhibition version, we decided to remove these mode buttons from the brush and put them on the frame of the canvas next to a "wipe canvas clean" button. This way, the brush remained simple, a tool to dip/"pick up" ink and draw with the ink, just like a regular paintbrush.

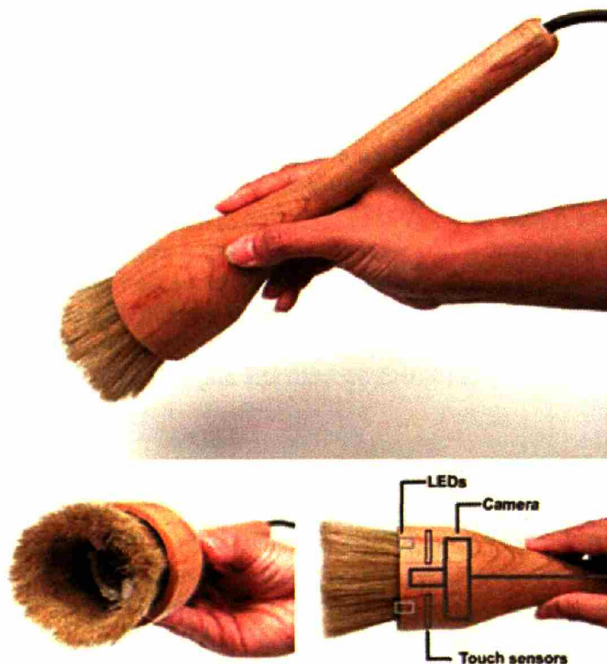
As a museum exhibit piece, the brush had to be robust yet beautiful. We decided to make a hardwood brush handle (turned from a single piece of solid maple wood) with all the electronic components tucked inside (figures below).



The brush handle on a lathe (left) and the video camera and components inside the brush (right).

### Scale, form, and orientation

Though the physical design of the brush was simpler, there were many improvements in both the software and hardware in the brush developed in phase 2. We experimented with different sensing technologies (e.g. contact switches, force sensors, piezo sensors). Force sensors embedded at the bottom of the brush bristles, gave the best result in reading the pressure applied on the brush bristles, without being influenced by the vibrations of the brush as a whole. With the force sensor input, unlike our previous technology with contact switches, we were able to vary the volume of ink flow. The more pressure artists apply, the thicker/fatter the ink flows on the canvas.

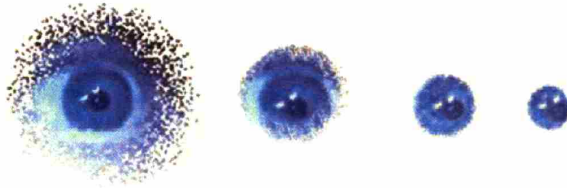


The AEC version of I/O Brush with a maple handle.

---

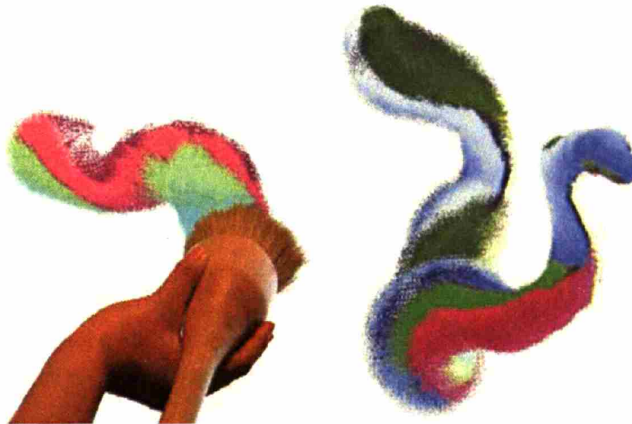
This allowed artists to be much more expressive with their brush strokes and movements.

We also explored a variety of sampling scales afforded by the size of the physical brush. The size of the physical brush bristles could not be too small, as people generally want to sample not just a small dot on a surface but some identifiable patterns and motifs. The brush could also not be too large or too heavy as people (including children) needed to hold and draw with it freely. Our solution was to keep the diameter of the bristle area "eye" size. It may not be big enough to sample a large motif such as a postcard size picture, but it is big enough to sample small units such as eye, letters, etc.



"Eye" ink used with varying pressure.

On the canvas, artists can control the size of the sampled image to be released by how much pressure they apply on the brush. The figure above shows different sizes of an "eye" ink produced by different amount of pressure applied onto the brush bristles.



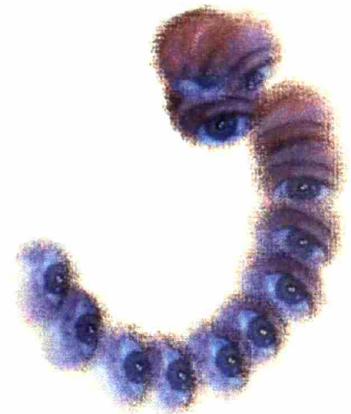
Applying pressure and rotating the brush creates rich stroke variations from a single "ink."

Our final hardwood paintbrush at the AEC was not too big even for small children. Our choice of having a paintbrush as a metaphor for "picking up" instead of using a syringe or pipette worked out well as it invited people to sample from each other's body and faces.

Another interaction we observed at the AEC exhibition was the orientation of the ink. The ink captured by I/O Brush is essentially an

---

image with an orientation. For example, if a person sampled an eye in sideways, the eye would appear on the canvas sideways as well. At the AEC, we observed people trying to turn their ink by rotating the brush as they draw. Yet the ink did not turn with the brush, as there was no mechanism to support that interaction. Our solution was to later add a MEMS-based inclinometer inside the brush. The resulting ink effect created by our most recent version of brush can be seen in the figure to the right. Adding the inclinometer inside the brush yielded more expressive capabilities through the physical interaction with the brush in addition to the pressure.



"Eye" ink being turned while drawing a curve.

For the AEC exhibition, we also increased the scale of the canvas. For our first prototype, we used a 21-inch Wacom(tm) tablet display. It is relatively large for an LCD screen, yet the size of I/O Brush demanded a bigger screen. For example, kindergarteners ran out of space when they were drawing their names on the screen. For the AEC exhibition, we incorporated a much larger 50-inch infrared vision based touch panel over a back projection screen. This scale worked well with the physical scale of I/O Brush. People, even little kids, moved and spread out using the whole canvas.

### Touching the portrait

When we look at painters painting with real paint, they touch the portrait a lot with their hands and fingers, taking a little paint off here or there, and smudging the corner of a stroke. In fact, when we worked with the kindergartener children in phase 1, the children did a lot of touching to their portrait on the LCD screen voluntarily even when there was no interactivity through the screen. In response to this, for the AEC exhibition, we improved our software to allow this "smudging" interaction by sensing when artists touch the portrait directly and smudge.



Smudging paint on the canvas.



Painting and smudging on the canvas.

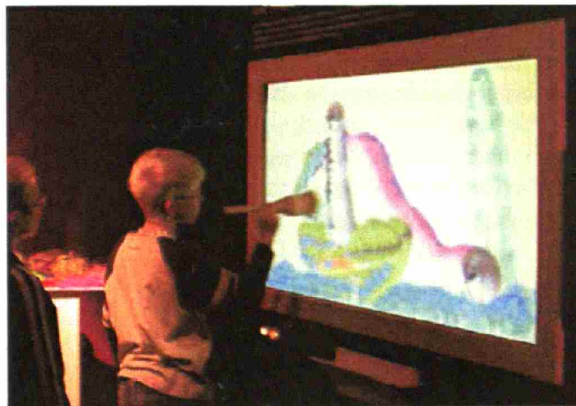


---

Figure above shows an artist at the AEC smudging his paint with fingers. This allowed finer control over their painting, which could not have been achieved with just the brush alone.

### **Offer a place to work with the ink: Palette**

One of the most interesting and important observations we made was how people preferred seeing what they are picking up with I/O Brush prior to painting with the ink on the canvas.



A child artist drawing with I/O Brush at the AEC.

Our own development version of the software had a little window in the corner of the canvas, which served as a monitor for displaying the image being captured by the video camera inside the brush. When we were developing and debugging the software, we had this window open so that we could see the camera inside the brush adjusting/focusing to the surface in real time. While we were at the AEC setting up our system prior to the opening day, we had our "debugging window" open. We had accidentally left the window open for a demonstration with the Art Director at the AEC before the opening of the exhibition. The director liked having the debug



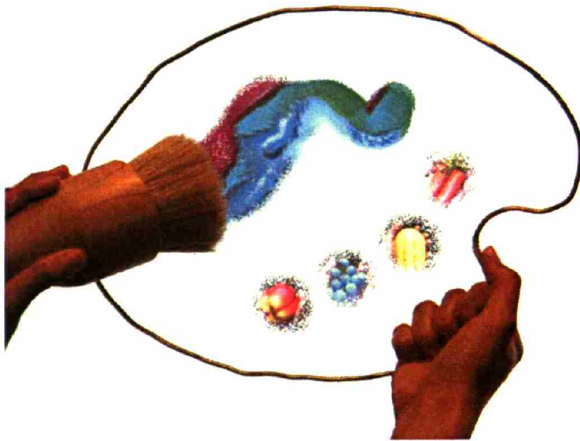
A real time "monitor" window shows what they are sampling.

---

window on the canvas so that people could see exactly what they were picking up from the camera. Over the next few days, it was clear this was a good decision. Several thousands of people used the brush during the opening week at the AEC, and people constantly looked at the monitor window.

However, there was a bit of awkwardness to having a "preview" window on the painting canvas as the window intruded the canvas space. An artist also had to look away from the physical objects they were sampling and look at the screen. Our solution was to provide another space dedicated for such an intermediate process, and keep away from the canvas but closer to the artist. This led to our development of a complementing palette for I/O Brush.

After returning from the AEC exhibition in the beginning of September 2004, we began developing the software of the palette. As of December 2004, the basic function of the palette software is complete and runs on the corner of the large canvas. Once more extensive studies of the functions of the palette are complete, the palette will run on a separate tablet PC that artists can carry around.



The software implementation of a palette shown with wire mockup frame.

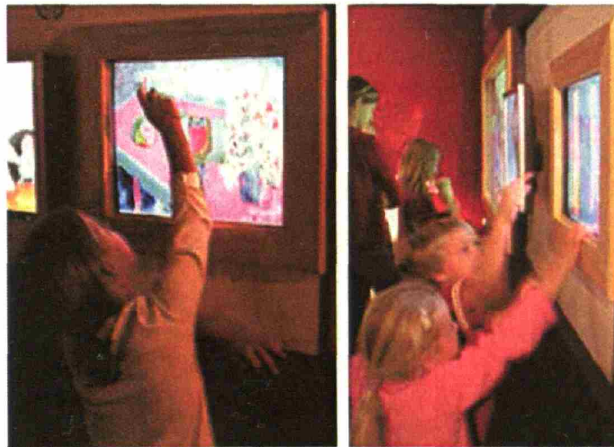
On the palette, artists can now sample and drop off multiple inks on a palette space. In our current prototype, up to 5 different distinctive inks can be stored on the palette so that the artist can go back and forth between these inks. To pick up an old ink, the artist simply brushes over the reservoir and the software assigns the ink as the current ink so that the artist can paint with it. The rest of the space on the palette is dedicated for mixing multiple inks. An artist can "mix" multiple inks by drawing in the space with multiple inks. By layering the multiple inks in the space, the artist can also create new ink. The mixed paint can then be picked up as new ink.

Portrait that tells stories behind the material: Canvas with memory

---

For the AEC exhibition, in addition to installing the I/O Brush and its large canvas, we also prepared a finished art piece painted with I/O Brush. This art piece also was an interactive demonstrational piece where each color in the portrait had an associated documentary film of where the ink came from. When the visitor touched a certain place on the portrait, the film of where the material came from emerged and played over the portrait briefly. For example, the petals of the flowers in a portrait were extracted from a ragged teddy bear. People quickly understood the idea and enjoyed finding out where the ink came from. Moreover, the activity picked the visitor's curiosity to inquire into the materials that made up the art.

This led to our implementation of the canvas that keeps a history of where the inks came from. Our current implementation of this technology works in the following way. The video camera inside the brush constantly streams video to the computer, but only the last 5 seconds before the brush makes the "touch down" is saved in the program. The saved "history" is mapped to the brush strokes on the canvas, so when a person touches it, the history movie plays back on the canvas. The idea is that the history movie captures the source of the ink, and so both the artist and the audience are able to identify where the ink originated from (e.g. one may see the face of a person trying to capture an eye or a button from the person's jacket, etc.) This way, the canvas serves as a place to hold both the artist's portrait and the histories of materials used in creating the portrait.



Children interacting with the portrait with history.

Both children and adults have tried the most recent version of our extended I/O Brush system currently installed at our own laboratory. While we are still in the process of developing our new suite of tools, we were most interested in finding out their uses of "palette" and the "history," the two features that were developed after the AEC exhibition.

---

Children grasped the idea of the palette and used it to both inspect what they picked up and to return to ink that they had picked up previously. They also got the idea of the brush recording the history of where it has been. For example, they made a stuffed animal dance before it was sampled and were happy to see the stuffed animal appear on the canvas dancing when they touched the ink. However, playing with the history function of the tool was so much fun that it sometimes seemed to distract them from ongoing painting activity.

Adults also appreciated seeing the ink they were picking up and being able to go back and forth between the old ink and new ink. Adults used the history function more symbolically than children. For example, one adult embedded a picture of his mouth moving behind a little bug he drew as a surprising touch to the portrait. Another adult drew a window through which the audience could see moving letters/message when they touched the window. We plan to conduct more extensive studies with adult artists over a longer period of time, but we are excited to see the potential the system has in providing artists with multiple layers of canvas where they can embed and construct complex messages behind the portrait.

Although the palette was not yet running independently on a separate computer, it seemed to have just enough functionality to evaluate the interactions and potential design challenges. For example, artists quickly exhausted the five reservoirs on the palette, wanting to keep more individual inks available on the palette. Therefore, the palette needs to be able to accommodate more reservoirs while at the same time keeping a reasonable size to be used as palette.

Some artists also expressed interest in controlling the ink further by adding a water repository on the palette so that they can control the transparency of the ink, just like they would with real watercolors. These accounts also serve as evidence that they were comfortable with the idea of having a palette with I/O Brush.



Touching a particular part of a portrait reveals where that ink came from. In this example, the canvas reveals the color came from a leather shoe.

---

Occasionally, artists touching the canvas in order to smudge the paint were misinterpreted by the system as touching the screen to activate the history to emerge. Currently, we distinguish these two actions just via the touch duration; further tuning of this threshold is needed.

Finally, the following figure is an example of an art piece made with our most recent system. It is noteworthy that the portrait has been made from material found in the artist's office. As the audience touches parts of the portrait and watches the documentary/history, it reveals that such a colorful portrait was put together by a collection of objects surrounding the artist's office.



"Colorful Dream"

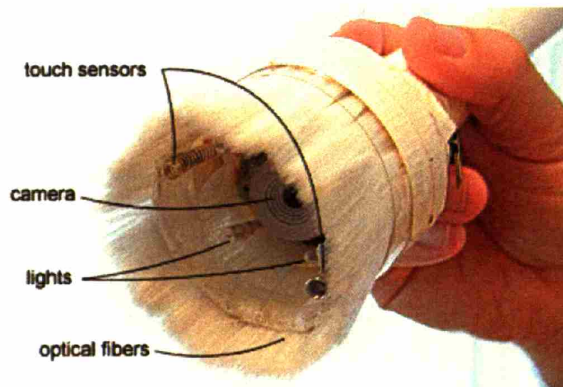
#### 4.1.5. Early Prototype

The early prototype of the brush housed a small (3x3cm) CCD video camera in its tip with supplement light bulbs around it. Spring-based flexible/bendable touch sensors that resemble the property of brush tips were also embedded inside of the brush. When the brush touched

---

a surface, the lights around the camera briefly turned on to provide supplemental light for the camera. During that time, the system grabbed the frames from the camera and stores them in the program. Also, woven into the brush tip were 150 optical fibers. Once the “ink” was captured, the fiber optics lit up, i.e., the brush tip was lit up, to indicate that the brush had picked up ink from that surface.

For the canvas, I first used a large Wacom Cintiq screen with a built-in graphics tablet. The coil of the Wacom pen tip was embedded inside the 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 let the child draw with that special ink s/he had just picked up. The brush had three modes for picking up ink: Texture, Color, and Movement. The Texture mode captured a snapshot of the brushed surface, which consists of one frame. The Color mode computed the RGB values of all the pixels in the captured frame (resolution of 640x480) and returned the most common RGB value so that the child could draw with a solid color. The Movement mode grabbed up to 100 consecutive frames of the brushed surface and let the child draw with the movement. When the child moved the brush across the canvas, the system dropped off the successive frames, but the end of the stroke showed 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 was masked to appear as a round-shape and its translucency level was set to a slightly lower value so that the child could layer ink like water color by quickly moving the brush, or paint with thick color by slowly moving the brush. The brush allowed the child to paint with the same ink indefinitely until s/he picked up different ink. The modes were switched by the simple turn of dial on the neck of the brush. Finally, the 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 the brush, giving it the authentic feel of a soft brush tip.

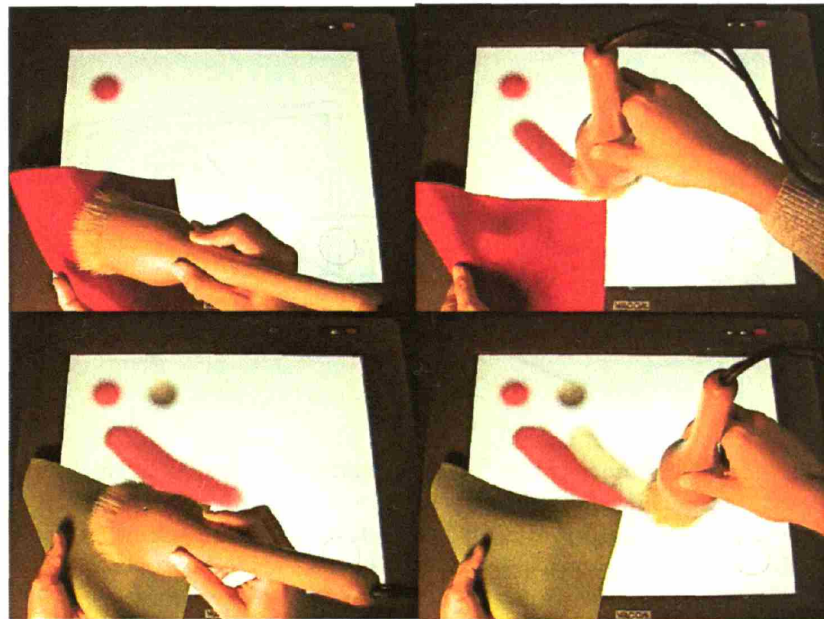
---

## 4.2. The Palette

In order to provide a platform for the artists to assemble elements taken from their world without spoiling the ongoing portrait on the canvas, a physical palette accompanied the brush. On the palette, artists may collect multiple colors, textures, and movements they have picked up, prior to applying them to the big canvas. This resembles the real painting activity closely while allowing artists to explore combination of their familiar elements to achieve interesting effects. The physical palette may also serve as a platform for artists to share and exchange their special inks with collaborating artist nearby.

The palette was implemented as a Wacom™ Cintiq tablet LCD connected to a second PC via local network to communicate with the main computer. The Wacom pen tip's coil was attached to the tip of the I/O Brush so that the display can detect the movement of the brush.

In the current implementation, the palette can collect up to 10 different inks in its reservoirs. The artist can switch between the 10 available inks on the palette as s/he paints on the canvas. When the artist picks up the 11<sup>th</sup> ink from the environment, the last active ink is replaced with the 11<sup>th</sup> ink. This 10-ink-limit could be removed by for example a scroll button on the side of a palette, allowing the artist to go further back in his/her palette collection history.



---

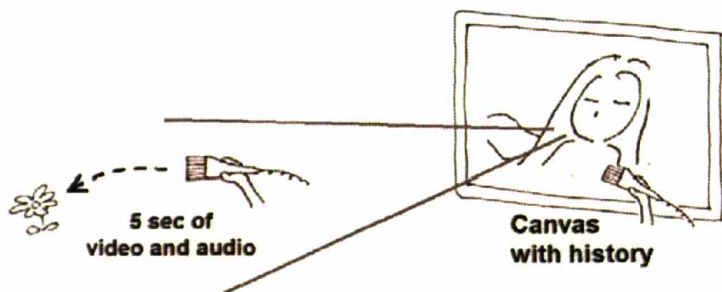
On the palette, the artist can also mix multiple inks. The “mixing” happens in the effect of grabbing a particular part of drawn surface. For example, if one takes a red, a green and takes the middle, it would produce a stripe made of the two as seen in the following illustrations.



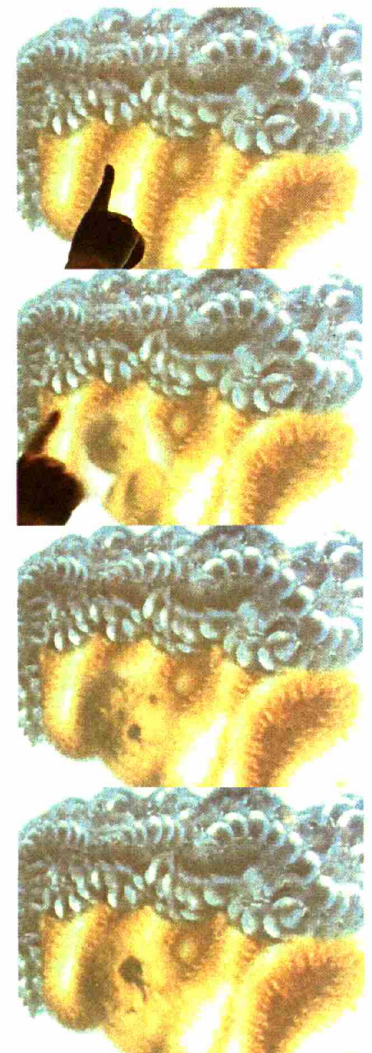
A new ink could be created by merging two different ink.

### 4.3. The Canvas with History

The canvas serves as a space where the artist builds her portrait, but it also serves as a space where the artist and audience can peek into the history of the portrait. The surface of the canvas is touch sensitive (via a touch screen overlay on a back-projected screen) so that when the audience touches a certain part of the portrait, the canvas ‘zooms in’ to the touched part and plays back a movie that was automatically recorded during the artist’s creation to document the process. In other words, each brush stroke on canvas has a sort of ‘hyperlink,’ which can take the audience onto a journey to where this specific element has originated.



To document the process of where the artist takes her ink from, the video camera inside the brush is active while the artist works with the brush. However, only the last 5 seconds before the artist brushes over the surface is be stored and linked to the ink. These 5-second “documentary” movies can be viewed on the canvas when the brushstrokes becomes activated by touch. This way, the canvas serves as a placeholder for both the artist’s portrait and the histories of materials used in creating the portrait.



Touching the canvas reveals where the colors came from.



---

## 4.4. Synergetic Creation

While the visual history is recorded, the system also records associating ambient sound via the microphone inside of the brush. This recording of the ambient sound also contributes to supporting synergetic creation by children and adult artists.

Synergy of creation happens when one form of expression augments another form of expression, and they together make sense, or rather, disambiguate each other and create an expression that is more than the sum of both. Typically (but not necessarily), the two expressions are not in the same modality. For example, a child may make scribbles on the canvas. The scribble may only make sense to the viewer when it is accompanied by the artist's verbal rendition of a motor bicycle sound (which in itself may not be recognizable as a motor bicycle): the visual and auditory expressions individually may not make sense, but they become clear when put together. This synergetic merge of two modalities may be achieved using I/O Brush as I/O Brush records sound while recording the history.

---

---

## 5. Evaluation

Evaluation of my system was carried out with two different groups — kindergarteners and adult artists.

With kindergarteners, my investigation centered around three questions:

1. How does the tool support children's creation?
2. How does children's expression change over time?
3. How does the tool influence the way children interact with the world?

In order to investigate the system's potential to support children's synergetic art creations, and to observe how children's expressions change over time, I conducted a five-week longitudinal study in a kindergarten classroom where children worked with the I/O Brush system a couple of times a week for five weeks. In order to investigate the third question, I have designed a series of questionnaires that asked children about art, objects, and their environment.

With the adult artists, I was concerned with evaluating the tool's potential as a new drawing tool for artists to expand their work. What kind of new portraits and new process of creation would they come up with this new tool? Evaluation with adult artists consisted of an informal observation at the Ars Electronica Center at Linz, Austria where I/O Brush was installed as an interactive exhibit, and an intensive case study with a watercolor artist who is also an art therapist.

### 5.1. Kindergarteners

In the year 2003, an informal observation using the very first prototype of I/O Brush was conducted with kindergarteners in their classrooms. As discussed in the previous chapter, the study provided valuable lessons about kinds of design and development needed for the next system.

Although over 40 children played with the system in 2003, it was a short-term evaluation. Each child in the study worked with the system only once and therefore, the study did not provide an opportunity to observe how children's creation with the tool may change over time.

A new study was designed where children got a chance to use the system for an extended amount of time. In order to compare the effect of I/O Brush, I have also decided to design an empirical study.

---

### **5.1.1. Study Design**

The kindergarten study took place at the Maria Baldwin School, a local public school in Cambridge, Massachusetts. Kindergarten classroom, Room 104 by Mrs. Janice Lund, became the test classroom. Mrs. Lund's kindergarten class consisted of 20 children (aged 5 to 6 at the time of the study). The children came from diverse backgrounds, both ethnically and socio-economically.

Permission letters were sent out to the parents of the 20 children a few weeks prior to the beginning of the study. Parents of 19 children out of the 20 have agreed to have their child participate in the study.

First, the 19 children who signed up for the study needed to be divided into two groups, the I/O Brush group (experimental group) and the control group. As discussed in the background section, children have a variety of work styles. Some are committed "visualizers" and some are "dramatizers" (Gardner, 1982). In order to distribute different type of performers between the two groups (i.e., to avoid having concentrated visualizers or dramatizers in one group), I have decided to do an initial drawing task with all 19 children where I could observe their performances and roughly identify the type of performance style each child has.

After the initial drawing task, 10 children were assigned into the I/O Brush (experimental) group and 9 children were assigned into the control group. With help from Mrs. Lund and her assistant teacher, the 10 children in the I/O Brush group were further paired up with a friend, resulting in 5 pairs.

#### **Classroom space**

Mrs. Lund's kindergarten class was physically divided into different corners/areas such as "Math Area," "Science Area," "Quiet Reading Area," "Doll Corner," "Block Area," etc. Kindergarteners' daily activities consisted of performing a variety of tasks such as counting a number of beads in a box, pattern drawing, spelling exercises, etc. in these different corners of the classroom.

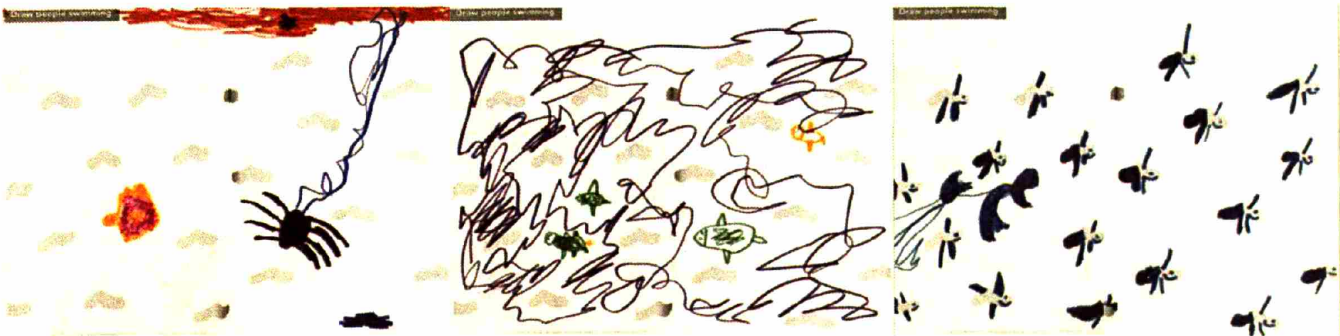
I/O Brush was installed in one corner of the classroom, an unused "computer area" with broken computers. In the classroom, I/O Brush was called "Magic Paintbrush" among the children and the teachers, and the corner of the classroom became the "Magic Paintbrush Area," one of the activity areas in Mrs. Lund's classroom.



### Schedule and Curriculum

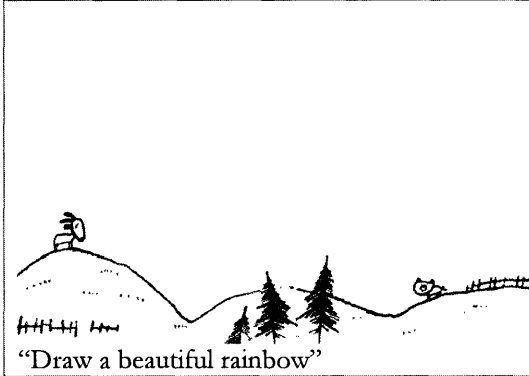
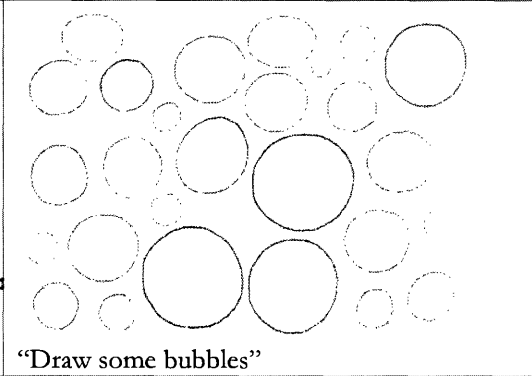
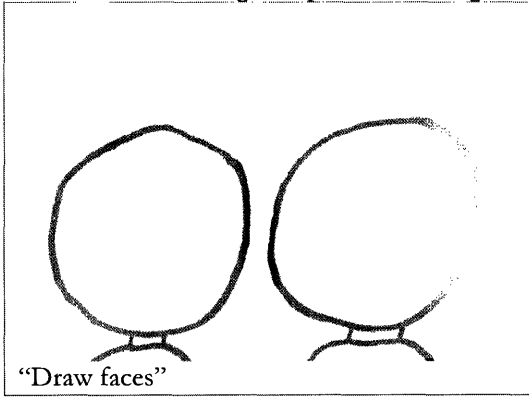
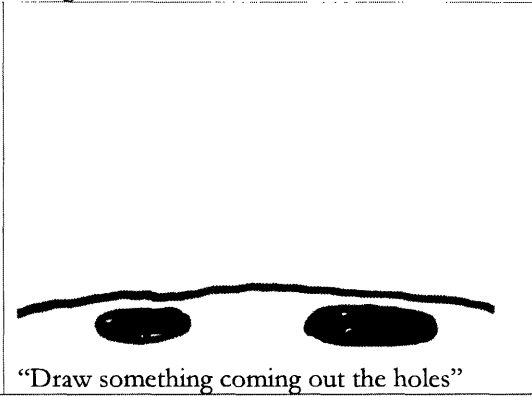
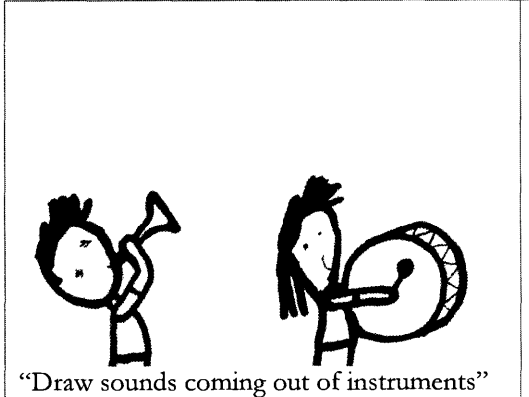
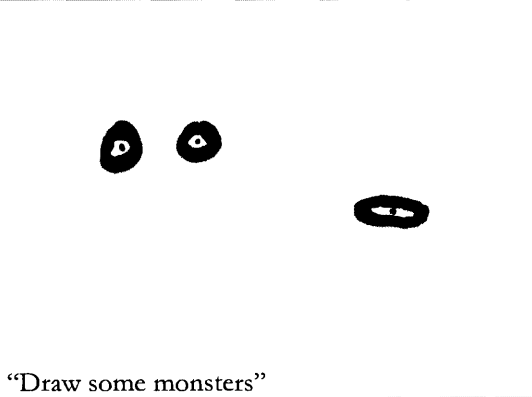
Designing a five-week longitudinal study required a curriculum that kept the study moving forward. Instead of having children work with a blank I/O Brush canvas every time and have them produce a random number of portraits, each child worked on three pictures per session—two “theme” pictures with some pre-made drawing prompts, and one “free style” that started with a blank canvas. Each week, children had one or two sessions with his/her partner. Therefore, each child worked on roughly 3 to 6 drawings per week for 5 weeks.

The “theme” pictures were borrowed from illustrations made by Taro Gomi, in his book called *Scribbles* (2004). The drawings in Gomi’s book elicited certain theme (e.g., “Draw people swimming!”) but they were open-ended so that children were invited to draw anything they want. The following pictures illustrate three children working on the same prompt but each child producing different drawing.



Three different kind of drawings produced by three different children who started out with the same prompt of “Draw people swimming!”

The “theme” pictures were also helpful in structuring the course of the study for the 5 weeks. Rather than introducing all the features of I/O Brush to children at once, each feature was introduced with an example in these theme pictures. The following table shows the designed curriculum and the overall schedule of the study:

Week 0	Pre-study questionnaires
Week 1	<p><b>Introduction to I/O Brush with basic color sampling</b>  Children work with the basic idea of capturing and painting with colors using I/O Brush.</p> <div style="display: flex; justify-content: space-around;"> <div data-bbox="340 363 865 737">  <p>“Draw a beautiful rainbow”</p> </div> <div data-bbox="865 363 1394 737">  <p>“Draw some bubbles”</p> </div> </div>
Week 2	<p><b>Introduction to “movements”</b>  Children draw moving face parts or moving lines using the movie mode.</p> <div style="display: flex; justify-content: space-around;"> <div data-bbox="340 867 865 1262">  <p>“Draw faces”</p> </div> <div data-bbox="865 867 1394 1262">  <p>“Draw something coming out the holes”</p> </div> </div>
Week 3	<p><b>Introduction to “sound” and “history”</b>  Children work with recording sounds, drawing, and playing back the sound.</p> <div style="display: flex; justify-content: space-around;"> <div data-bbox="340 1392 865 1787">  <p>“Draw sounds coming out of instruments”</p> </div> <div data-bbox="865 1392 1394 1787">  <p>“Draw some monsters”</p> </div> </div>
Week 4	Free style
Week 5	Free style
Week 6	Post-study questionnaires

---

Total duration of the study was approximately 6 weeks. The children in the control group had the same schedule for the “pre-study” and “post-study” questionnaires, but they had to wait to play with I/O Brush until when the experimental group children were done with their I/O Brush session.

Two video cameras were used to record the drawings and activities of the children. One was installed behind the projection screen to capture their ongoing drawings, and another was used to follow children around the classroom.

### **Questionnaires**

In addition to observing children’s use of I/O Brush and how their expressions with I/O Brush change over time, I was interested in observing whether or not the experience with I/O Brush influenced children’s perception of the world.

In this effort, I designed a series of questionnaires that asked how children perceived their environment (e.g., their own classroom, their own room at home) and objects they encounter everyday (e.g., food, natural material [such as wood], architecture [houses]). The questionnaires were given out during the pre-test and post-test periods to both the I/O Brush group and the control group. The following sections describe further details about the questionnaires.

#### ***Questions about their physical environment:***

In order to investigate how children describe their surroundings and whether or not this changes after the experience with I/O Brush, the children were presented with the following questions before and after working with I/O Brush.

**“Can you describe your own room?”**



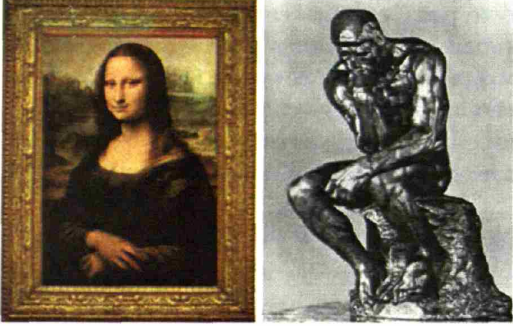

**“Can you describe your classroom?”**

The children’s answers were videotaped for analyses.

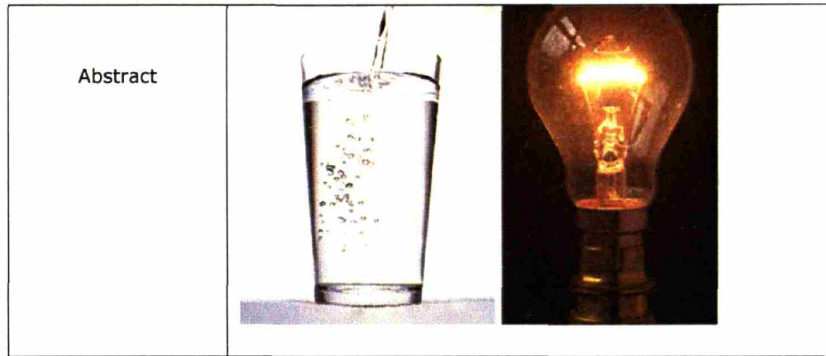
#### ***Questions about material:***

Would the children who used the I/O Brush system have an expanded perspective behind the creation even outside of the domain of art? In order to investigate whether or not children’s perception about material change, a series of questions about where objects and materials around them could come from, were presented to the children.

14 pictures of different objects were presented to the children and they were asked about the material, process, and possible application of each object.

Food	
Building	
Art	
Nature	





For each picture, children were asked each of the following 7 questions. The questions are modeled after Gardner’s experiments on children’s perception of art (Gardner, 1982).

“What is this?”	Questions about the <i>object</i> itself.
“Where does it come from?”	
“What is it made of?”	Question about the <i>material</i> .
“Who made it?”	Questions about the <i>process</i> .
“How is it made?”	
“Can you make it yourself?”	Questions about <i>applied use</i> .
“What kind of things can you do with this?”	

The children’s answers were tallied, and the quality of answers were scored and compared between the two groups.

**Questions about colors:**

Finally, at the end of the 5th week, children in both the I/O Brush group and the control group were asked about colors and where the colors they see come from. They were shown the copy of a painting by Matisse and asked what colors they see and where the colors could come from.



### **5.1.2. Kindergarten Results**

In this section, I report a summary of findings over the five weeks with the children.

#### **Mastery of Tool**

The children immediately understood the basic idea of working with the I/O Brush system, picking up colors and painting with the colors, to using the palette. The advanced features, such as capturing movements, history, and sounds, were introduced to the children in the following weeks and gradually introducing the additional features seemed to help children understand them easily. In the following sections, I describe some of the issues that came up during the children's mastery of different aspects of the system.

#### ***The Brush***

As soon as the brush was passed on to the children, the children's eyes were everywhere—searching for things in their environment to try out and immediately reaching out to try them. They found the idea of picking up the paint and drawing with the paint easy to work with.

The drawing techniques of the brush did take some time. For example, the speed with which children moved the brush was an issue. Children had the tendency to move the brush quite fast on the canvas with uneven pressure. In such cases, the brush left individual dots on the canvas instead of steady flow of ink. Some of their early paintings accidentally resembled impressionist-style paintings consisting of many

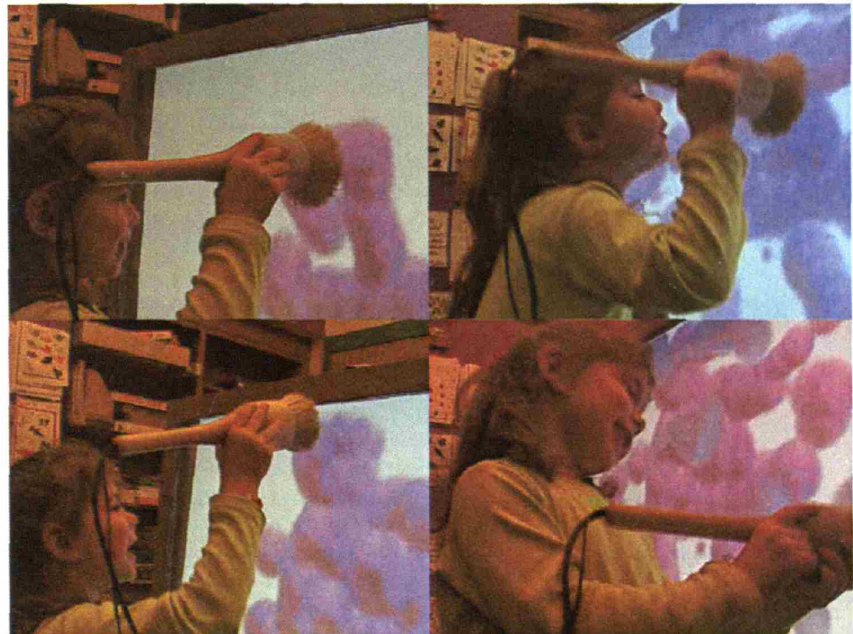
---

dots. Over time, children seemed to learn to control the speed, as they watched the flow of the ink vary depending on the speed of their strokes.



Unlike the first prototype, the new I/O Brush was fashioned with force sensors at the bottom of the bristle. This provided greater expressivity with ink flowing out with different sizes. Controlling the amount of pressures to be applied on the brush also took some practice for some children.

Perhaps, the children were not used to drawing on a vertical canvas with a big paintbrush. Over time, the children learned to physically control the brush quite well.



I/O Brush uses the physical pressure applied on the bristle as a trigger for the embedded camera to take a snapshot. Instead of the classic

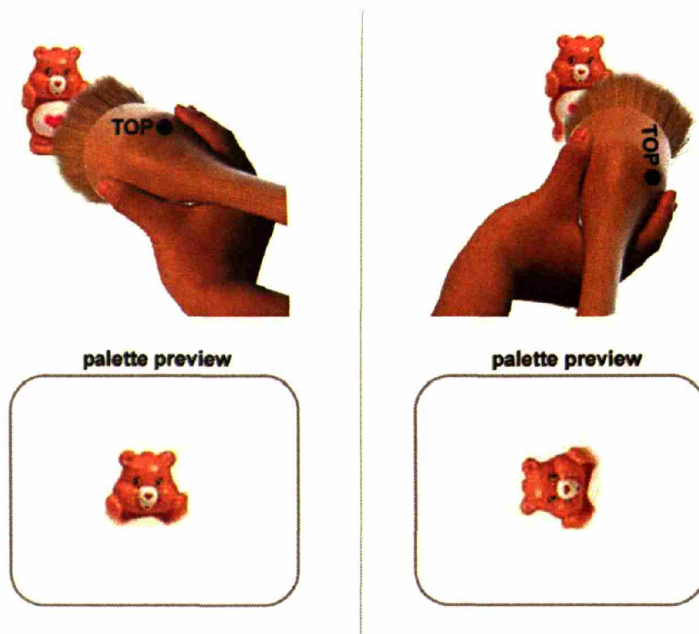
---

approach to getting the ink by pressing the target surface with the brush, some children found out an alternative way to pick up attributes from their objects. Some children discovered by themselves that the pickup can also be triggered by squeezing the bristles. The following examples illustrate their use of the brush.



Zoe (pictured above) held the brush with the bristle side up and squeezed the bristles to take a snapshot of her object. She also used the "palette" to monitor what she is picking up.

This method gave the children more flexibility for picking up attributes from uneven surfaced objects.



The camera inside of the brush had the relative "top" in taking an image. This relative top was indicated by a little dot on the brush. Most children ignored this mark, but some children did carefully

---

position the brush in the right orientation before sampling the ink, so that they could align what they were picking up in the correct orientation.

As the brush was equipped with an inclinometer, one could also turn the ink on the canvas by physically turning the brush. Some children approached getting the right orientation this way, by turning the ink directly on the canvas.

### *The Palette*

The palette helped the children navigate their activities on different levels. On the first level, it was helpful as a “preview” window of what kind of ink they were picking up. As children saw the preview, they confirmed by saying, “Yes, I got it!” or “No, I’m actually going to get a different color.”

The palette also became a place where they could show each other their personal inks they collected. The palette became a reference point where they asked and explained to each other, “Where did you get that color from?” “I got this from that yellow puzzle!”



When the items they wanted to work with were far to reach, the children collaborated by taking the divided role of “ink taker” and “ink monitor.” For example, one child would pick up from an object away from the palette and another child would tell his partner, “Yup, you got it! I see it!” by looking at the palette. Children were willing to work together this way, but this also meant that they did not always have total control over what they were capturing with I/O Brush. I will come back to this issue in my future design discussion, later in this thesis.



The children helped each other in finding the colors they needed for their portrait. Sometimes the colors they were looking for were so close to them, they needed another's perspective in finding it. For example, Charlotte said, "I need reddish color..." Her friend quickly pointed out that she was wearing some:



"I need the reddish color..."



(Her friend gives her a hint.)



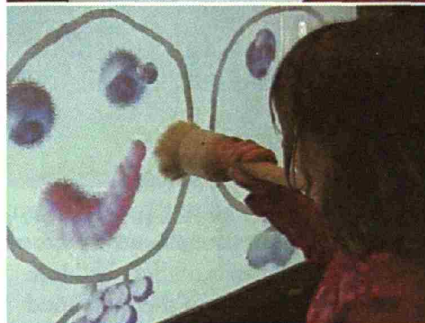
"Oh."



(takes the red from her clothes)



(checks the color on the palette)



### ***Magic Fingers***

The I/O Brush canvas is a touch sensitive screen, so once the paint was applied on the canvas, the children could also touch the canvas with their fingers and smudge their paint. The smudging function was introduced to the children during the first week of working with I/O Brush.

Interestingly, one pair of children thought that the I/O Brush makes their fingers magic and that is how they can smudge the paint with their fingers. Though not introduced to the smudging function this way, they always put their fingers into the brush before smudging. One time, I did intervene (as I was afraid they were poking at the camera inside the brush) and told them they do not need to stick their fingers into the brush in order to smudge. Yet they continued to believe that they had the magic power on their fingers from the Magic Paintbrush. They proudly confirmed with each other next day, "I put both of my

---

fingers (right and left index fingers) into the magic paintbrush and I get the magic on both of my fingers!”

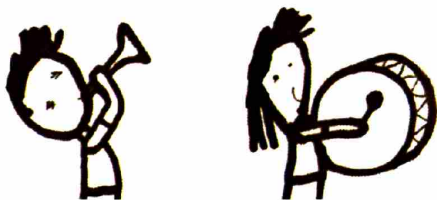


### ***Sound and History***

The sound and history recordings were one of the most complex features of the I/O Brush system, so they were introduced to children during the 3rd week after all the other basic functions were introduced to them.

In the week 3, the I/O Brush system was also moved to a private room adjacent to Mrs. Lund’s classroom, which was occasionally used by the school’s literacy specialist. This provided a quiet space where children could work on their sound without the distraction from the quite loud ambient sound of classroom.

The sound function was demonstrated to the children using the “Draw the sound coming out of the instrument” theme picture:



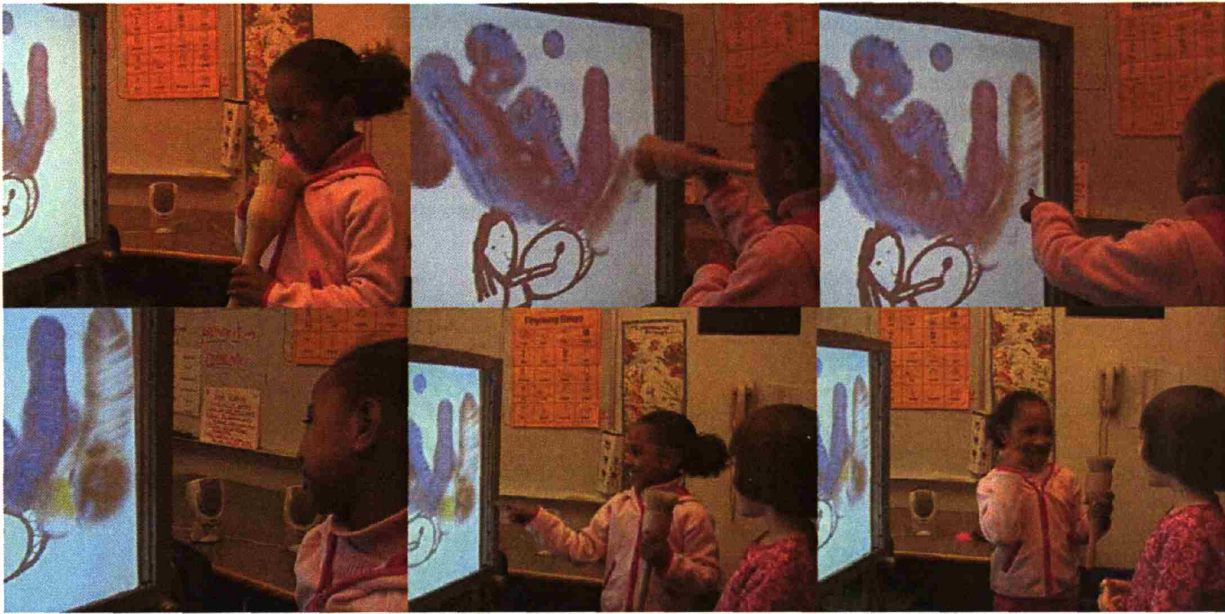
“Draw the sounds coming out of these instruments!” The drawing prompt used to introduce the sound recording function of I/O Brush.

Children understood the idea of recording sound and video associated with the ink they pick up. However, recording only 10 seconds of their talking was a bit difficult for them to understand. Some children talked



---

much longer than the 10 seconds and therefore, some of their recordings were cut off by the system. The children were quite content with seeing their moving images and voices appear on the canvas, even when they were cut off. When they found their voices were cut off, they usually tried the second time.



Pictured above: Capturing special ink by putting the sound and visual info into the Brush. Drawing with the brush transfers her activity on the canvas. When that part of the drawing is touched, the visual with associated sound comes up on the canvas.

### **Mastery of Expressions**

By the end of the 3rd week, all the features of I/O Brush were introduced to all the children. It was also the end of 3rd week when different individual styles of working with I/O Brush emerged. In this section, I give some examples of children's performance styles.

#### ***Visualizers (Georgia and Lilly)***

Georgia and Lilly were most concerned with the visual aspect of their project. When they worked with sound during the 3rd week, they seemed to have enjoyed working with this feature. But later in the same session, they quickly focused back on their visual drawings. They did not actively record any more sound into their ink and when the sound and history were accidentally triggered on the canvas later, they waited until the playback ended and they continued with their drawings.

---

When they made a mistake on their drawing, they picked up “white ink” from the palette and carefully removed the unwanted part of their drawing. They also worked on several versions of their drawing. They were the ones who asked the question, “Can I do mine from the beginning again?” the most. They asked for a blank canvas after they had worked on their drawing for some time, sometimes abandoning their beautiful work.

For example, Georgia, age 5, who was one of the youngest children in the group, painted the following picture. She then suddenly stopped and said, “I messed up!”



Georgia asked for a blank canvas and started her picture from scratch. Then she finished the beautiful portrait pictured below.



---

As they had worked on different versions of their pictures, Georgia and Lilly produced the highest number of drawings.

Georgia and Lilly were also very particular about the kind of ink to be picked up. They often had debates over their colors, such as “That’s not blue, that’s green. Greenish blue.” Over time, they also developed a certain model about what kind of objects gave them the best results for the colors or patterns they were looking for. For example, they found out certain types of textures produce different shades of colors. They observed the black from their stuffed panda bear produced more grayish black than the black from a plastic bucket. Over time, they seemed to have more knowledge about what kind of texture produces what kind of shade, and chose different textured objects according to their need.

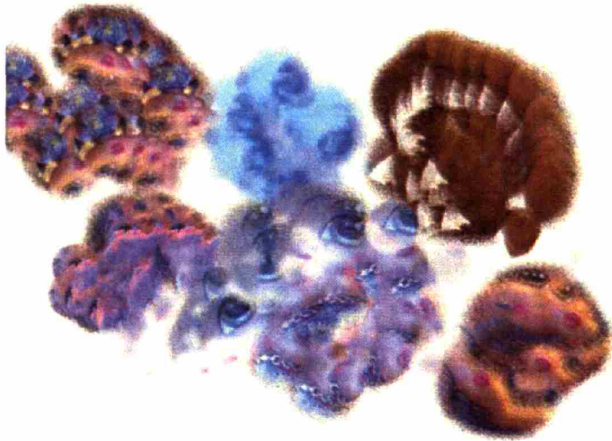
### ***Dramatizer/Verbalizers (Alanna and Zoe)***

In contrast to the visually oriented Georgia and Lily, Alanna and Zoe focused on the verbal aspect of their creation. For Alanna and Zoe, I/O Brush was a tool to act out their play scenes and put them on canvas for their ongoing play and reflection. For them, the main goal was not a visual painting, but a canvas full of their acted out audio-visual scenes using their favorite toys.



Alanna, who usually assumed the director role, often set up a scene with her favorite dolls and little toys on a table in advance. After she had set up a scene, she brought the I/O Brush and started narrating her play scenes. When she was done narrating, she squeezed the I/O Brush bristles to take a final snapshot of the scene, and then she moved to the canvas to paint with her recorded ink.

The pictures by Alanna and Zoe usually resembled collections of blobs and squiggly lines (quite a contrast to Georgia and Lilly’s drawings), but their drawings were to be appreciated from a different perspective. That is to touch and reveal the dialogs and acts embedded inside their portraits.

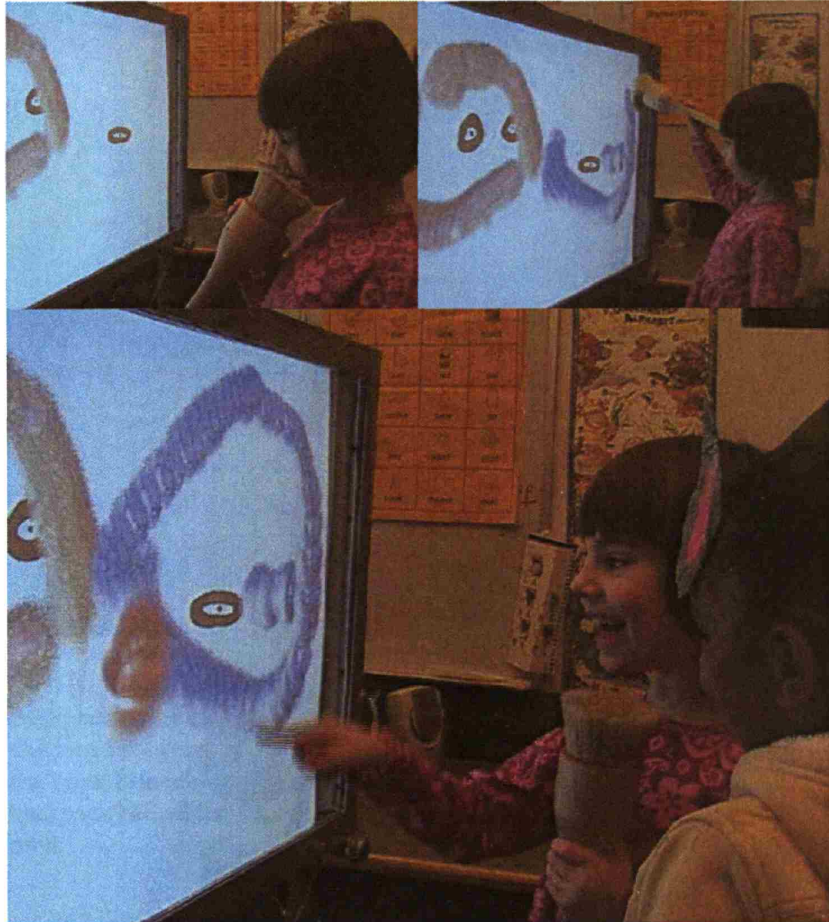


Since the 3rd week, when the sound and history functions of the brush were introduced, Alanna and Zoe focused only on these features. Alanna also directed her partner, Zoe, to say certain words during her act.



They touched different parts of their portrait to play back their recorded video and audio. As they heard and watched their playback, they incorporated them in their play. “Did you see that Baby? That was for you!” as they talked to their dolls.

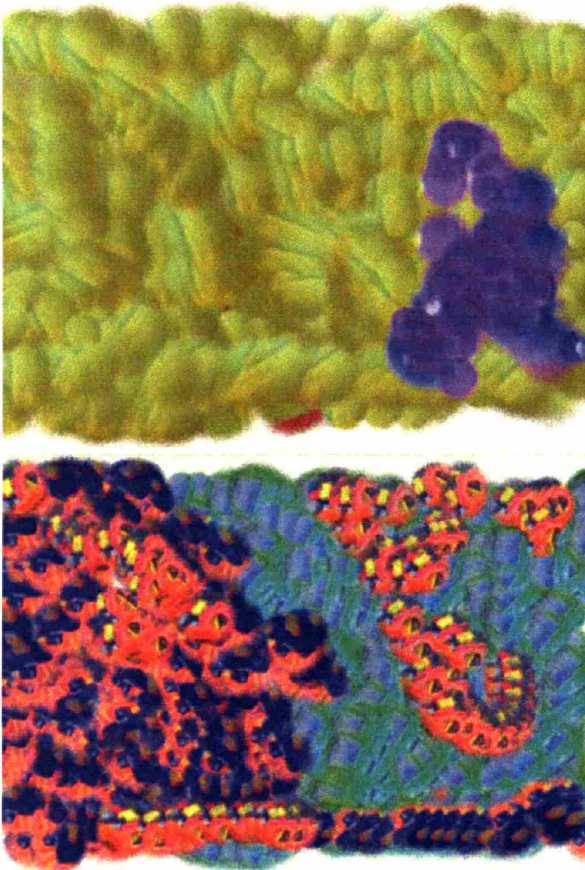
Zoe, who was a less directing personality, worked more privately during her turn, often recording her own quiet singing voice into the brush.



Pictured here is Zoe, recording her moving/singing mouth to complete the picture of "monsters."

Another dramatizers used their canvas to play out their ongoing play of superhero powers. After the 3rd week, Emanuel and Eric established their own style, which was to fill the entire canvas with colors. It did not matter which "theme" they were originally working with. At the end, they wanted to have a huge canvas filled with the colors they picked up.

They announced to each other at the beginning of their session that they are filling the entire canvas "so that no one else can draw on the canvas!" They were also the pair who was fixated onto Smudging, fueled by their "magic power".



### **Personal Objects and Peer Culture**

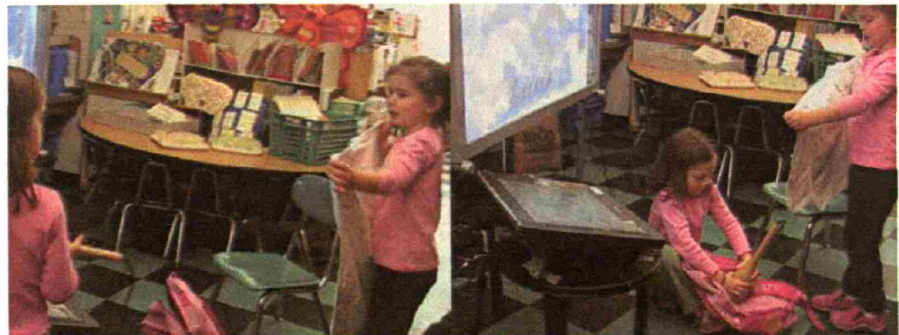
Children spent about half of their time looking for colors, patterns, and textures in their environment. As the brush was tethered to the canvas, they could not run around the classroom with it. But the children usually went to get the item they wanted in the classroom and brought the items to the I/O Brush area to paint with them.



Backpacks were one of the most frequently used personal items. The children also were well aware of who owned which backpack. Among the boys, Prince's backpack was the most popular one, because his backpack had all the super heroes (Spiderman, Batman, and Superman) on it.

### *Lilly's blankie*

Some of the items children used were very personal items. For example, while Georgia was painting, Lilly brought her own blanket from her cubby and asked Georgia, "Do you want to use my blankie?" "Blankie is my favorite thing in the whole world!" In an effort to make her personal item become part of her friend's painting, Lilly tried hard to explain which features of her personal items her friend might want. In spite of her effort, Georgia said, "No thanks!" because she was busy painting with her own backpack.



---

Some children were quite content with the colors available right next to them. Their cubbies offered a palette of winter coats colors.



### *Inbar's picture*

Inbar, who had just turned five in January 2005, was the youngest kindergartener in the I/O Brush group. When she worked with the "Draw faces" picture, she drew a face of a boy and a girl. When drawing the boy's face, Inbar borrowed colors from her classmate, Tamesghen. She borrowed colors from Tamesghen's shirt to draw the boy's clothes and Tamesghen's hair to draw the boy's hair. The eyes for the two faces were taken from her own eyes, however. After drawing the girl, she drew a little heart between the two figures (a little pink blob in the figure below). And then, as she pointed at her picture, she told her friend, Charlotte, "This is me and Tamesghen in love!" loud and proudly with a big smile. Charlotte took a moment to respond and said, "You mean, you guys are friends, right?" Inbar nodded with a big smile.



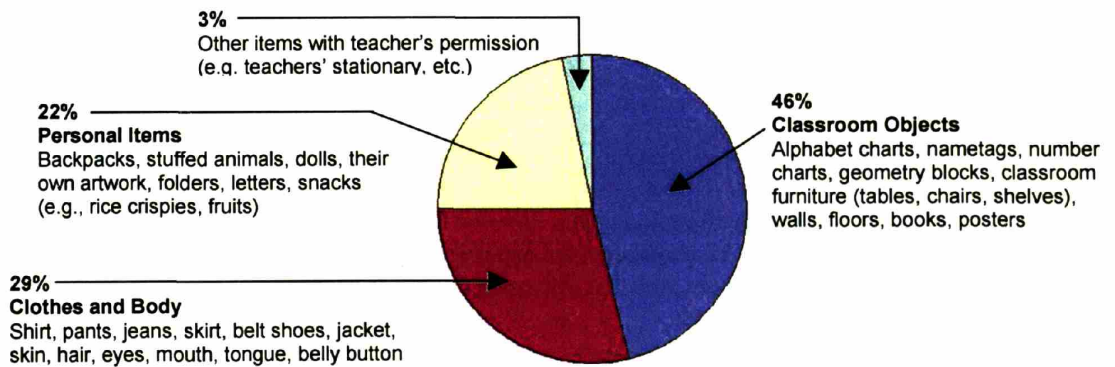
"I'm going to make you and me!"





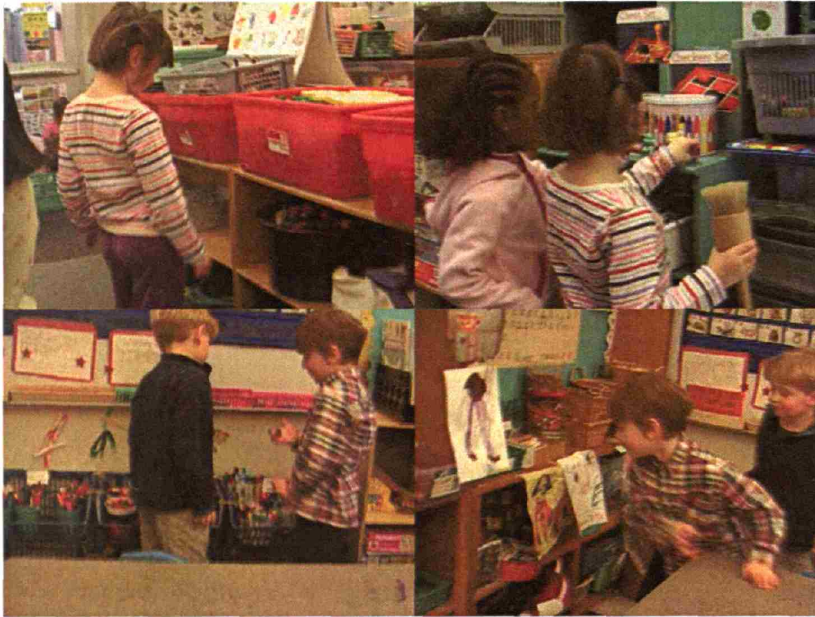
"Me and Tamesghen in Love" by Inbar

The following table summarizes the kind of items used by the children.



### Looking at the Environment Actively

A lot of actions happened behind the scenes of creating portraits with I/O Brush. Children ran around the classroom searching for colors and patterns for their portraits. Almost half of the children's time working with I/O Brush was spent on exploring objects in the classroom. Did such experience of looking around their classroom influence the way they looked at the colors, objects, and materials in their environment?



As described in the previous sections, the children in the I/O Brush group were asked a series of questions about their environment, materials, and colors, both before and after working with I/O Brush. The children in the control group were asked the same question during the same week as the children in I/O Brush group were interviewed.






### ***Describing the environment***

In order to investigate how children describe their surroundings and whether or not this changes after the experience with I/O brush, the children were presented with the following questions before and after working with I/O Brush.

**“Can you describe your own room?”**

**“Can you describe your classroom?”**

Two distinct styles in answering these questions were found in both the I/O Brush group and the control group. One style was to focusing on the visual aspects of their space in giving their answer. For example, the children who were visually oriented described their environment as having, “Twenty cubbies, red mats, book shelves, chairs, tables...” giving a list of items they saw in their environment. Another style was to focus on the activities that happen in their environment. For example, the children who used this style described their environment as having, “morning tasks when you first come to school, and then music class, and then gym class, and then choice time...”

Food	
Building	
Art	
Nature	
Abstract	

The visually oriented children who focused on the visual aspects in describing their environment in the pre-study interview described their environment exactly in the same way in the post-study interview. The activity-oriented children who described their environment based on the ongoing activities in the space also kept their style and described their environment in the same way in the post-study interview. There was no significant qualitative difference between the I/O Brush group and the control group. Working with I/O Brush did not actively change the way the children describe their environment verbally.

### *Describing materials*

During the pre- and post-study questionnaires, the children were also asked to describe materials in their environment in more specific way. Total of 14 pictures (two pictures from each of the five categories shown left) were presented to the children in sequence and they were asked questions about the material, process, and possible application of each object.

For each picture, children were asked each of the following 7 questions modeled after Gardner's experiments on children's perception of art (Gardner, 1982).

"What is this?"	Questions about the <i>object</i> itself.
"Where does it come from?"	
"What is it made of?"	Question about the <i>material</i> .
"Who made it?"	Questions about the <i>process</i> .
"How is it made?"	
"Can you make it yourself?"	Questions about <i>applied use</i> .
"What kind of things can you do with this?"	

Some children were able to elaborate answers to their questions about *where* the materials come from and what the materials are *made of*. For example, when asked where tomatoes come from, some children answered, "From trees." When asked, "Where do trees come from?" they were able to answer, "From seeds." The children were asked, "Where do \_\_ come from?" or "What is \_\_ made of?" until they did not have any more answer.

---

The children who could give a chain of answers during the post-study questionnaires (e.g., tomatoes came from trees, trees come from seeds, seeds come from little packages) gave similarly well-connected chain of answers during the pre-study questionnaires. Similarly, those children who were able to give answers to the questions about the process of materials (e.g., “Who made it?” or “How was it made?”) during the post-study period gave similarly well-formed answers during the pre-study questionnaires.

There was no significant qualitative difference between the I/O Brush group and the control group in answering questions about the object itself, materials, and the process of materials.

A question about the applied use of object, “Can you make it yourself?” was an interesting question to ask to the children because half of the children, in both the I/O Brush group and the control group, thought that they were asked if they could make the “picture” presented to them as opposed to the objects represented in the picture. In another words, half of the children treated the presented pictures as an object (as in a drawing or photo) and not a representation of object (such as tomatoes, houses). When asked, “Can you make it yourself?” with a picture of tomatoes shown to them, half of the children said, “Yes, it’s easy, just make red circles...” treating the picture as a drawing/object. Half of the children answered, “No, it would take too long!” or “No, I have only grown sunflowers before.”

In the control group, those children who treated a picture as an object (as opposed to a representation of an object) seemed to remain the same in their treatment of the pictures. That is, they continued to say “Yes, I can make it. In this color or that color!” treating the picture as an object. In the I/O Brush group, however, those children who treated a picture as an object in the pre-study period seemed to change their answers in the post-study period. From answering, “Yes, I can draw it (the tomatoes)” during the pre-study period, they changed their answer to, “No, unless you are a farmer” during the post-study period. This finding suggest that the children in the I/O Brush group treated the picture more as a representation of object than an object over time.

### ***Describing colors***

In the post-study question session, a picture by Matisse was presented to the children. Different parts of the portrait were pointed out to them and the children were asked, “What is this color?”

All children answered, “Blue!” “Yellow!” “Black!” “Red!” proudly in response to the colors pointed out to them. After naming the colors, children were also asked, “Where could ‘Blue’ come from?”

In response to the question regarding the origin of color, the most frequent answer from the control group children was, “I don’t know.”

---

A few control group children said, for example, "Yellow comes from a star!"

Some children in the I/O Brush group, also said "Yellow could come from the moon" as they first looked at the picture. But then they usually raised their head, looked around, and started to say, "It could come from that bucket!" pointing at the yellow bucket in the classroom. Once they made a reference to objects in their environment, their answers snowballed. "It could come from there! Or there! Or there!" pointing at objects as they see. A lot of children also got up from their seats and showed me the things that they saw.



The children were asked, "What colors do you see and where the colors could come from?"



The following is an example of a child who was in the I/O Brush group describing where the color blue could come from:

"The sea! (Then looks up and notices colors in the cubbies.) Charlotte's jacket (as she points). All the blue stuff over there. Look at my lunch box, it's blue!"

Another example of a child in the I/O Brush group describing where the color black could come from:

(As she pointed at objects around her.)  
"Black could come from shoes (pointing), chairs, (my) hair, your hair (pointing), lunch box, eyes, bucket, belt black belt, markers, necklace, the sky when it gets dark out!"

---

The children in the I/O Brush group made significantly more associations to the objects in their environment ( $M=4.45$ ) than the children in the control group ( $M=0.66$ ),  $t(17)=1.74$ ,  $p<0.05$ .

For the children who worked with the I/O Brush, the blue was no longer just blue, but the color that reminded them of items they have seen in their experience and what they see right in their environment.

### Children's creations from "Draw Faces" prompt

Here are some examples of drawings children did from the theme "Draw Faces" pictures.



Some children got the eyes, mouth literally from their body parts, whereas other children got the colors from other objects such as blocks and dolls, and transformed the attributes taken from these objects into face parts of their drawings.

---

### Children's free style creations

The study resulted in a total of over 200 pictures. Here are some examples of the "free style" portraits done by the children.



---

## Summary

In summary, children understood the idea of I/O Brush and used it to capture and make portraits with colorful attributes found right in their environment. The children invested about half of their time working with I/O Brush in exploring their environment and choosing the colors/material for their art. Through that process, they talked about their material with their friends and made certain models about what kind of objects produce what shades of colors.

The technology supported the children's individual style. Some children focused on visual aspect of their projects with I/O Brush, carefully working with the tool's ability to capture colors and textures. Some children focused on the tool's ability to capture audio-visual history of where the material comes from. These drama-focused children used the history feature to capture their ongoing dramatic play.

Using the system's function to capture the visual and audio attributes from the environment and integrating these attributes into one piece was difficult for young children. The children tended to focus on one feature/aspect of technology that they liked the most. For example, the visually oriented children tended to work only on the visual aspect of tool and play/drama oriented children tended to focus only on recording the drama and playing these back for their ongoing play.

Perhaps a longer study with more detailed analysis of individual child's conceptual change over time would reveal the tool's potential to support their growing styles and ideas.

Most significantly, the children's experience with exploring the environment seemed to give expanded perspectives about the colors they saw subsequently. The children seemed to associate colors they saw in a presented object with objects in their environment.

Finally, the children found I/O Brush as a tool they were willing to work with almost every day during the 5-week study period. I was positively surprised by how excited the children were every time they saw me coming into the classroom in the morning. When they spotted me, they asked, "Do I get to work with the magic paintbrush today?!"



---

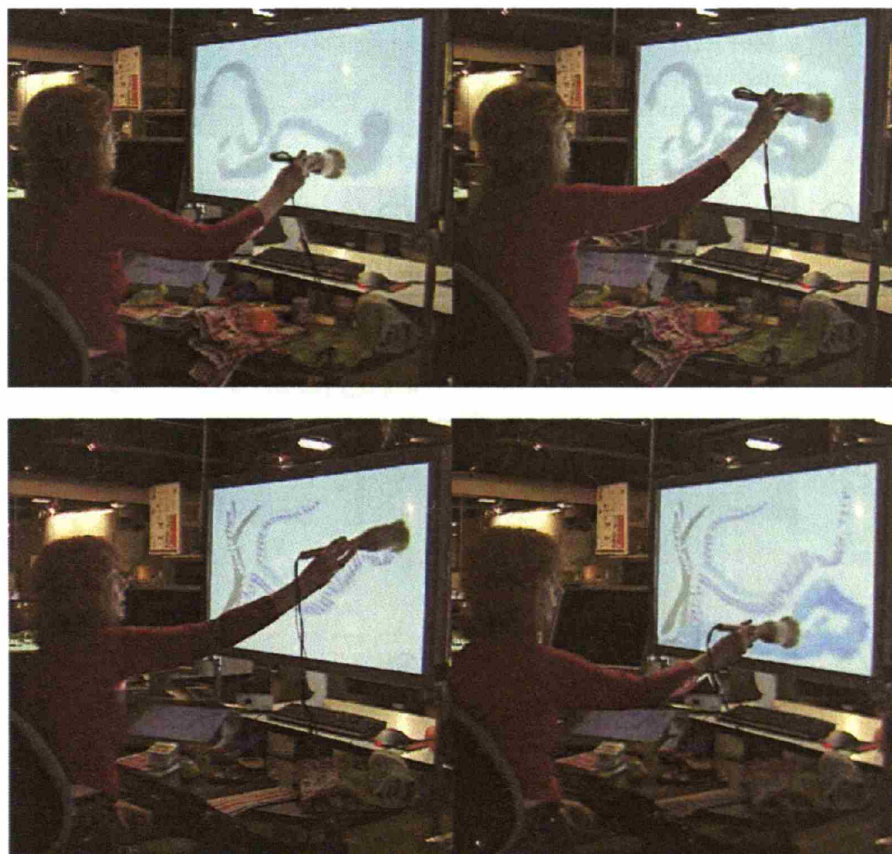
## 5.2. Case Study with an Artist

I had the privilege to work closely with an artist, Ann Hoban. She is an art therapist and watercolor artist based in the greater Boston area.

### Session One at the Media Lab

The first session with Ann was done at the Media Lab. I gave Ann an introduction to I/O Brush with examples from colorful objects I have collected and placed on the table.

She immediately tried out a variety of strokes with different pressures and angles. As seen in the following pictures, she was immediately able to control different expressions with strokes allowed by the physical manipulation of the brush.



This first session was intended as a tryout session for her to see if it was a tool she was willing to work with again in the future. She agreed

---

enthusiastically to another session. She later described her experience in email correspondence:

"What you are creating with the I/O Brush is nothing less than the opportunity to use the entire environment for paint. The capability of having motion occupying parts of the surface is a feature that is particularly exciting to me..."

Items Ann worked at the Media Lab were not personal enough. When we discussed a location for our next session, one of the first locations Ann wanted to take the system was outside. Given the outdoor incompatibility of the current system, we had to settle on an indoor location. We decided to conduct the next session at her house as we thought it would be interesting to have her own personal space as palette.

### Session Two at Ann's House

The second session with Ann was done at her own house. The I/O Brush system was set up at her apartment. While I was setting up my equipment, Ann was also busy moving between rooms, bringing in and arranging an impressive collection of personal objects.



Ann spent more than one hour retrieving and arranging objects on her kitchen table. Her kitchen table became an amazing physical palette of

---

personal objects. A collection of old keys, a basket full of seashells, a plate full of sliced apples neatly arranged, a collection of stones and gems, etc. She arranged her objects in such a way so that different themes, patterns, and colors seemed to emerge in anticipation even before she started to paint.

A new process of painting was brought out where artists spend time preparing the material they work for their portrait.

One of the first paintings she created was called, "Family Women." She used personal family photos as the source of her ink. Photos symbolized her favorite female family members, including her two daughters and her grandmother who meant dearly to her.



She touched her photos with the brush and used the palette to make sure she was capturing the faces of her favorite women. While Ann captured faces of her favorite women, she recorded personal messages. The following is a transcript of her talk while she painted her portrait:

"This is my nana Folly, my father's mother, Jenny." (as she picks up a photo of young Jenny)

"Jenny is a sweet sweet sweet lady. You can see the sweetness in her face" (as she paints)

"Then this is my mother, Joyce Ladd. Joyce Lindsey Ladd" (Ann picks up another photo, this time her mother's).

"Joyce, the ultimate lady. An artist" (she paints her mother's photo on the canvas)

"And then Lindsey and Maggie when they were little. I'll show you Lindsey first." (Ann picks up pictures of her daughters)

"Lindsey. Is very dramatic." (as she paints)

"And now here's Maggie who worships Lindsey."

"So we have Lindsey, we have Maggie, we have Joyce, we have Jenny." (as she looks at her portrait)

"I'm getting a grown up picture of Lindsey."

"Uhhh, good, good, good good..."

---

(as she looked at her portrait) "So this is a family portrait."



As she painted her favorite faces on the canvas, it was as if she was talking to the canvas, saying, "There you are!"



"Family Women"

A close-up look of her portrait reveals recent photos of her daughters embraced by their baby photos and baby photos of Ann's aunt.



When she was finished with her "Family Women" portrait, she completely switched gears and moved on to another entirely different personal collection. Her next portrait was called, "Birds of a Feather." The portrait was a colorful anthology of all things bird – her collection of real bird feathers, plastic pink flamingos, stained glass parrot, folk-art crow, stuffed Tweety bird, etc.



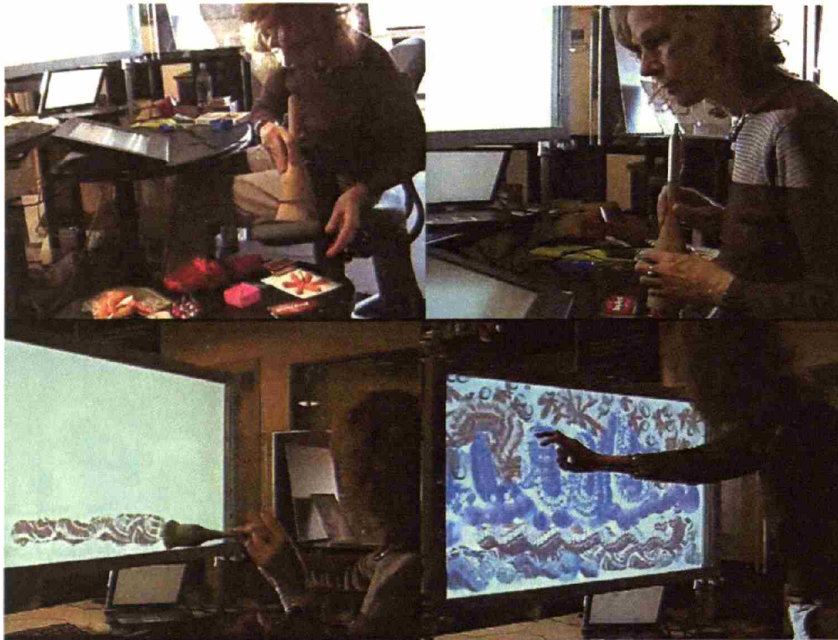
"Birds of a Feather"

---

The portraits Ann made at her house were very personal and raw. In contrast to the lines and curves she has drawn previously at the Media Lab, Ann's portraits at home were an audio-visual "collage." The portraits consisted of blobs of personal ink, which was a bit unexpected at the beginning. However, if the source of one's ink is personal pictures or personal objects with specific shapes and forms, one has the challenge of preserving their photographic identities on canvas so that they still make sense. It is understandable that she did not want to distort or smudge her favorite faces on the canvas.

### **Session Three at the Media Lab**

Ann's third session was back at the Media Lab. She had brought some of the personal objects and materials, which she did not have the time to work with during the last session.



Ann carefully arranged the physical palette, chose certain patterns from her physical objects as she looked at the palette, and smudged parts of her patterns to control the details.

As in the second session, Ann spread her personal items on the table in advance and worked her way through the arranged physical objects.



"100 Carrot Sweets"

Details reveal that the portrait was carefully created with colorful candies.



Close-up view reveals that they are made of colorful candies and their packages. "Hershey Kisses" (on the left) and "Red gum" and its package (on the right).

I asked Ann how the process of preparing the physical palette influence the decision about what kind of portrait she is about to create. She elaborated on her process. The following is a transcript of her answer:

---

"It evolves. It evolves. It's conceptual. The 'Big Red' (the gum) reminded me of bricks, which became the foundation. And the 'Nature Valley Granola' is a, the earth that goes even underneath the bricks, because if it's green it means that there's some life and, leaves and earth. (She pauses.) So it's conceptual and feeling. And thinking of the decorative feel at the end. The balance of colors and forms, and movement. The carrots with the star. The (Hershey's) 'Kiss' in the middle is a star. So I have that as the sky. And the Altoid thing is a big snake. Who is moving its way through the ground, through the field. So it's like (gestures the snake like movement on the canvas) like the life form moving through the ground and the sky, of the current culture of, this culture has done with food."

"Kind of complex what was going on in my head. Because there was a visual thing going on but there was also the conceptual thing of, it was like shifting back and forth between the concept of crazy things this culture does with food and embracing that because it's so crazy, and it's also colorful, and making painting with those forms. To make a decorative surface that was balanced with its colors."

"Because I can get very very depressed about what we are doing to the environment. And how far a way we are from the earth. But part of it is fun. Part of it is that we are trying not to be so depressive these days. Like having the real carrots is, probably the only real food in here. Which is why I have 'carrots' in the title. We still have access to real food. Even these are manipulated pieces of real carrots."

Ann used the colorful package designs originally designed to grab consumers' attention. She reused/reconstructed these colorful design to give them a new meaning into her portrait. One can only imagine what kind of portraits would come out if someone like Andy Warhole had I/O Brush.

Until I had the chance to observe Ann's process in reusing the colorful designs and symbols in our culture, I thought taking the I/O Brush system to outside and having the nature was the ultimate palette. But watching Ann's work made me realize the grocery shops and supermarket could be an interesting and colorful atelier unlike any other where artists can work with symbols and colors our culture could offer.



What kind of portrait would Andy Warhole create if he had I/O Brush?

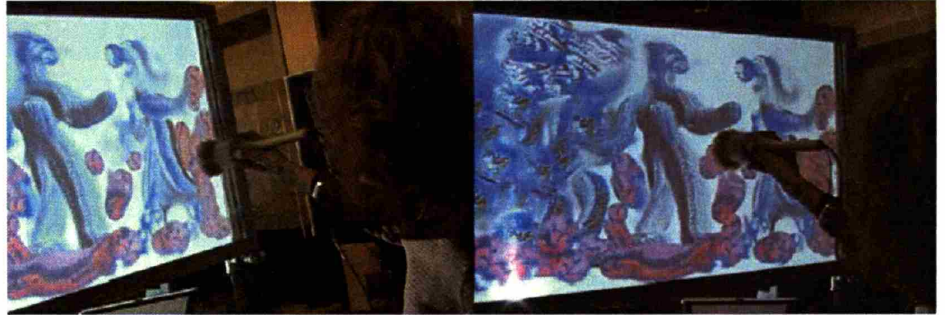


Scenes of grocery shop displays may give artists hints for their colorful work



---

One of my favorite pieces by Ann was called "Dance."



At first glance, the portrait is reminiscent of a dance between two ghosts or aliens. Yet, a closer look reveals that the head is made of something rather comical.



"Dance"

---

At first glance, the portrait is reminiscent of a dance between two ghosts or aliens. Yet, a closer look reveals that the head is made of something rather comical.



### Summary

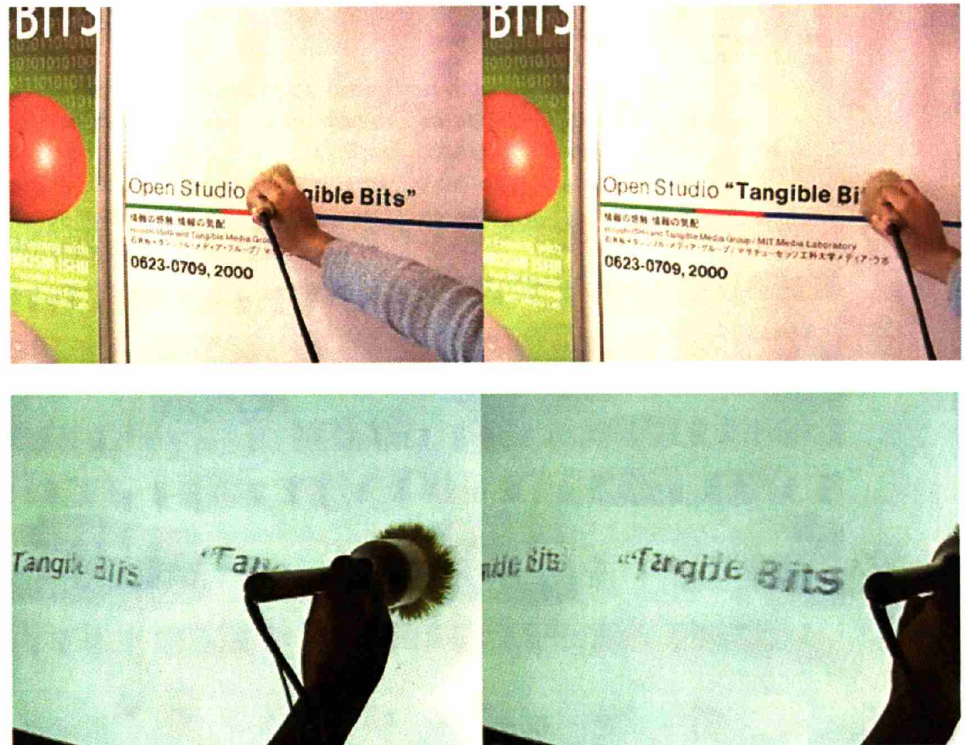
I/O Brush system brought a new process of creating art where artists spend as much time creating a physical palette as creating the portrait itself. The physical palettes are made with physical objects and material from their environment where some objects stand for the artists' very personal experience and life. Parts of the process of creating physical palette were documented via the system's history recording function and revealed on the canvas when the artist or audience touch the ink.

### 5.2.3. Beyond Static Collages

One of the unique qualities of I/O Brush is the possibility of inventing dynamic expressions that could be made by combining capturing and painting techniques based on time and space.

There are several ways to create dynamic animated ink/objects on the canvas. For example, when one brushes over a static text in a movie mode and brushes over the canvas with the ink in the right speed, one can make the brushed over text scroll on the canvas.

	Static	Dynamic
Object		✓
Capture	✓	
Draw		✓

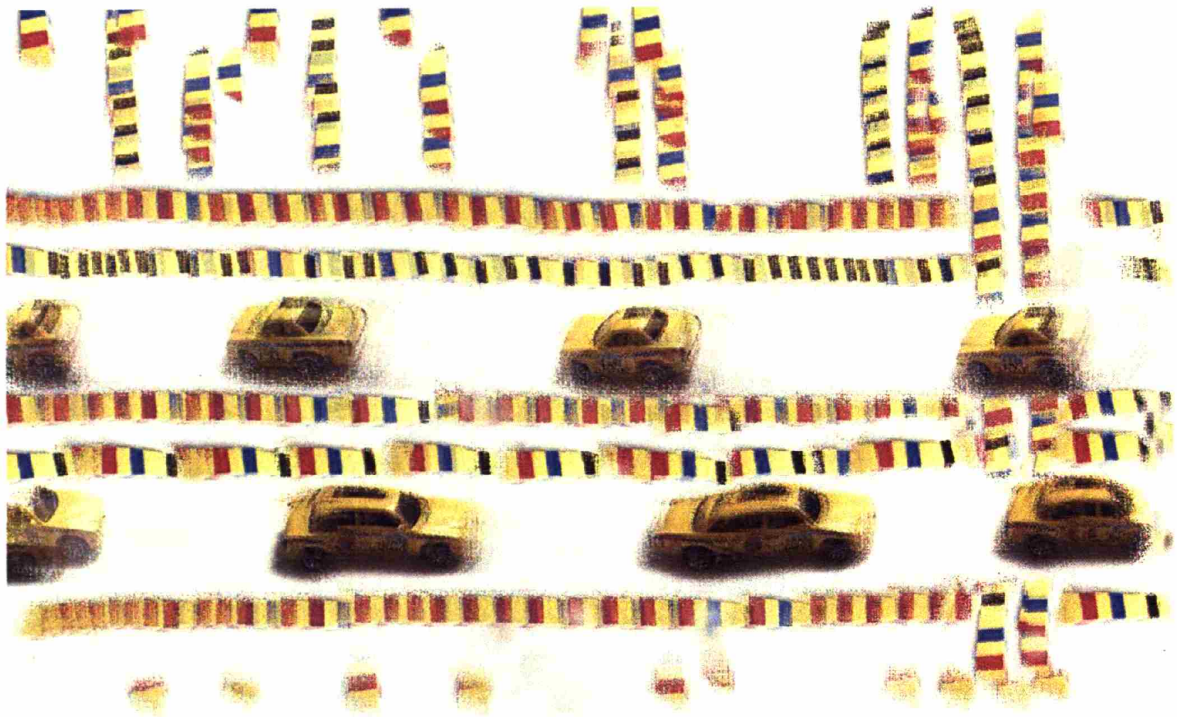


One can also capture dynamic object such as butterfly flapping its wings. When this object is captured with dynamic relative movement (e.g., tilting the brush), the resulting ink on the canvas is an animated butterfly wondering around while its wings flapping.



	Static	Dynamic
Object		✓
Capture		✓
Draw	✓	✓

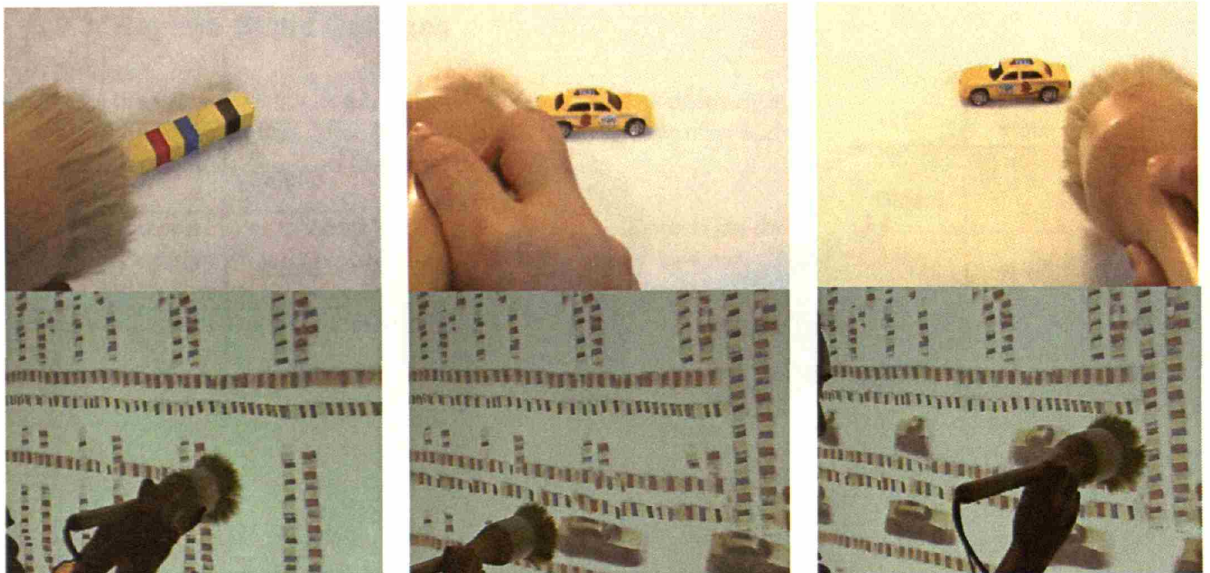
An example of a portrait inspired by Mondrian's portrait was created with techniques combining dynamic capture and drawing:



"NY" inspired by Mondrian.

The yellow taxis drive down the roads. The movements of the taxis were created by capturing a static toy taxi and combining it with a dynamic brush stroke on the canvas.

When using the moving ink, depending on the direction of the capturing motion, the artist can create a variety of dynamic motions.



---

With the combination of capturing and drawing temporal and spatial attributes dynamically, invention of new artistic expressions can be allowed. If in the future, I/O Brush could be in hands of hundreds of artists, we may see galleries of artwork full of new artistic expressions made with the I/O Brush system.

---

---

---

## 6. Discussion

In this chapter I will discuss the implications and the directions for future work.

### 6.1. Developing Synergetic Creations

With kindergarteners, I have observed the tool's potential to support a variety of styles that children have in working on their ideas. Children had personal relationships with objects around them, such as dolls, backpacks, and their favorite classroom objects. Their work reflected upon the aspects of objects and interactions with these objects that were dear to them. For some children, their ideas were represented in the form of directed visual and sound play. For some children, their ideas were captured in the careful combination of selected colors, patterns, and what they were drawing.

After their experience working with I/O Brush, children also seemed to look at features of objects in their environment, especially the colors, a little differently than before. When asked where the colors they saw in a painting could come from, the children who played with I/O Brush associated things that they see in the environment while the children who did not play with I/O Brush made no such association. I/O Brush as a tool encouraged the children to observe their environment and actively make associations.

Not seen in the kindergartener's work was the integration of different media, audio and visual, into one portrait. Using multiple aspects of the tools and integrating them into their portraits was difficult for kindergarteners, as they tended to focus on one feature or aspect of the technology they liked the most.

In fact, integrating audio and visual features into one piece seemed to be difficult even for adult artists. A case study with the artist Ann showed that even an adult artist wanted to use one feature of the tool at a time. When she focused on one aspect of the tool, for example, the sound, her portrait took on a different character than when she was focusing on the visual aspect of her work.

The I/O Brush system may be a new tool just like any other new tool that requires some time to master to its full potential. Many adult artists, including Ann, had indicated that they would hope to some day own a tool like this to continue with their creations further.

---

## 6.2. Future Designs

### 6.2.1. Future Design of the Brush

Much improvement has been made on the brush since its first implementation. Several possible future designs are discussed in this section.

#### Size and Shape of the Brush

The current brush size is determined by the size of the camera. With the advancement of small high quality video cameras, the size of the brush could become smaller.

The shape of the brush could also be elaborated further. The brush may be a flat-head brush, etc. It could resemble more a real paintbrush by having different paintbrushes from which artists can pick depending on their ongoing work.



#### Portability of System

In time, the system could be taken outside and made mobile to profit from nature directly. Finaly (2003) tells an interesting story behind the invention of portable paint boxes. With the invention of the collapsible tin tube, portable paint boxes were born. "Without oil paints in tubes, there would have been no Cezanne, no Monet, no Sisley or Pissarro: nothing of what the journalists were later to call Impressionism. Impressionism, after all, was a movement that depended on recording nature in nature. Without being able to use colors outside it would have been hard for an artist like Monet to record the impressions that the movements of the light had made on him, and so create his atmospheric effects."





In a way, the technology presented in this thesis also opens up a new arena where children and artists have access to elements that were difficult to obtain (or rather did not even think about obtaining) before. As the technology allows children and artists to rely a great deal on the context they are in, they may inescapably pay attention to the objects and elements that surround them. The portrait also may serve as a remembrance of the context the artist has been in. For example, a portrait a child creates in a classroom may have a palette of colors quite different from a portrait the child creates in her own room at home. Likewise, a portrait an artist creates in an urban setting may contain different colors/tones from the one the same artist creates in a country setting. In time, just as the impressionist movement was brought about by the invention of the ink tube, our effort to provide a suite of technological tools to turn the environment into a color palette may contribute to bringing about a new generation of artists and expressions afforded by their physical world.

### **Previewing Ink**

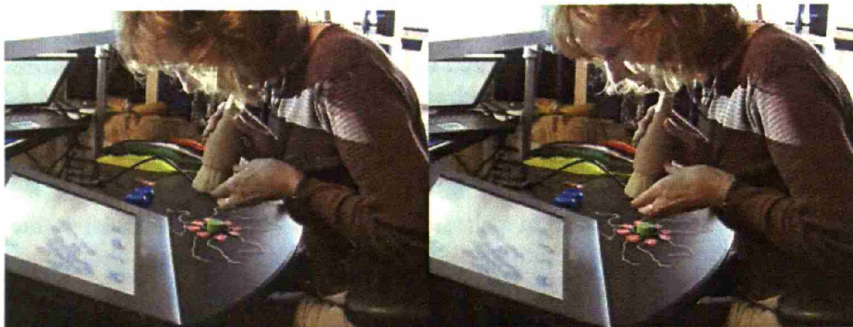
The palette was initially motivated as a space where artists can mix and work with several kinds of ink. However, a more important function of the palette turned out to be the previewing of ink and the switching between different inks.

When previewing ink, the objects children were working with needed to be very close to the palette, in the right orientation with the brush. When the objects they wanted to try out were far away, or could not be brought out right in front of the palette, they had a problem with how to monitor their ink as seen in the following scenario of a boy trying to capture the pattern underneath the table.



A boy went underneath the table to pick up ink from the underside of the table with I/O brush. He said to his friend, "Can you watch (the palette) for me?"

Ann, the artist also mentioned her struggle with previewing. She said, "It's like trying to dry my hair in the mirror."



Holding the brush at the right height and position while looking at the preview screen allows artists to take larger patterns from a collection of physical objects. But sometimes it was like "trying to dry hair by watching a mirror."

One solution is to attach a preview monitor (e.g., via a little LCD screen) directly onto the brush so that the preview goes everywhere the brush goes. However, this may make the brush much larger physically and will require a clever design solution to house the display on the brush.

### 6.2.2. Synesthetic transformation

Synesthetic transformation happens when an expression in one modality gets transformed into an expression of another modality. For example, a child may pick up fuzzy brown texture from his own hair and put the static 'texture ink' on the palette. He might then pick up a small hiccup sound with the brush and apply that on the brown texture.

On the palette, the ink might then transform into a 'moving ink' with the rhythm of the hiccup. In contrast to a synergetic creation, a synesthetic transformation results in a single modality. For example,

---

the audio property of a hiccup is transformed by the system into a visual property, and later can be mixed on the visual level with the other elements on the palette.

Perhaps it is also possible to take ink that was created via synergetic fusion (e.g., visual and sound), and mix it further with properties obtained from a synesthetic transformation. Some artists may enjoy this improvisational quality in the system.

The idea of a synesthetic drawing tool could also extend further. For example, what would it mean to mix our favorite music with the pattern of our favorite shirt? 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.

### **6.2.3. Extending the I/O Brush idea with different sets of sensors**

In addition to the current set of sensors (i.e., camera, force sensors, inclinometer, and microphone), I/O Brush could be a host for a variety of sensors that probe the condition of a surface. For example, a thermometer on the tip of the brush could measure hotness or coldness of the surface giving the artist another aspect of their environment to make art with. A laser-based range meter can measure the distance between the brush and the surface so the camera can focus automatically or apply different effects based on the distance. A low-range radar sensor can detect the structure of the surface from a distance. Other vibration-based sensors can measure the surface structure such as roughness or smoothness.

If all these sensors could be added to the brush, could the metaphor of a brush be extended beyond the domain of art? Could the metaphor of brush be used in the Medical domain, e.g., to take the consistency of skin?

In the kindergarten classroom, some children used I/O Brush as if it was a periscope. The children 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. Can the idea of I/O Brush be extended to design a new kind of microscope or periscope?

Another idea is to take the I/O Brush idea and bread it with cell phones and other handheld devices with cameras. More and more large-scale displays are starting to appear in public spaces. Perhaps, cell phones with camera could become a kind of I/O Brush where people who own it create a new kind of art collaboratively in public spaces.

### 6.3. What “The World as a Palette” Means...

Over the course of the last two years, the I/O Brush project has received lots of positive feedback from people who have heard of it through the web, trade shows, and conferences. Many people found the idea exciting and wrote nice articles about the project.

However, not all people perceived I/O Brush as a creative tool. The following article was particularly interesting:

MIT's infamous Media Lab, from which many inducing technologies have found their way into the world, has produced a device whose sole and only purpose appears to be copyright infringement. Furthermore, it is designed to be used by children, training them from an early age to engage in copyright crimes! Who knows how many innocents will be corrupted by the Fagins and Child Catchers of MIT?

This is explicitly training children to violate the rights of reproduction and derivative works. Unbelievable! Shocking!

And just what does MIT expect the children to do with their infringing works? Undoubtedly, because they are in digital format, share them with people! Perhaps they expect that they will be shared via the internet! Thus, violating the right of public distribution!

From "Hatch's Hit List #45 - MIT's I/O Brush"  
[http://www.corante.com/importance/archives/cat\\_hatchs\\_hit\\_list.php](http://www.corante.com/importance/archives/cat_hatchs_hit_list.php)

One way to react to this is to compare it with what happened to the music sector with digital sampling. When the technology to digitally sample audio and music was first invented, there were many concerns about copyright violations. This technique of course was possible before the invention of digital audio sampling if the artist had the 1-million-dollar Fairlight CMI, or painstakingly worked with tape loops. But the invention of digital sampling made the process much easier and more accessible. While there was a tension, it was clear what immense artistic potential suddenly was uncovered, and lots of music was produced that was based on samples of real sounds such as animal sounds.

---

Although some old fashioned artists initially thought that sampling was cheating, most of the others eventually agreed on that creating collages from existing sound bites is as hard as creating music itself. It just changed the approach, or rather, enabled additional approaches for making music. Even more, the whole idea of sampling has penetrated all commercial music business completely: Today, it is hard to find a top 40-chart song that does not contain any samples. For any modern music composer, the audio spectrum includes not only sounds from well-known instruments, but also any other imaginable sound that can be captured by a digital sampler.

In the past, artists often chose not to pursue copyright infringement suits because digital sampling can re-create interest in an original work or artist. It happens often that digitally sampled music of an original work is able to reach a new audience. Eventually, the community agreed on a time limit (e.g., one can sample from copyrighted music and re-use it if it is under three seconds). This process of artistically re-working audio samples has become an art genre in itself, and has produced famous artists which might not have gotten famous without this technology. Hopefully, something similar may happen to I/O Brush.

As children and artists begin to produce beautiful and original art with I/O Brush and share it with others, the meaning of “world as palette” may become clearer. This thesis reports on the dawn of such a possible development.

---

---

---

## 7. Conclusions

“It is creative apperception more than anything else that makes the individual feel that life is worth living”

—Winnicott (1971, P.65)

The principal contribution of this thesis is the invention of a new medium for artistic expression and learning that can empower child and adult artists alike by letting them become aware that they too can invent new materials and tools instead of using off-the-shelf products.

In addition to inventing new materials to make art with, working with the tool seemed to expand people’s perception about the world. When presented with colors and asked about them, the children who had the experience of working with I/O Brush subsequently looked at their environment actively in describing the colors they saw. Moreover, after using I/O Brush, children actively made associations with what they saw in their physical environment. The colors the children saw were no longer just colors, but something that reminded them of something they had seen in their past. Children, after using I/O Brush, were more likely to look at the painting actively. They were able to readily observe particular features of the painting (decomposing the painting into the color blue, black, yellow, or red), go back to an earlier stage of the composition, and imagine where the colors could come from and how they may be made. Why would this be important? Because next time when these children paint or choose colors and materials for their projects, they may think about them more actively and make greater associations with their memories so as to have more possibilities than before.

For artists, the I/O Brush system as a tool opened up a new design space for the expansion of their creativity. Artists may not only invent new expressions with the tool over time but also may broaden their repertoires of medium for their art.

It is this ability to engage in critical “perception” rather than merely “recognizing” what is, that leads to enjoyment, learning, growth, and possibilities – to experiences that transform people from totally determined entities into open entities of self-cultivating energy. It gives value to life by making each act of perception a unique, objective experience (Csikszentmihalyi, 1981).

The experience of perception is important because that is how learning occurs— by enlarging or changing the habitual framework of interpretation. The way we look at the world is no longer the same as before when the scheme through which we interpret an object is

---

changed or modified. We grow not by looking at the world the way it is, but by looking at it creatively, noticing, discovering, and interpreting its peculiarities. I/O Brush gives that kind of opportunity, to go beyond the boundaries set by culture and to create new meanings.



---

**Appendix A:**  
**Permission letter to parents**

---

---

Dear Kindergarten Families,



The Baldwin School and MIT have the opportunity to work together on an exciting research project. At the MIT Media Laboratory, Professor Hiroshi Ishii and his graduate student, Kimiko Ryokai are building a computer-based paintbrush, called MagicBrush that invites children to turn their environment into a color palette to paint with! The MagicBrush looks and feels like a real paintbrush. However, the brush has a tiny camera inside and a touch sensitive tip, so instead of picking up the ink or paint, the MagicBrush can pick up the color/pattern of any surface it touches. Children may brush any surface with the MagicBrush (e.g., the chairs they are sitting on, pictures from their favorite picture books, their shoes, and etc.) and the brush picks up the pattern and color of the brushed surface. On the canvas, the brush lets children draw with that special ink they have just picked up. Children's artwork will be printed on a regular sheet of paper so it can be shared with their friends and family. In order to evaluate the MagicBrush, MIT is collaborating with teachers at Baldwin school to integrate the MagicBrush into the classroom project based activity.

We are writing this letter to find out if you would be willing to have your child participate in this exciting study. Your child's participation in the study is voluntary and you are free to withdraw your child's consent at any time. It involves about 15 minutes of your child's time during his or her "choice time" activity in Mrs. Lund's class, once or twice a week during Feb 14th to March 18th (about 4 weeks). During their time playing with the MagicBrush, Mrs. Lund and a researcher who has extensive experience working with children, will observe how your child plays using the MagicBrush. Your child's play with the MagicBrush will be videotaped so that the researchers can analyze them at a later time. The videotapes will be kept in a locked cabinet, accessible only to the investigators. With your permission, we would also like to use short clips of your child's interaction with the MagicBrush for academic purposes only.

We think that this is a great opportunity for your child to experience a part of the future of educational technology that is being developed at the Media Lab. If you and your child are interested, please complete the form below to indicate the level of participation you would prefer. Please sign both copies, return one copy to your child's classroom teacher, and keep one for your reference. If you have any questions, please do not hesitate to call professor Hiroshi Ishii at MIT Media Lab (617-253-7514) or Mrs. Lund at Baldwin (617-349-6525). You may also contact the chairman of the internal review board at MIT (617-253 6787). Thank you very much for your support!

Sincerely,

Janice Lund and Kimiko Ryokai

Child's Name \_\_\_\_\_ Date of Birth \_\_\_\_\_

\_\_\_\_\_ I give permission for my child to participate in the study and excerpt from the videotape potentially shown for research and teaching purpose.

\_\_\_\_\_ I give permission for my child to participate in the study only, but would not like an excerpt to be shown for research and teaching purpose.

\_\_\_\_\_ I would not like my child to participate in the study.

I understand that my child's participation in this study is voluntary and I am free to withdraw this consent at any time.

Parent/Guardian Signature \_\_\_\_\_ Date \_\_\_\_\_

---

---

**Appendix B:**  
**I/O Brush Technical Manual for Ars Electronica**  
**Center**

---

---

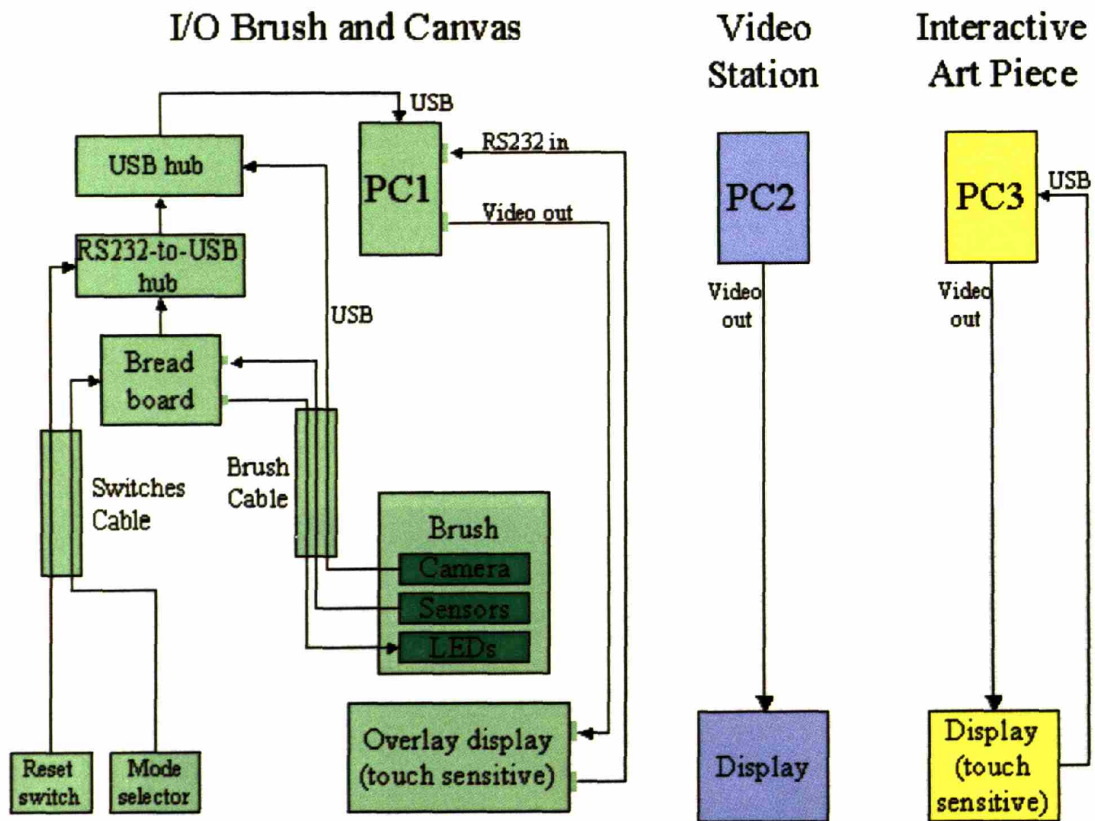
# I/O Brush Technical Manual for Ars Electronica Center

Version of October 4, 2004  
Kimiko Ryokai and Stefan Marti  
[kimiko@media.mit.edu](mailto:kimiko@media.mit.edu), [stefanm@media.mit.edu](mailto:stefanm@media.mit.edu)



---

## System diagram



## Components

The whole I/O brush installation consists of these main components:

- Brush
- Breadboard, USB hub, RS232-to-USB hub
- PC
- Overlay touch panel
- Interactive art piece
- Video station

In the following, we will describe all components in detail.

### Brush

The brush is a wooden body that contains all the electronics, sensors, camera, bristles, etc. It also has a cable that connects these components to a breadboard.



---

The body of the brush is hand made from hard maple wood, professionally wood-turned, a process that took several days to complete because of the complex inner and outer shape of the wooden piece.

The bristles are original brush bristles, hot glued to a laser cut outer ring made of transparent acrylic.

The outer ring is attached to an acrylic inner ring, which is slightly bigger diameter. The two rings are attached to each other via the four force sensors, to guarantee maximum sensitivity.

The force sensors are attached with thin double-sided tape to the inner ring, and with double-sided foam tape to the outer ring. The foam tape is necessary to (1) distribute the force evenly over the sensor, and (2) buffer the pushing force (vertical travel of the outer ring) that gets applied when the user presses the brush to an object or surface. To prevent the two rings from getting pulled apart (negative pressure), there are two safety screws that span the two rings, but do not apply force to them. In order to not influence the sensor readings, the holes in the rings are larger in diameter than the diameter of the screws, and the nuts are not tightened completely: the nuts—two for each screw on the outer ring side—are secured with a drop of epoxy glue, instead.

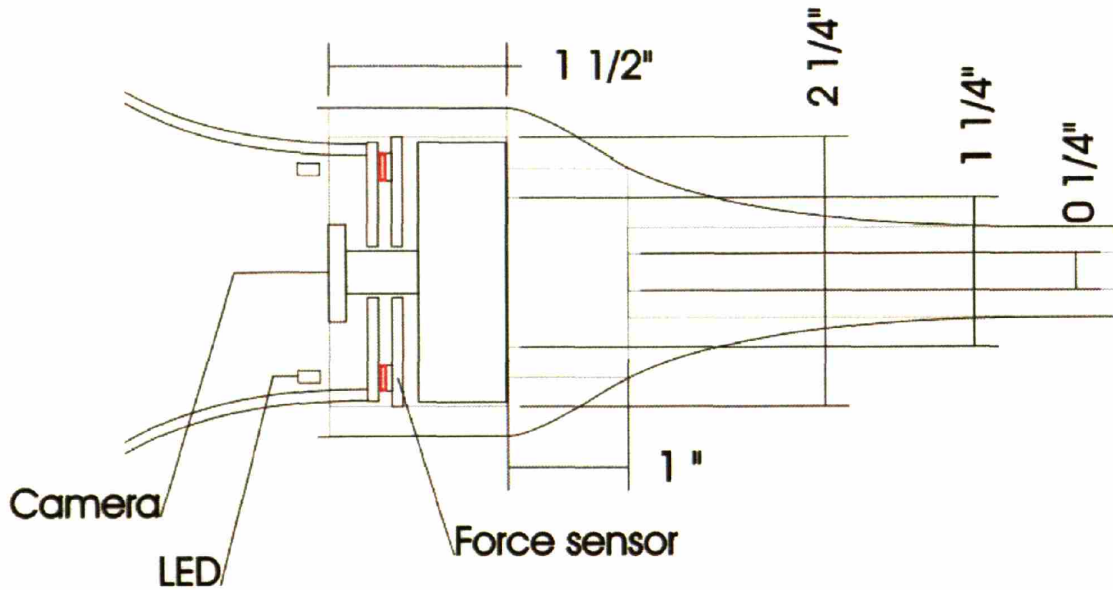
The camera used currently in the brush is a standard USB Logitech webcam.

The sensors used are Force Sensing Resistors (FSR) from Interlink Electronics (model 400: 0.3” circle with solderable tabs)

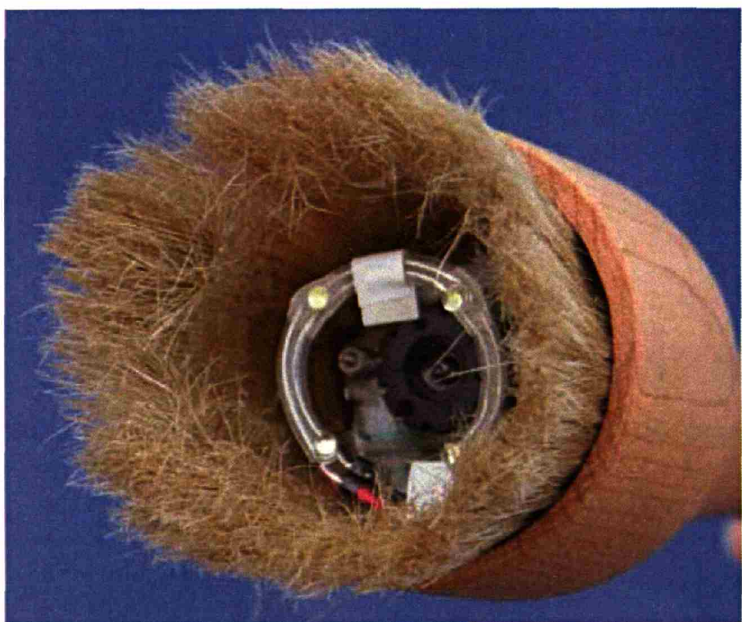
<http://www.interlinkelec.com/documents/datasheets/fsrdatasheet.pdf>

<http://www.interlinkelec.com/documents/usersguides/fsrguide.pdf>

These sensors are very thin, since they are made of several layers of polymer film. They are very sturdy and reliable, but (as mentioned before) *they are do not like negative forces*. If such forces occur (pulling forces), the components of the film might separate. In order to prevent negative forces, there are the two (not tightened) screws described above. Note that negative forces do only happen if somebody PULLS the bristles of the brush—something only little children might do when unattended...



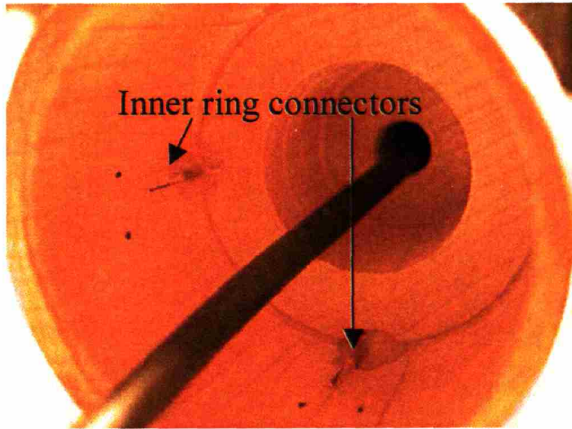
*A construction sketch of the head of the brush, showing the location of the force sensors (red), the camera housing, the camera lens, the white, the LEDs, the two acrylic rings, the bristles, etc.*



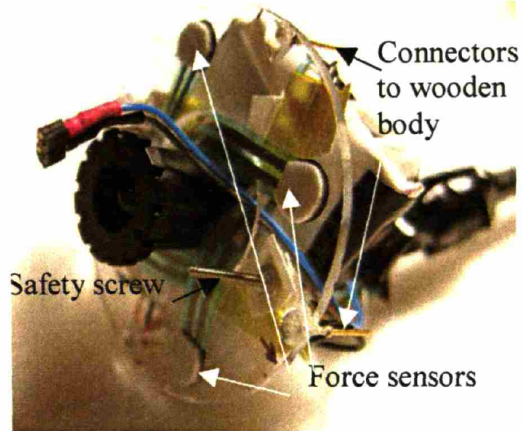
*Finished head of the brush. Note that in this picture, the ring of white LEDs is not yet glued to the side of the bristles.*



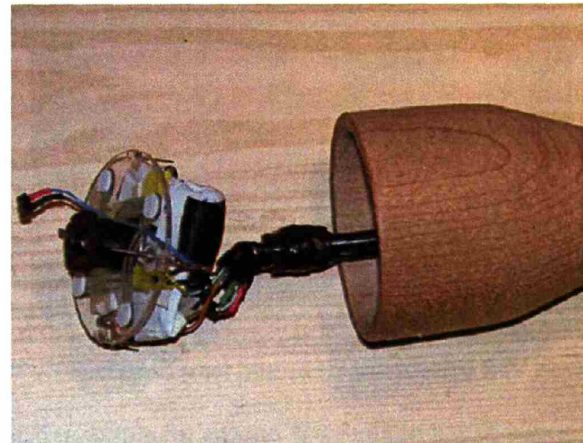
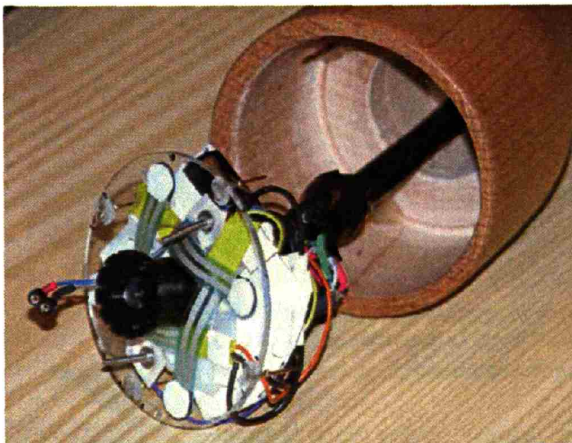
*The outer ring with the bristles.*



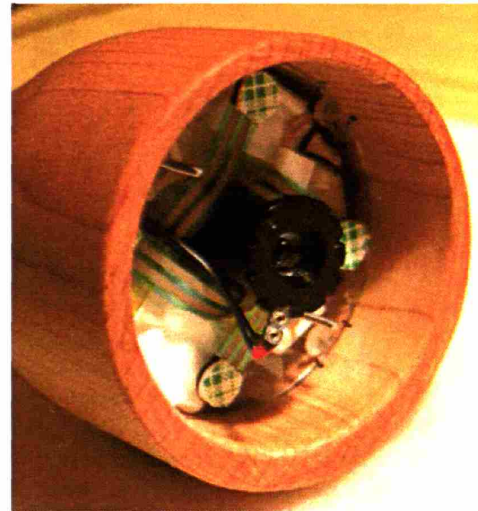
*Inside view of the wooden brush head. Visible are two connectors (out of four) that the inner ring snaps into. In the current version of the brush, the inner ring additionally is glued to the wooden walls with epoxy at the location of the four connectors. This means the inner ring (and therefore the whole assembly with the bristles) cannot be detached easily. If it has to be removed, then the glued parts have to be cut out first, which can be done only by Kimiko Ryokai.*



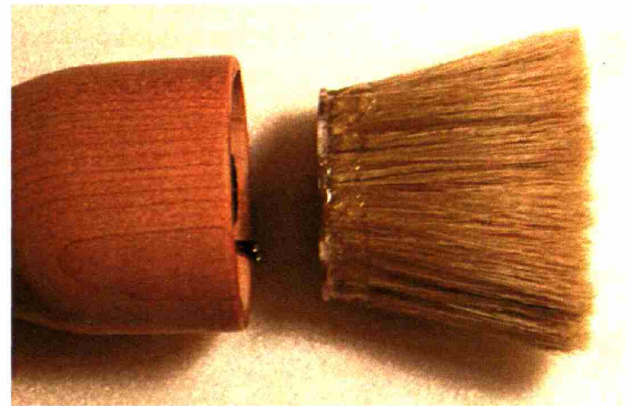
*The inner ring with the camera attached. Visible two of the four pins that snap into the plugs on the picture left. Also clearly visible are the four force sensors, which are attached to the inner ring and (with double sided foam tape) will be attached to the outer ring. They are the only connection between inner and outer ring, which guarantees that all the forces applied to the bristles are measured by the four pressure sensors. Also visible is one of two screws that prevent the outer ring from being pulled off.*



*In the above pictures, the brush cable is inserted into the brush and the inner ring is ready to get mounted to the wooden brush head.*



*Now the inner ring and the camera are mounded. The two wires and connectors sticking out beside the lens will eventually provide power for the white LEDs. The 2-sided foam tape is still covered with the protective layer.*



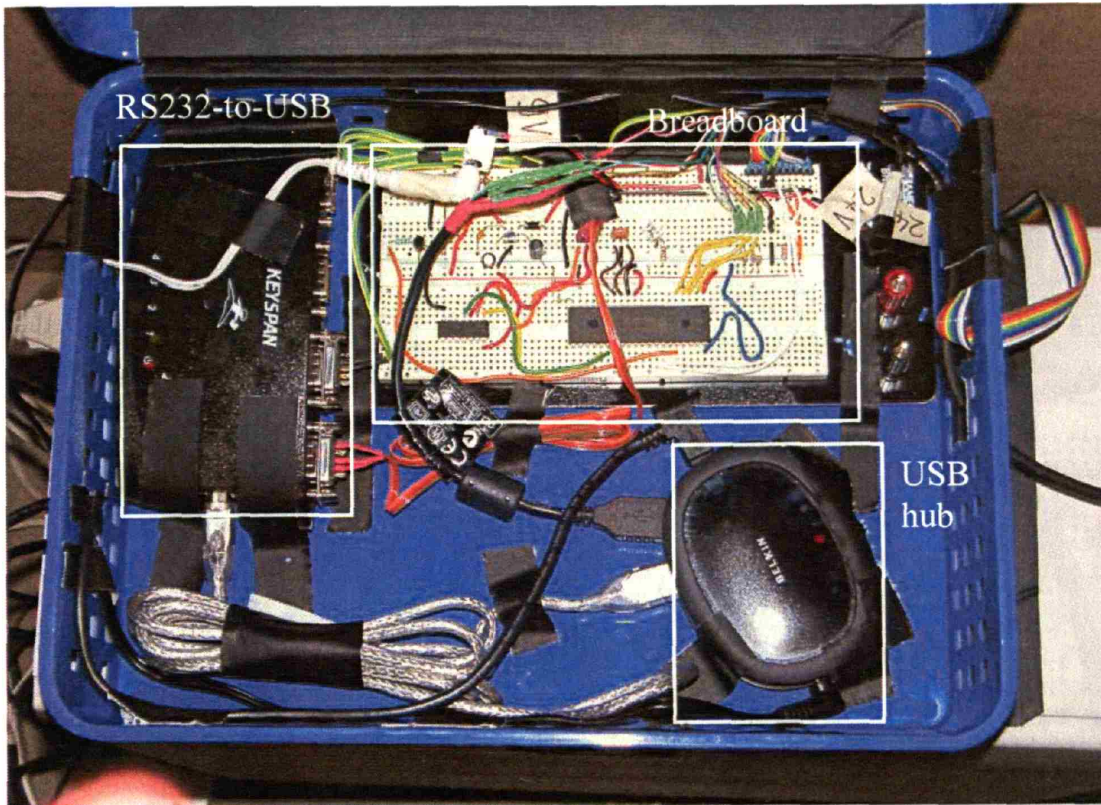
*The outer ring with the bristles is ready to be attached to the inner ring.*

### **Breadboard, USB hub, RS232-to-USB hub**

The breadboard acts as a connection between the brush and the PC. Its function is to digitize the sensors of the brush and send them via serial port to the PC. It also lights up the white LEDs in the brush when the brush touches an object to pick up.

The serial connector of the breadboard (3 wires, brown/red/orange) is connected to an RS232-to-USB hub. Also connected to the RS232-to-USB hub is the reset button (2 wires, green/yellow).

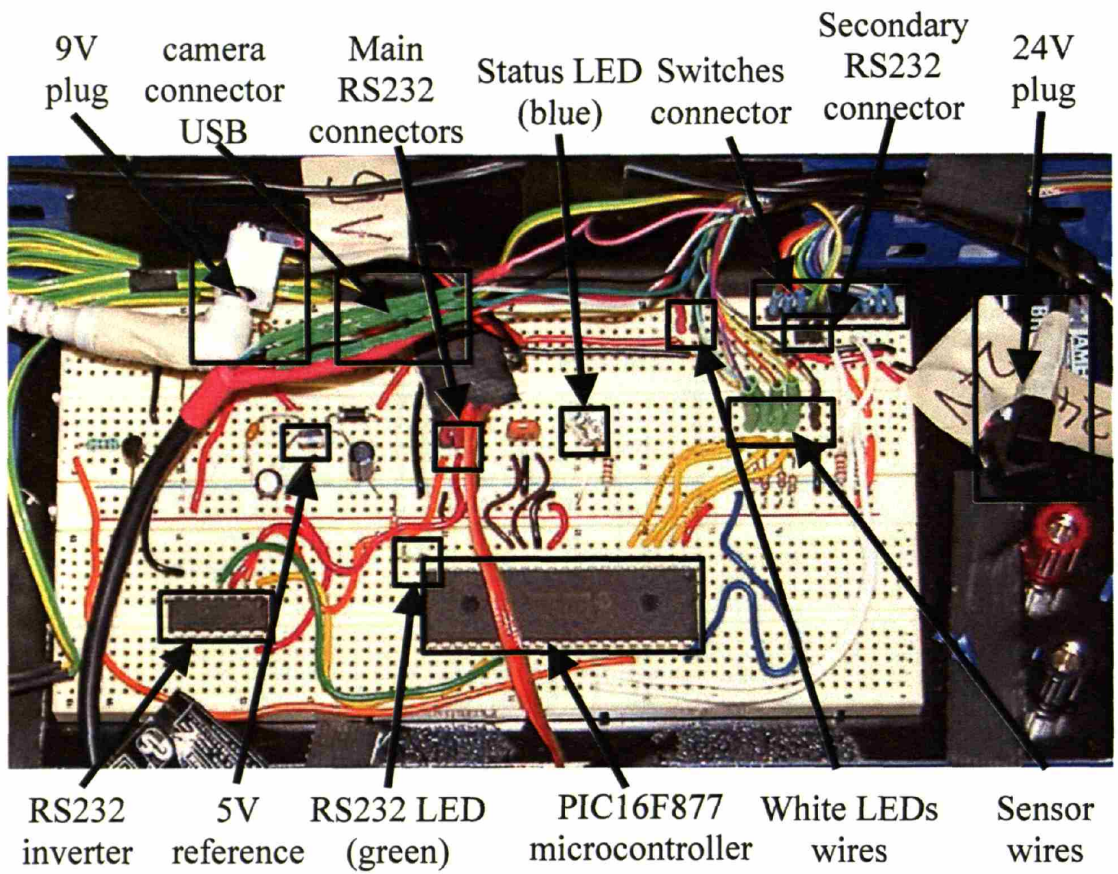
The USB signals from the RS232-to-USB hub (breadboard) and the USB camera are collected in the USB hub.



The main components on the breadboard are:

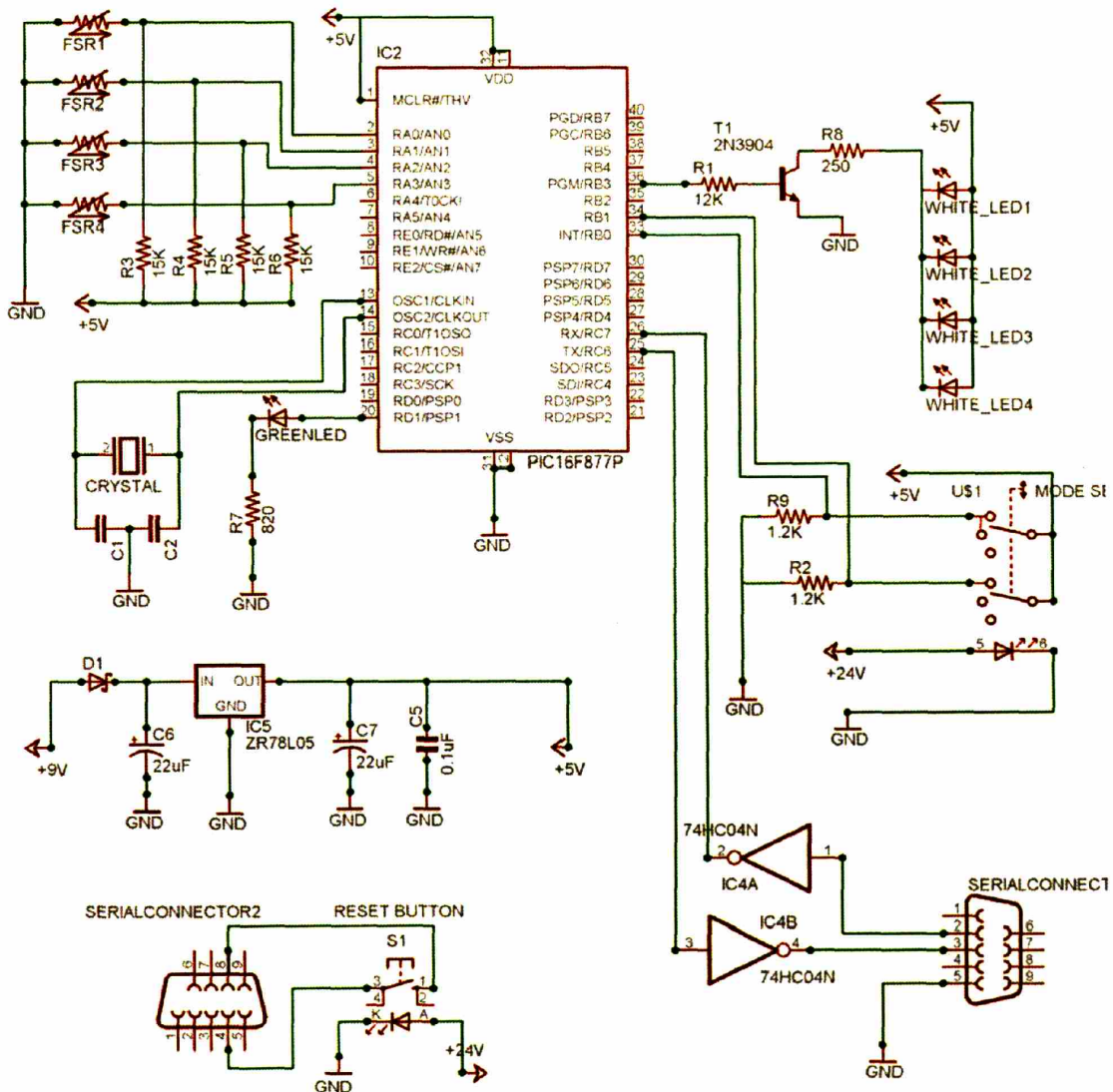
- Micro controller (PIC16F877) that digitizes the analog sensor signals
  - Power-conditioning circuitry, to create the stable internal 5V from the 9V external power supply
  - Components for the serial communication with the PC, based on a MAX233 chip
  - Connectors for all the cables and connectors, such as:
    - Power for breadboard (from 9V power supply: black plugs)
    - Mode selector switch and reset button (rainbow colored cable band)
    - Power for orange lights on mode selector switch and reset button (from external 24V power supply, white plugs)
    - Sensors (5 wires: yellow/orange/light green/purple for sensors 1-4, and black with white stripe for ground).
    - RS232 cable to RS232-to-USB hub (which goes to USB hub and to PC), for communication with PC (orange/red/brown wires)
    - Connection to second RS232 port, for sensing the reset button (two wires, green/yellow).
- Note that there is no analog-to-digital conversion of any kind on this port. The reset button merely closes two lines on the serial port (DTE ready line 4, and RTS line 8), which is detected by the iomon.exe code that listens on this port. This is of course not serial communication according to RS232 standard.

It also contains status LEDs: a blue LED lights permanently when the 5V reference is ready, and a green LED that blinks if the communication between windows code and microcontroller is running. Note that the green LED only blinks when the windows code is actually running.



**Schematic of circuit on breadboard**

Below is a schematic of the circuit, which includes the breadboard, the brush, and the switches.



## PC

The PC runs the actual software that generates the images on the screen.

Connected to the PC are:

- Touch screen, via serial connector (COM2)
- USB hub (breadboard, camera)
- Projector

Graphic resolution of this PC is set to 1280x1024. Although the projector doesn't support this resolution natively, it is better to run it like that, because the pixels are (due to interpolation) a bit fuzzy, which is good for our purpose.

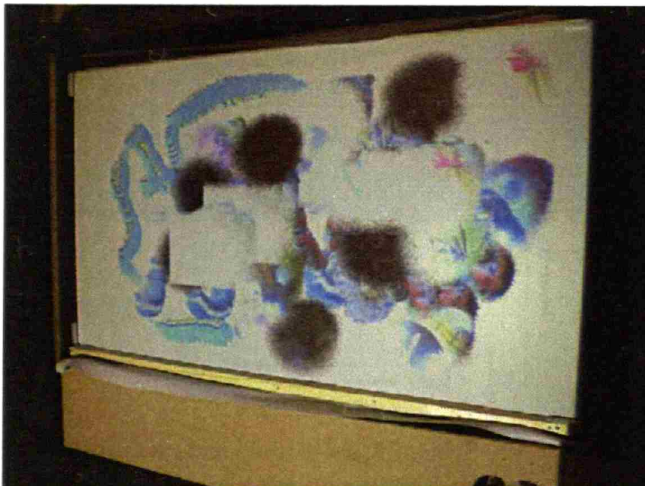
---

## Touch panel overlay

The large *NextWindow* touch panel overlay is using vision to detect objects on the screen (<http://www.nextwindow.com/products/plasma.html>). It is the only technology that allows measuring the presence of the soft bristles on a surface. We tested both inductive and resistive technologies, but neither of them worked reliably.

The panel uses two cameras to detect the position of the objects on the screen. Although theoretically possible, it cannot detect more than one object, though. It has been calibrated with custom calibration points, since the panel is 16-to-9 and the projector can only provide 4-to-3. Although it should not be necessary to re-calibrate it, there is an *AutoCalibraor.exe* icon on the desktop that will repeat the calibration steps, including the custom calibration points, which are stored in the file `C:\Program Files\NextWindow\2400\Calibrator.ini`.

The projector has to be set up so that the upper left corner of the Windows desktop is also on the upper left corner of the overlay touch panel. This means, the lower part of the windows desktop is not visible, which is good, because that's where the few Windows icons are that cannot be removed from the desktop. These icons are not visible anymore in projector mode, of course.



*Back view of the touch panel overlay and projection. Note that the projection aligns on the top right corner (view from behind) with the overlay touch panel. The top right corner is also where the preview window is visible.*

## Interactive art piece

The interactive art piece is an executable on a Windows PC (.EXE file) with a touch screen. Although it is originally written in Macromedia Director MX (Lingo), it is converted to the executable file that just has to be clicked on.

The latest art piece is in the Startup folder, and is called  
`artpiece_Projector_090304_v1.exe`

In the same Startup folder, there is also a folder "quicktime" that contains all 24 QuickTime movies that are necessary for the interactive art piece.

The graphic resolution of the PC has to be set to 1280x1024. (The executable expects this resolution.)



---

## Video station

The video station is a normal PC that runs a movie of an I/O brush demonstration in a loop. The file is AVI and is played by a Windows Media Player *full screen* mode. A link to the AVI file is in the Startup folder, so it will start up automatically, but still has to be switched to *full screen* mode manually by pressing “Alt-Enter”.

Note that the file is quite large. The current version, “iobrush\_movie\_090204\_v2.avi” is 476MB large. We also noted that if the video is played in non-full-screen mode, there are some artifacts visible on the right side of the video. They are not present in the full-screen version, though.

## Start-up procedure

Make sure that all components are plugged in:

- Touch panel power: it makes a few beeps when powered up
- Touch panel serial plug into Windows PC serial port 2 (the lower of the two, on the back of the computer)
- USB hub into USB port of PC: we are using currently the left one in the back of the computer.
- USB hub power supply: this has to be done before the PC starts up, or the PC will complain about not having enough power to power all devices connected. A red power LED must be on, and two orange LED’s for each cable plugged into it (serial-to-USB hub, and USB cable from camera)
- Brush cables into breadboard. These are single pins: 5 for the sensors, 2 for the white LEDs, and 5 for the USB camera)
- Switch cables into breadboard: this is the rainbow colored cable with the wide 10-pin header at the end.

Then power up in the following sequence:

1. Power to breadboard (9V power supply, WHITE plug on breadboard): after plugging in (or resetting) this connector, all LED’s on the board (green and blue) as well as the white brush LEDs should blink rapidly for 1 second, and then all go off except the blue LED.
2. On the PC, start the system with the link “IOBrush Start aec083004”. The link contains the following file name, path and arguments:

```
C:\AEC\iomon.exe COM4 "C:\AEC\projector.exe"
```

This will start a command line window (iomon.exe), which in turn will start the actual projector EXE file. The screen will turn completely white, except where the mouse pointer was, there will appear round “stain marks.” This means, the system is ready.

If the mode selector switch and reset button do not light up in orange color, also connect the 24V power supply to the jack on the breadboard marked with “24V” (black connector). This can be done at any time, since the power goes to the switches’ lights directly, and is independent from what is going on on the PC or on the breadboard. However, DO NOT CONFUSE THE 9V AND THE 24V CONNECTORS! The 9V connector is white, where as the 24V connector is black.

Also note that the white 9V power supply is actually a multi voltage supply. DO NOT change the settings on the power supply, and do not use any other voltage than 9V!

---

## Tips for info-trainers: Do's and Don'ts for visitors

### General treatment:

1. First and most importantly: **the brush is fragile**. Please tell the visitors to treat it gently, and supervise them when they use the brush!
2. Do NOT drop the brush. It will probably break, but we don't want to find out, right?
3. Do NOT pull the cord, neither on the brush side nor on the wall side. Avoid tripping over the cord: this will pull the cable very much, which might damage the brush.
4. Do NOT pull the bristles.
5. Do NOT throw the brush, or swing it around holding just the cord. Some very young visitors will probably try doing that...
6. Do NOT knock with brush on the screen: the wooden body of the brush might actually break the glass, which is very dangerous.
7. After use, please put the brush back on its tray. Do NOT leave it on the table with the objects to pick up: somebody certainly will trip over the cable.

### General handling:

8. In order to pick up something, press the brush towards an object. As soon as the white lights come up in the brush, it will start picking up. However, in normal mode, only the LAST picture will be kept. Remember, if the white lights inside the brush don't come on, or flicker, then you do not pick up the object properly. Instead, press a little harder when picking up, so that the lights are on as long as you touch the object.
9. Once you have picked up an 'ink', you can paint on the screen. Best is to move the brush slowly with light or medium touch. The lighter you press, the thinner the line will be.
10. Avoid pressing the brush very hard (on objects or on screen): it will eventually damage the bristles, and will eventually scratch the glass of the overlay panel!
11. If you have picked up an 'ink' and decided to stamp it on the screen (not moving when touching the screen), avoid staying on the same spot on the screen for more than two seconds. If you do, the brush might create green circles and overwrite the ink you just picked up. This is because the brush on the screen picks up the screen itself after some time of no movements, which is not what you want.
12. I/O brush has two states: picking up something, and drawing with that something on screen. This means, normally do not pick up ink and AT THE SAME TIME draw on the screen. This happens when two or more visitors are using I/O brush at the same time. Or rather, you can pick up and draw on the screen simultaneously, but then the person who draws on the screen will get the color that is changing continuously (which can be fun).
13. Do NOT put objects on the screen to pick them up from there, like a book. The screen will see the object(s) on the screen and get confused of whether the user wants to pick up or draw. Remember, I/O brush can only pick up objects OR draw, but not at the same time.
14. Don't forget that you can smudge the color. However, after each time you smudge, you have to wait a few seconds to smudge again.

### Movie mode

15. If you turn the knob on the front wall to the RIGHT, the brush goes into movie mode.
16. Picking up the eye is not as simple as it looks: it takes some practice! The most common error is that the lights do not light up continuously. If the lights flicker, then you have to press a little harder.
17. I/O brush can only pick up three movies, each maximum 1.5 seconds long. The fourth movie will overwrite the first one, etc.
18. If the movie you pick up is less than 1.5 seconds, you will see leftover frames from the older movie that you just overwrote. That is normal.

- 
19. There are other ways that the eye to show the movie mode: for example, brush over text (from the colorful books provided), and then paint on the canvas: you will see that the line is changing colors as you move along the canvas: this is a nice effect, too, and much easier to demo!

## Color mode

20. If you turn the right orange knob on the front wall to the LEFT, the brush goes into color mode. This means, you will pick up only the main color of what the brush sees.
21. If you don't get the color that you expected from an object, keep the brush where it was and turn the knob to the middle position, and you will see what the brush sees right now. Adjust the position of the brush so that the brush sees as much as possible of the color you want, and turn the knob back to left. Then you should get the color you expect to get—but it is harder than you think! Very often, although the colorful object is in the middle, there is black or white color around it, which makes it difficult for the brush to find the real color. Note that the brush does not give you the *average* color of all the colors it sees, but the *single color* that it sees the most. In other words: if you brush over a yellow and red striped pattern, you will NOT get orange!

## Restarting

22. You can clean the screen by hitting the left orange button. Do hit only once—that is enough. Restarting takes a few seconds, during which you see the text “Einen Moment, bitte!” As soon as the hourglass mouse driver disappears and some stain rings show up, the system is ready again.
23. IMPORTANT: Restart only when you are in NORMAL mode (when the button is in the middle position).
24. Do NOT restart when you are in COLOR mode (knob turned to the left). If you do so, it just won't paint. Just turn the knob to the middle (NORMAL mode), and it will work again. After you have painted once in NORMAL mode, you can turn the knob back to left, and paint in COLOR mode.
25. If you restart in MOVIE mode, you will NOT see a preview of the first movie on the top left of the screen. However, you can still pick up a movie. Just paint with the first movie, and from the second movie on you will see the preview on the top left corner of the screen. But remember, we recommend that you restart only in NORMAL mode (knob in middle position).

## Other hints

26. You CAN paint over the things that are already on the screen. Some visitors don't realize that.
27. You CANNOT paint over movies on the screen.

## Software

### PC software

The PC software contains of two executables: a monitor program (`iomon.exe`) that starts up automatically the actual program (`projector.exe`). This means, the actual program (`projector.exe`) should not be started manually: the monitor program does that automatically. (If you start `projector.exe` manually, the system works normally, except that the reset button does not work.)

The idea behind this is that when the user presses the orange reset button (the round button on the left side under the large screen), the monitor program (`iomon.exe`) kills the actual I/O brush program (`projector.exe`), and after a few seconds, restarts it.

The `iomon.exe` is a command line program that has to know to which serial port the reset button is connected to: this is currently port 2 of the *Keyspan* RS232-to-USB hub, which appears as COM4 on the PC.

---

It also needs to know which program it has to start up, kill, restart etc. The current command, stored as a link in "IOBrush Start aec083004", is:

```
C:\AEC\iomon.exe COM4 "C:\AEC\projector.exe"
```

Usually, we run the compiled version of the Macromedia Director code. In order to debug the sensor values (the most likely thing to do), we have to run the original Director script. At this point, basic knowledge about Macromedia Director MX and its programming environment is necessary.

To test the sensor values:

1. Open the most recent .dir file in "My Documents\IOBrush\AEC\_debug". Currently, that is "timedelay\_iobrush\_082004\_modified\_aec\_090304.dir"
2. In script 10, uncomment the two lines 177 and 178 by removing the double hyphen at the beginning of the lines:

```
-- put "sensors : "&sensor  
-- put "mode: "&mode_selected
```

The lines will look like that afterwards:

```
put "sensors : "&sensor  
put "mode: "&mode_selected
```

3. Click on the *Message Window* so that it is visible.
4. Rewind the movie, and run it.
5. You should see the sensor values (4 bytes, each between 0 and 1024), and the next line the mode (1 value, 0-2)

Note that you most likely will see that sensor 1 has a somewhat erratic value. If the brush is not pressed, sometimes its value is close to 0, but sometimes it stands closer to 400. We decided that sensor 1 is not reliable, and disregard its value in the most recent director code. This does not influence the performance of the system at all, since in praxis just one of the sensors has to be working reliably! We have four pressure sensors for two reasons:

1. Four-times redundancy: if a sensor stops being reliable, it can be disabled. We actually only need one working sensor! Note that an elevated base level (as with sensor 1) does not mean the sensor is broken. It just means the sensor encounters a pressure even without the bristles being pressed. Such an offset could also be calibrated for, if necessary. We do not know, however, what causes the standby pressure that sensor 1 sometimes shows.
2. In later versions of the brush, we intend on using the direction of the pressure for refined drawing expressivity. The current brush, however, does not have these capabilities implemented.

The most likely change that you might want to make is **adjusting the sensor threshold of the brush**. This might be necessary if a sensor starts to act "weird" by either not giving a value anymore (very unlikely), or having an elevated base level (likely), due to mechanical damage of the brush.

In script 10, find the line 187:

```
if sum > 600 then
```

As you can guess, the current threshold is set to 600, which means that for three sensors, each has to have an average value of 200 to trigger the picking up behavior (indicated by the white LEDs coming on), or painting on canvas. Adjust this value, up or down, but **BE CAREFUL WHEN YOU CHANGE THIS VALUE!** You will have to test the brush thoroughly to see if it works the way you expect: test picking up different colors from different objects, and paint a lot to see if the change is better or worse!

If you have make changes to the Director code, store it as a different file name. Then you have to 'recompile' it, or rather, make a *projector* file: In the menu, choose "File→Create Projector". Then locate the director file

---

you have just modified, and add it as “Director Movie” file type. The locate the following extras, and add them as “Xtra” file type:

- IOBrush\DirectorMX\Xtras\DirectComm\Windows\Runtime\DirectComm.x32
- IOBrush\DirectorMX\Xtras\VideoMask1.1\VideoMask.x32

Then “Create” the projector.

Rename the file to “projector.exe”.

Then go to the directory

```
C:\AEC\
```

There you will find another “projector.exe” file there, the old one. RENAME THIS FILE SO THAT YOU HAVE A BACKUP! (You can also move it to a safe location instead, but remember where it is, because this one works!)

Then copy the new projector.exe file to:

```
C:\AEC\projector.exe
```

That’s it! Of course you have to check now if everything still works! You don’t want to run the projector.exe file by itself, because you can’t test in the reset button works fine. Use the Iomon link (“IOBrush Monitor aec083004”) instead, which will start the projector.exe file in this directory.

## Microcontroller software

The software is written in C and compiled with a CCS compiler. It is burned onto the PIC with a PICstart burner, so cannot be accessed externally. However, since it also contains a so-called boot loader, the PIC can be reprogrammed via serial port. This is an extreme measure, needs special reprogramming software on the PC, and should only be done by Stefan Marti.

If you want to test the PIC software separately from the Macromedia Director code, you can use a normal serial terminal program like Windows *Hyperterm* or *SecureCRT 4.0* to test it. The serial port settings are: 115200 baud, 8N1, no flow control (neither hardware nor software), COM3 (with the current configuration).

Turn off the breadboard power supply, start the terminal program, then turn on the power to the breadboard. You should see the following line:

```
I/O Brush prototype 2, polling, v3.4 starting up...
```

Then nothing will happen until you press the numbers 0, 1 or 2 on the PC. Each time you press one of these numbers, the microcontroller will return the values of the four sensors (values between 0 and 1024), and a fifth number that represents the position of the mode selector switch.

We are using a polling method to communicate between Windows code and microcontroller code: the microcontroller does not send data unless requested by the Windows code. The Windows code currently asks the microcontroller 20 times per second for its values.

If you want to see a more continuous string of sensor values, just keep pressing “0” on the keyboard, and the microcontroller will spit out data more continuously.

## Interactive art piece software

The interactive art piece is written in Director MX Lingo, and then compiled into an executable (the projector). The current version is called

```
artpiece_Projector_090304_v1.exe
```

It currently contains a painting with links to 24 embedded QuickTime movies.

---

This software is written for a touch screen, but can also be tested with a normal mouse. Note that the mouse cursor is hidden, though.

We have found out that the smoothness of the videos depends greatly on the speed of the CPU. We do not recommend using less than a 1.4GHz computer. It will run much nicer on a faster computer, though!

## FAQ

**Q:** What if the PC complains that the USB port does not have enough power?

**A:** The USB hub must have the power cable plugged in before the PC starts up, or the PC will not have enough current to power the things plugged into the USB hub. Unplug and plug in back the power supply. If the PC still complains,

1. Unplug the power to the USB hub
2. Unplug the two USB cables that go into the hub (REMEMBER which one was plugged in where!)
3. Plug back in the power to the USB hub
4. Plug back in the two USB cables that go in to the hub: if looking at the hub with the writing "Belkin" horizontal, the black USB cable (the one from the camera) goes to the right most plug. The silver USB cable (from the serial-to-USB hub) goes to the second to right plug of the hub.

**Q:** What if I start up the PC programs, and it starts up fine, producing the little round stain marks where the mouse was, but I still can't draw on the screen?

**A:** Make sure the green LED on the breadboard is blinking. If the LED is not blinking after the windows program has started, then the breadboard is not communicating with the PC. Do the following:

1. Unplug the power of the breadboard (9V plug).
2. Stop the PC program (Control-Alt-'dot', or if this doesn't work, Alt-Tab to the Windows command line window, and then ESCAPE several times until you see the actual window, then Control-C to kill it.
3. Then plug back in the 9V power supply for the breadboard: all it's LEDs will blink rapidly, then stop.
4. Then restart the PC program with the Iomon link ("IOBrush Monitor aec083004"). The green LED on the breadboard should blink about twice a second.

Sometimes it is necessary to go through the above procedure 2 or 3 times (probably because the serial port is not always freed properly when the PC program is killed).

**Q:** How can I open the brush?

**A:** You can't! The current prototype is glued together with epoxy resin glue, and only the artists can take it apart. Next versions will have screws, though.

**Q:** What is the most likely way the brush breaks?

**A:** That's very hard to predict. However, we estimate that because the brush is a mechanical part, it will break mechanically in some way before the electronics or the software will cause errors. In our opinion, a failure will not be catastrophic, but rather gradual. We think that the first thing might happen is that the brush lights do not go off easily anymore, or in other words: the white LEDs might be on sometimes even though not object or surfaces is touched. This means probably that mechanical parts in the brush will influence the sensor values. This might come from accidents, like when the brush fell down to the ground and the outer acrylic ring got moved or even damaged. Such a failure could be counteracted by adjusting the threshold level of the sensors. This procedure is relatively simple, but requires knowledge in Macromedia Director (because the code later has to be transformed to an EXE file, a process described above). HOWEVER, it is better (and easier) to send back the brush to us, and we will fix it for you.

---

## Appendix: Microcontroller code

```
// I/O Brush prototype 2, polling version
// Copyright (C) 2004 MIT Media Laboratory
// Concept, design, and programming by Stefan Marti stefanm@media.mit.edu
// Code fragments by Vadim Gerasimov

#include <16F877.H>
#list

// Configure PIC to use: HS clock, no Watchdog Timer,
// no code protection, enable Power Up Timer,
// and disable brownout
#fuses HS,NOWDT,NOPROTECT,PUT,NOLVP,NOBROWNOUT

// Tell compiler clock is 20MHz. This is required for delay_ms()
// and for all serial I/O. These functions use software delay
// loops, so the compiler needs to know the processor speed.
#use Delay(Clock=20000000)

//serial stuff
#use RS232(Baud=115200,xmit=PIN_C6,Rcv=PIN_C7,parity=N,bits=8)

// Declare that we'll manually establish the data direction of
// each I/O pin on ports A to E.
#use fast_io(a)
#use fast_io(b)
#use fast_io(c)
#use fast_io(d)
#use fast_io(e)

// Set variable that maps to memory
#byte PORTA = 5
#byte PORTB = 6
#byte PORTC = 7
#byte PORTD = 8
#byte PORTE = 9

//=====
// Define this ONLY for initial PIC programming to include the serial programming function
// After that, comment it out!

//#define InitialProgram = "true"
//=====

// LED pins
#define GREEN_LED PIN_D1 // (output)

// Serial programming switch
#define PROGR_ON PIN_B7 // (input)

//A/D pins
#define SENSOR1 PIN_A0 // (input analog)
#define SENSOR2 PIN_A1 // (input analog)
#define SENSOR3 PIN_A2 // (input analog)
#define SENSOR4 PIN_A3 // (input analog)

//Mode switch
#define MODE_SWITCH1 PIN_B0 // (input) mode switch 1
#define MODE_SWITCH2 PIN_B1 // (input) mode switch 2

//Brush LEDs
#define BRUSHLIGHT PIN_B3 // (output) lights on the brush

// Macros to simplify I/O operations
#define GREEN_LED_ON output_high(GREEN_LED)
#define GREEN_LED_OFF output_low(GREEN_LED)

#define BRUSHLIGHT_ON output_high(BRUSHLIGHT)
```

---

```

#define BRUSHLIGHT_OFF  output_low(BRUSHLIGHT)

// How fast does the serial communication LED blink?
#define BLINK_HOW_FAST 10

//threshold--PIC internal, obsolete now
#define THRESHOLD 1000

// Function Prototypes
void blinky();
#define inline void reprogram();
void do_adc();

// Global variables
char cmd; // last command character
long value[4]; //array with sample values
long sum;
long value_inv[4];

char char1, char2;
char user_mode;
int picked_up_something = 0;
int serial_traffic = 0;
int green_led_status = 0;

void blinky()
{
    int j;
    for (j=0; j<10; j++) {
        GREEN_LED_ON;
        BRUSHLIGHT_ON;
        delay_ms(50);

        GREEN_LED_OFF;
        BRUSHLIGHT_OFF;
        green_led_status = 0;
        delay_ms(50);
    }
}

#ifdef InitialProgram
#ORG 0x1F00, 0x1FFF
void self_program()
{
    long addr, count, val, i;
    disable_interrupts(GLOBAL);
    while(getc()==0xAB) {
        *(&addr)=getc();
        *(&addr+1)=getc();
        *(&count)=getc();
        *(&count+1)=getc();
        for (i=0; i<count; i++) {
            *(&val)=getc();
            *(&val+1)=getc();
            if (val==read_program_eeprom(addr)) putc(1);
            else {
                write_program_eeprom(addr, val);
                if (val==read_program_eeprom(addr)) putc(1);
                else putc(0);
            }
            addr++;
        }
    }
    #asm
    movlw    0
    movwf   0x0A
    goto    0
    #endasm
}
#endif

```

---



---

```

// Jumps to self_program()
// This is normally called from command processor.
// Note: If you want serial programming to work make sure you can always interrupt
//       your program from serial port and have a command that calls this function
inline
void reprogram()
{
    putc(cmd); // Return the 0xA5!! This is necessary for the CF.exe,
              // the Windows code written by Vadim--it expects that
    puts("");
#ifdef InitialProgram
    self_program();
#else
    #asm
    movlw 0x18
    movwf 0x0A
    goto 0x700
    #endasm
#endif
}

// Self-programming function, reprograms PIC through RS232.
// The host sends pieces of code as:
// 1 byte header 0xAB
// 2 bytes start address
// 2 bytes (N) number of words to program
// N words (N*2 bytes) program words
//
// After each program word function sends back
// 1 if word programmed successfully
// 0 if not
//
// Send non 0xAB byte to exit the cycle and restart

void main()
{
    setup_adc(ADC_CLOCK_DIV_32); // set ADC clock to 20MHZ/32
    setup_adc_ports(ALL_ANALOG);
    // Since we've declared #use fast_io(A to E) above, we MUST
    // include a call to set_tris_a to e at startup.
    set_tris_a(0b00001111); // all As are outputs, except A0-A3 (SENSOR1-4)
    set_tris_b(0b10000011); // all Bs are outputs, except B0, B1 (mode
                          // switches) and B7 (programming switch)
    set_tris_c(0b10000000); // all Cs are outputs, except C7 (serial receive)
    set_tris_d(0b00000000); // all Ds are outputs
    set_tris_e(0b00000000); // all Es are outputs

    // Enable interrupts(INT_RB);
    enable_interrupts(INT_TIMER2);
    enable_interrupts(GLOBAL);

    setup_timer_2(T2_DIV_BY_4, 250, 5); // 1mS interval @ 20 MHz

    // Startup blinking
    blinky();

    printf("\r\n\r\nI/O Brush prototype 2, polling, v3.4 starting up...\r\n");

    if (input(PROGR_ON)) { // if the 'programming switch' is on
        printf("--> I am now in serial programming mode--send your stuff...\r\n");
        while (1) { // wait for the serial signal
            cmd = getc();
            if (cmd== 0xA5) reprogram();
        }
    }

    while(1) {
        if (kbhit()) {
            char1 = getc();
            user_mode = '0'; // default, just in case
        }
    }
}

```

---

---

```

    if (!(input(MODE_SWITCH1)) && (input(MODE_SWITCH2))) {
        user_mode = '0';
    }
    if (!(input(MODE_SWITCH1)) && !(input(MODE_SWITCH2))) {
        user_mode = '1';
    }
    if ( (input(MODE_SWITCH1)) && (input(MODE_SWITCH2))) {
        user_mode = '2';
    }
    do_adc();
    printf("%lu\t%lu\t%lu\t%lu\t%r\n", value_inv[0], value_inv[1], value_inv[2], value_inv[3],
user_mode);

    // old  new  meaning
    // "00" "0"   picking up color, not touching
    // "01" "1"   picking up color, touching (white LED on)
    // "1x" "2"   painting on canvas (all LED off)
    if (char1 == '0') { // brush is PICKING UP COLOR (not on canvas), but NOT TOUCHING
        BRUSHLIGHT_OFF;
        if (picked_up_something == 1) {
            // used for laser fiberoptics
        }
    }

    if (char1 == '1') { // brush is PICKING UP COLOR (not on canvas), TOUCHING something
        BRUSHLIGHT_ON;
        picked_up_something = 1;
    }

    if (char1 == '2') { // this means, brush is PAINTING ON CANVAS
        BRUSHLIGHT_OFF;
        picked_up_something = 0;
    }

    // now we blink the green LED on and off, after about 20 requests from the PC lingo code
    serial_traffic++;
    if (serial_traffic >= BLINK_HOW_FAST) {
        serial_traffic = 0; // reset counter

        // now toggle the green LED
        if (green_led_status == 0) { // green LED is currently off
            GREEN_LED_ON;
            green_led_status = 1;
        }else{ // green LED is currently on
            GREEN_LED_OFF;
            green_led_status = 0;
        }
    }
} // end of KBHIT
} // end of while loop
} // end of Main

void do_adc ()
{
    int i, j;
    for (i=0; i<4; i++) {
        set_adc_channel(i);
        delay_us(10);
        value[i] = read_adc();
        value_inv[i] = 1023 - value[i];
    }
}

```

---

**Appendix C:**  
**I/O Brush Handling Instructions for Ars**  
**Electronica Center**

---

---

---

# I/O Brush V.2 for AEC – Handling Instructions

The new version (v.2) has several physical improvements over the last version:

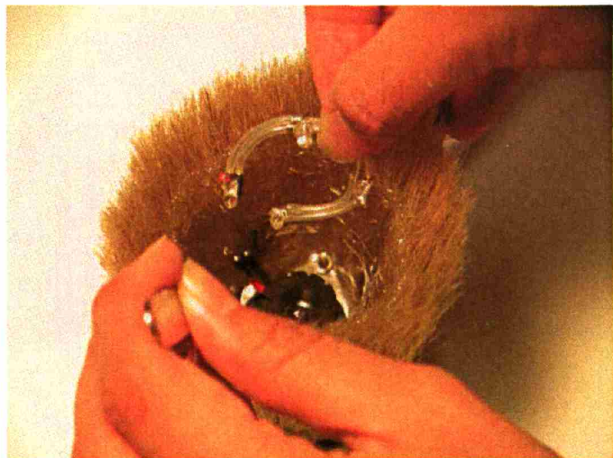
- The **aluminum rings** replace the previous plexi rings (this will tolerate much more physical pressures)
- The **brass inner legs** that attach to the wooden case (secures the inner ring to the wooden case)
- The **removable inner parts** (the screws on the wooden case both secure the inner parts and allow easy access to them)



## 1. Removing the inner parts from the brush

### Step 1: Remove the white LED ring

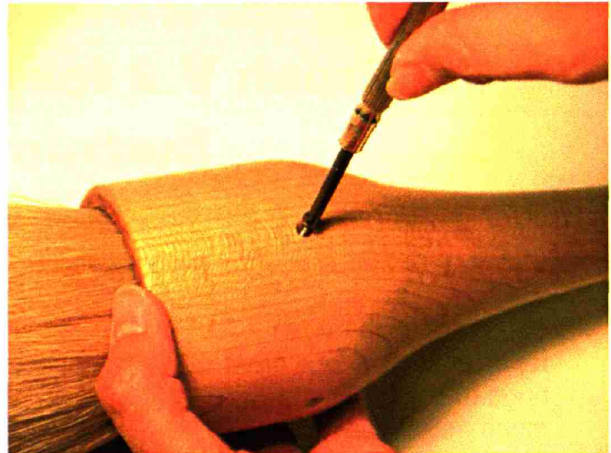
You may need to use tweezers (pinzette) to hold the wires. Be careful not to pull the wires too much/hard.



---

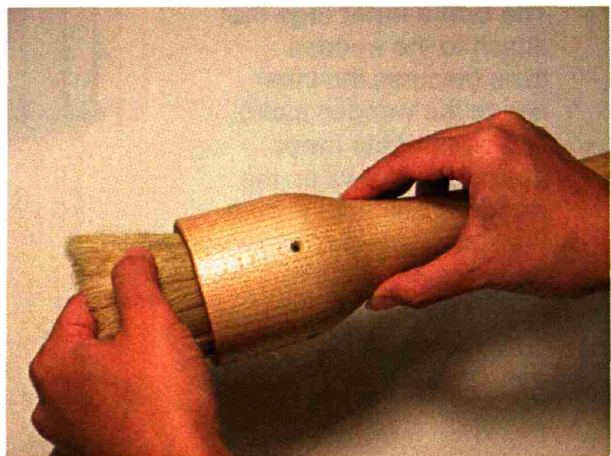
**Step 2: Remove the screws from the wooden case**

Be careful not to loose the screws!



**Step 3: Carefully wiggle out the content.**

Please do not pull hard at once, but slowly pull the content out.



Please also make sure to **feed/push the cord from the back as you are pulling.** You could otherwise unplug or tear the inner wires accidentally!



---

Slowly pull out the content as you feed the cord from the back...



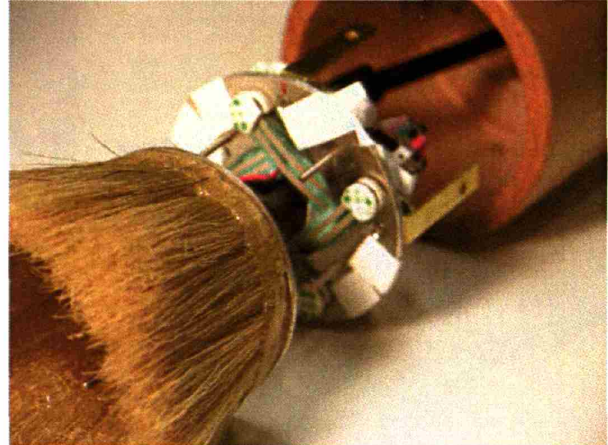
**Step 4: Detach the bristle/hair ring from the inner ring.**

There are 4 small bolts each with tiny interlocking nuts (2 nuts on each bolt). Each nut & bolt has "thread locker" on it making it tight. You may need to access the bolt from the back and hold the nuts with thin pliers.

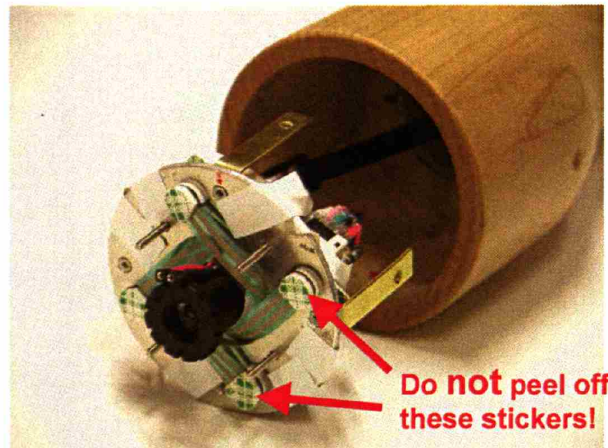


---

Once you remove the nuts from the bolts, you can remove the bristles/hair ring from the inner ring.



The force sensors are attached to the surface of the inner ring with a strong double-sided tape. Even though both sides of the sensors have double-sided tape, one side is for the “cushioning” purpose only. In other words, do not peel off the stickers on the outer side. The sensors should be only attached to one side (the inner ring).



## 2. Putting back the brush together

### Step 1: Attaching the bristle/hair back

Very important! The inner and outer aluminum rings must be **loosely** held together. So when you are screwing those tiny nuts back on the 4 bolts, you should **not** screw them all the way. When you screw the nut all the way, **go back about one turn** to make it loose. When you feel that it's almost too loose, that's good. It really should be that loose! (Otherwise, the sensors

will be pressed permanently and will have an elevated baseline. This means that even when there is no pressure on the bristles, the sensor





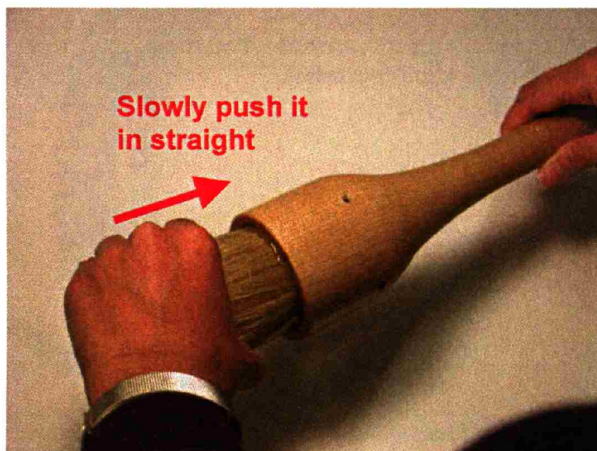
values will be far from zero.)

Each bolt should have **two** nuts locking each other. This is to prevent the nuts from moving up and down, or coming off. These nuts should be tight and have some sort of "thread locker" to make them tight and unmovable without tools.



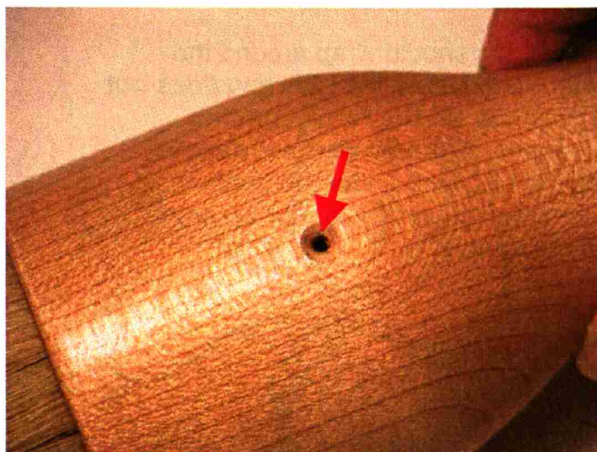
**Step 2: Slowly push the part back inside the brush**

Look at the alignment (please follow the markings inside [i.e. 1, 2, 3 & 4]). And slowly push it in straight.



Make sure that the hole in the brass leg inside matches the wooden hole outside.

If not matched, you could bend the brass leg inside by screwing the bolt in.



---

### Step 3: Put the screws back on the brush

Please make sure that the screws are straight!



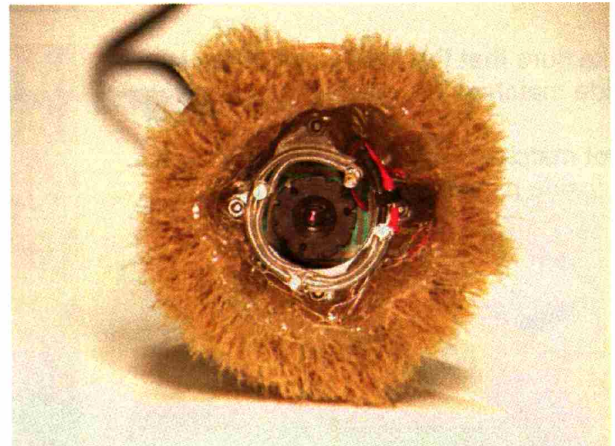
### Step 4: Put the LED ring back on

Please follow the color markings. You may need to use tweezers (pinzette).



### Step 5: Placing LED

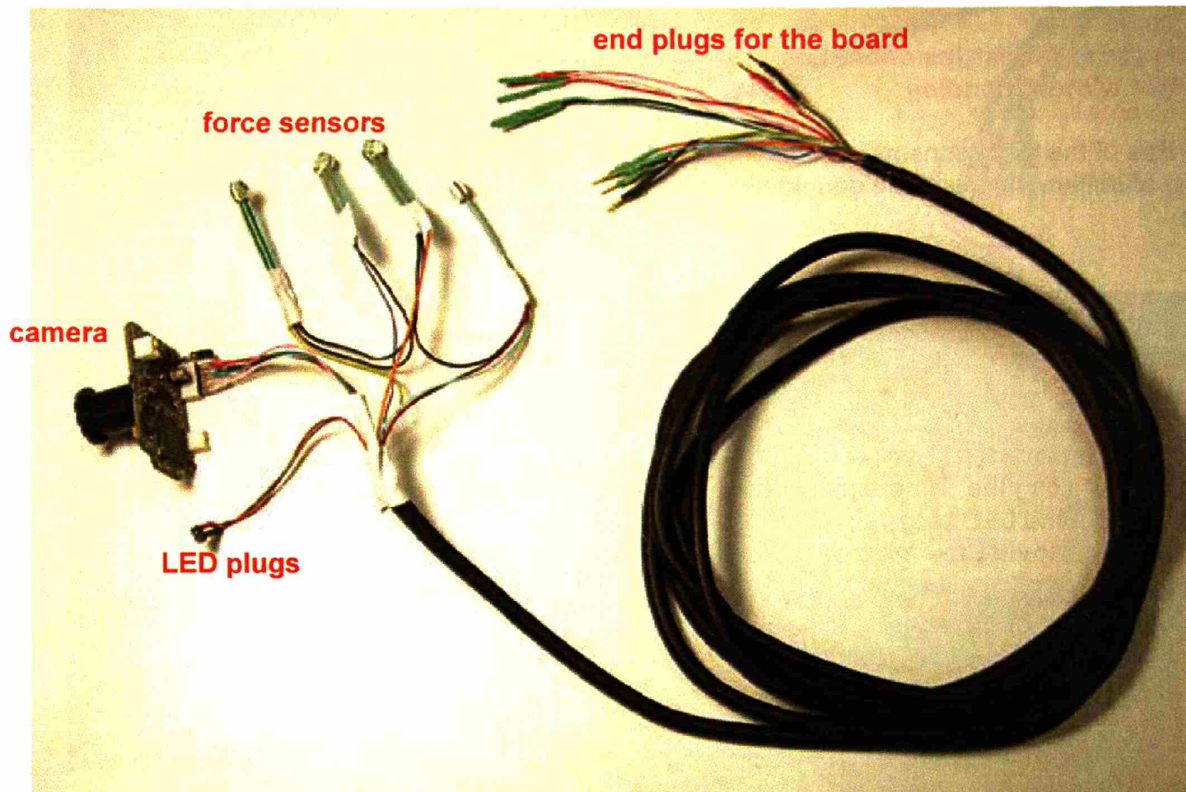
The LED ring should wrap around the camera. Make sure the LED ring does **not pull or press on the force sensors** underneath. It should also **not dangle**. Place the LED ring under the horizontal metal screw (covered with epoxy) so that it does not dangle.



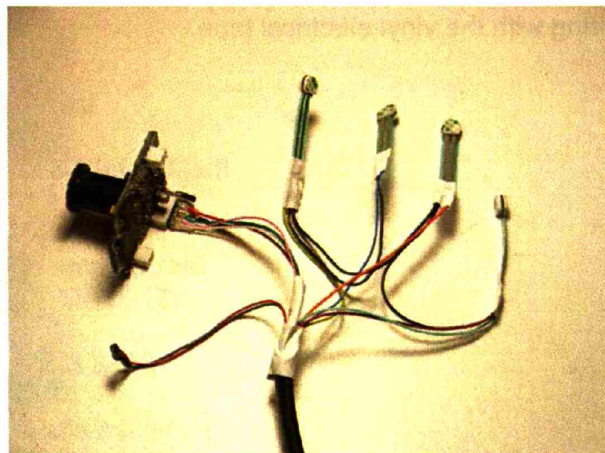
---

### 3. The I/O Brush inner components

Here we show you the components inside:



The **camera**, **LED plugs**, and **force sensors** must be neatly encased inside of the brush (see the pictures below).



The force sensors must be secured on the inner aluminum ring without being bent. If the sensor's film-strip is bent or is moving around, it interferes with the sensor reading.

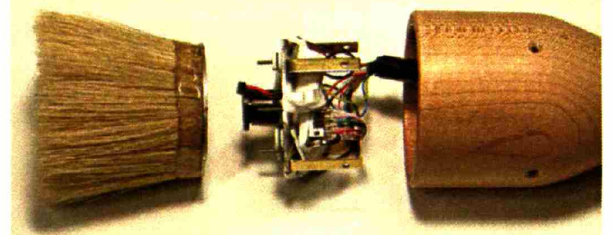
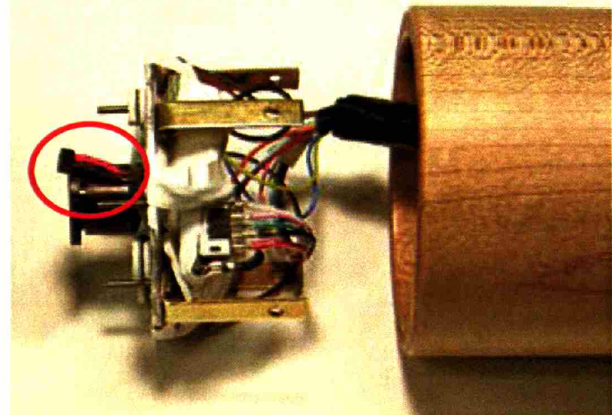
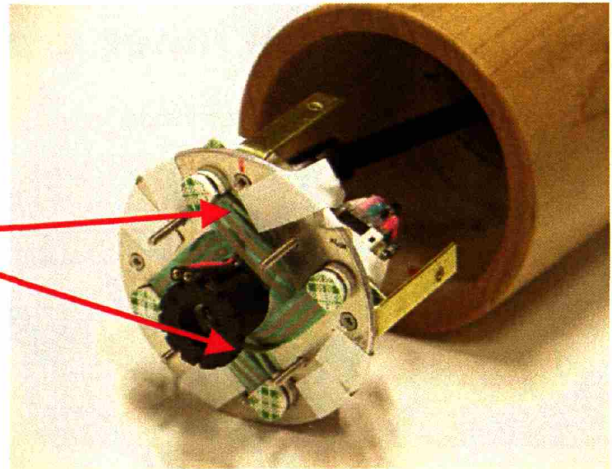
**These green film-strips should be straight without bending.**

The **tips** of the force sensors are attached to the aluminum ring with the double-sided tape.

The **ends** of the force sensors should be taped to the aluminum ring with vinyl electrical tape.

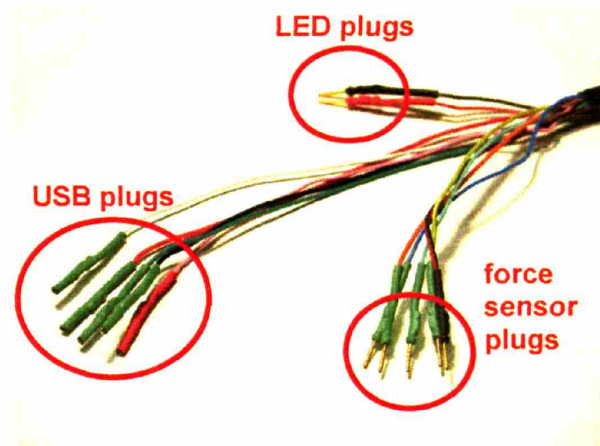
The LED plugs should sneak out of the middle hole along the camera, between the sensors. But the LED plugs should **not be pressing or moving** the force sensor strips.

The camera should be also taped down to the ring with the vinyl electrical tape.



---

Finally, please follow the color code of the shrink-wrap when connecting the ends of the wire.



Once the ends of the cable are connected to the board, the wires should be taped down to the box so that they will not be accidentally unplugged!



Thanks!

Kimiko Ryokai & Stefan Marti

MIT Media Lab  
E15-349, 20 Ames Street  
Cambridge, MA 02139

+1 617-253-8026

[kimiko@media.mit.edu](mailto:kimiko@media.mit.edu)  
[stefanm@media.mit.edu](mailto:stefanm@media.mit.edu)

---

---

---

## References

Bers, M. U. & Cassell (1998). J. Interactive Storytelling Systems for Children: Using Technology to Explore Language and Identity. *Journal of Interactive Learning Research* 9(2) (1998), 183-215.

Birch, C. L., & Heckler, M. A. (Eds.). (1996). *Who Says? Essays on Pivotal Issues in Contemporary Storytelling*. Little Rock: August House.

Brown, A. (1992). Design Experiments: Theoretical and methodological challenges in evaluating complex interventions in classroom settings. *The Journal of the Learning Sciences*, No.2(2), pp.141-178.

Bruckman, A. (1997). "MOOSE Crossing: Construction, Community and Learning in a Networked Virtual World for Kids." PhD Thesis. Massachusetts Institute of Technology, Cambridge, MA; 1997.

Bruner, J. (1986). *Actual minds, possible worlds*. Cambridge, Mass. : Harvard University Press, 1986.

Buck, R.C. (1948). *The HTP Technique: A Quantitative and Qualitative Scoring Manual*. Clinical Psychology Monographs, 5,1-20.

Csikszentmihalyi, M. (1996) *Creativity : flow and the psychology of discovery and invention*. New York : HarperCollinsPublishers

Csikszentmihalyi, M. & Rochberg-Halton, E. (1981). *The meaning of things : domestic symbols and the self*. New York : Cambridge University Press, 1981.

Daiute, C., Campbell, C., Griffin, T.M., Reddy, M., & Tivnan, T. (1993). Young authors' interactions with peers and a teacher: Toward a developmentally sensitive sociocultural literacy theory. In C. Daiute (Ed.), *The development of literacy through social interaction* (pp. 41-63). San Francisco: Jossey-Bass.

Decortis, F. & Rizzo, A. (2002). New Active Tools for Supporting Narrative Structures. *Personal and Ubiquitous Computing*, Volume 6 Issue 5-6, 2002.

Dewey, J. (1934). *Art as Experience*. New York: Perigee Books.

Druin, A., Stewart, J., Proft, D., Bederson, B., Hollan, J. (1997). KidPad: a design collaboration between children, technologists, and educators. *Proceedings of CHI'97*, ACM Press, (1997).

- 
- Dyson, A.H. (1993). A sociocultural perspective on symbolic development in primary grade classrooms. In Daiute (Ed.) *The development of literacy through social interaction*. San Francisco: Jossey-Bass Publishers.
- Feldman, D. (1994). *Beyond the universals of cognitive development* (2nd ed.). Norwood, NJ: Ablex.
- Finlay, V. (2003). *Color: A Natural History of the Palette*. Ballantine Books, 2003.
- Frei, P., Su, V., Mikhak, B., and Ishii, H. (2000). curlybot: Designing a New Class of Computational Toys, *Proceedings of CHI2000*, ACM Press. (2000), 129-136.
- Gardner, H. (1982). *Art, mind, and brain : a cognitive approach to creativity*. New York : Basic Books, c1982.
- Getzels, J. W. & Csikszentmihalyi, M. (1976). *The Creative Vision: A Longitudinal Study of Problem Finding in Art*. John Wiley & Sons, New York.
- Gleason, J.B. (2001). *The development of language*. Boston: Allyn ad Bacon.
- Goldberg, M. (1997). *Arts and Learning: An Integrated Approach to Teaching and Learning in Multicultural and Multilingual Settings*. New York: Longman, 1997.
- Greene, R. (1985). 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.
- Harris, D. B. (1963). *Children's drawings as measures of intellectual maturity: a revision and extension of the Goodenough Draw-a-Man Test*. New York: Harcourt Brace.
- Heath, S. B. (1983). *Ways with words: Language, life, and work in communities and classrooms*. Cambridge University Press, 1983.
- Heaton, K.B. (2000). "Physical Pixels." Masters Thesis. Massachusetts Institute of Technology, 2000.
- Ishii, H. & Ullmer, B. (1997). Tangible Bits: Towards Seamless Interfaces between People, Bits and Atoms. *Proceedings of CHI'97*, ACM Press, (1997), 234-241.
- Kellogg, R. (1970). *Analyzing Children's Art*. National Press, Palo Alto.
- Klepsch, M., & Logie, L. (1982). *Children draw and tell*. New York: Brunner/Mazel.



---

Korzenik, D. (1972). "Children's drawings: Changes in representation between the ages of five and seven" (unpublished doctoral dissertation, Harvard Graduate School of Education, 1972.)

Machover, K. (1949). *Personality projection in the drawings of the human figure*. Springfield, IL: Thomas.

Michaels, S. (1986). Narrative presentations: An oral preparation for literacy with first graders. In: Jenny Cook-Gumperz, (Ed.) *The Social Construction of Literacy*. Cambridge: CUP. Pp. 94-116.

Michaels, S. (1991). The dismantling of narrative. In A. McCabe & C. Peterson (Eds.), *Developing narrative structure*. Hillsdale NJ: Erlbaum (pp.303-351).

Montemayor, J., Druin, A., Farber, A., Sims, S., Churaman, W., & D'Amour, A. (2002). Physical programming: Designing tools for children to create physical interactive environments. *Proceedings of CHI2002*, ACM Press. (2002).

Naested, I. R. (1998). *Art in the Classroom: An Integrated Approach to Teaching Art in Canadian Elementary and Middle Schools*. New York: NY: Harcourt Brace & Company, 1998.

Papert, S. (1980). *Mindstorms*. New York: Basic Books. 1980.

Papert, S. (2000). "What's the big idea: Towards a pedagogy of idea power." *IBM Systems Journal*, Vol. 39, pp.3-4.

Pellegrini, A. D., & Galda, L. (1991). Longitudinal relations among preschoolers symbolic play, metalinguistic verbs, and emergent literacy. In J. Christie (Ed.), *Play and early literacy development* (pp. 47-67). Albany: State University of New York Press.

Piaget, J., & Inhelder, B. (1963). *The child's concept of space*. London: Routledge and Kegan Paul.

Rekimonto, J. (1997). 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).

Resnick, M. & Rusk, N. (1996). "Access is Not Enough: Computer Clubhouses in the Inner City," *American Prospect*, No.27, pp.60-68.

Resnick, M., Martin, F., Berg, R., Borovoy, R., Colella, V., Kramer, K., Silverman, B. (1998). Digital Manipulatives: New Toys to Think With. Paper Session, *Proceedings of CHI'98*, ACM Press, 2, (1998), 81-287.

Resnick, M., Rusk, N. & Cooke, S. (1999). *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.

---

Resnick, M., Berg, R., and Eisenberg, M. (2000). Beyond Black Boxes: Bringing Transparency and Aesthetics Back to Scientific Investigation. *Journal of the Learning Sciences*, vol. 9, no. 1, pp. 7-30.

Rogoff, B. (1990). *Apprenticeship in Thinking: Cognitive development in social context*. New York: Oxford University Press.

Rosen, B. (1988). *And none of it was nonsense : the power of storytelling in school*. Portsmouth, NH: Heinemann, 1988.

Rozin, D. Easel. <http://fargo.itp.tsoa.nyu.edu/~danny/easel.html>

Ryokai, K. & Cassell, J. (1999). Computer Support for Children's Collaborative Fantasy Play and Storytelling. *Proceedings of Computer Supported Collaborative Learning '99*, Palo Alto, CA, (1999), 510-517.

Schank, R.C. & Cleary, C. (1995). *Engines for Education*. Lawrence Erlbaum Associates, 1995.

Schkolne, S., Pruett, M., & Peter Schroder. (2001). Surface Drawing: Creating Organic 3D Shapes with the Hand and Tangible Tools. *Proceedings of CHI2001*, ACM Press. (2001)

Silvers, R. (1997). *Photomosaics*. Henry Holt and Company, Inc., New York, NY, 1997.

Stanton, D., Bayon, V., Neale, H., Ghali, A., Benford, S., Cobb, S., Ingram, R., O'Malley, C., Wilson, J., Pridmore, T. (2001). Classroom collaboration in the design of tangible interfaces for storytelling. *Proceedings of CHI2001*, ACM Press.

Sulzby, E. (1986). Writing and reading: Signs of oral and written language organization in the young child. In W. H. Teale & E. Sulzby (Eds.), *Emergent literacy: Writing and reading* (pp. 50-89). Norwood, NJ: Ablex.

Teale, W.H. & Sulzby, E. (1986). *Emergent Literacy: Writing and Reading*. Norwood, NJ: Ablex, 1986.

Trousdale, Ann M., et al. (1994). *Give a Listen: Stories of Storytelling in School*. Urbana, IL: National Council of Teachers of English, 1994.

Tzafestas, E. S. (2000). Integrating drawing tools with behavioral modeling in digital painting. *Proceedings of the 2000 ACM workshops on Multimedia*.

Vygotsky, L. S. (1991). *Imagination and creativity in the adolescent*. Soviet Psychology, 29.

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Cambridge, MA: Harvard University Press.

---

Vygotsky, L. (1960) cited in J. Wertsch (1991) *Voices of the mind: A sociocultural approach to mediated action*. London: Harvester Press, chapter 2, 18 - 45.

Vygotsky, L.S. (1935) *Mental development of children during education*. Moscow-Leningrad: Uchpedzig.

Vygotsky, L. S. (1931). *Pedologija podrostka*

Winnicott, D.W. (1971) *Playing and Reality*. London: Tavistock Publications.



Room 14-0551  
77 Massachusetts Avenue  
Cambridge, MA 02139  
Ph: 617.253.5668 Fax: 617.253.1690  
Email: docs@mit.edu  
<http://libraries.mit.edu/docs>

## **DISCLAIMER OF QUALITY**

Due to the condition of the original material, there are unavoidable flaws in this reproduction. We have made every effort possible to provide you with the best copy available. If you are dissatisfied with this product and find it unusable, please contact Document Services as soon as possible.

Thank you.

**Some pages in the original document contain color pictures or graphics that will not scan or reproduce well.**